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Integrated DPSIR-ANP-SD framework for Sustainability Assessment of Water Resources System in Egypt

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Abstract: *Nowadays fresh water severe scarcity is a global concern and it is alarming for the future. In order to fully understand the progress of the water system and its impacts, a sustainability assessment of water resources is needed. This accelerates the achievement of sustainability and management of water resources. This work aims to assess the sustainability of the water resources system by applying the integration approach proposed by (Xu, 2011). This integration approach is based on integrating the DPSIR-ANP method to the System Dynamics (SD) model, which is considered as a unique work in water resources management field. SD is a computer simulation model to understanding the behavior of complex systems over time, while Analytic Network Process (ANP) is a decision finding method used in model complex decision problems which contains feedback connections and loops. DPSIR is an analytical framework for describing the interactions between the economy, society and the environment. This integrated approach enables decision makers to view the sustainability problems of water resources system more comprehensively. The results showed that there is an increasing impact on the sustainability of water resources systems in Egypt over the research period. This is attributed to the increase in water resources consumption due to the increase in population, agriculture expansion and an increase in the value of GDP. So, the officials for managing water resources in Egypt should take actions to increase the efficiency of water use and increasing the renewable water resources for compensating water shortage.*

Keywords— Water resources; Sustainability assessment; System Dynamics; ANP; DPSIR framework; Egypt

1. Introduction

Water is the most vital natural resource on Earth after air where its quantities almost constant. It is essential to humans, plants, and animals to keep alive. In addition, it is important for the ecological balance of the earth. It covers 71% of the Earth's surface. Also, it frames 75% and 80% of human body weight and total composition of most vegetables respectively. In addition, water shortage or pollution cause 80% of diseases pervasive all over the world. Thus, water needs and the development process are inseparable, as the quantity of water used per day indicates human civilization and progress. (State Information Service, 2017). Nowadays severe water scarcity is a global concern and it is alarming for the future. On the demand side, the rapid growth of population and the fast development of economy worldwide have compelled on higher water demand. On the supply side, less predictable rainfall due to climate change causes less reliability of natural water sources (Xi and Poh, 2013). Sustainable water management needs innovative practices of water management, to balance water needs and water availability in the different water sectors, meanwhile to provide good quality and sufficient water in the present and future (Xi and Poh, 2013). The overview of the sustainable management of water resources is necessary because it can consolidate socio-economic and environmental themes into the management of all water resources processes (Sun et al., 2016).

Water is the backbone for sustainable and integrated development in Egypt. Water resources in Egypt are the quota of Nile water, drainage water, the limit amount of rainfall, wastewater treatment, and desalination of seawater. The water demand has duplicated as a result of population growth, agricultural extension, tourist uses as well as industrial development and a rise in the standard of living. Egypt's portion of Nile water is 55.5 billion cubic meters (BCM) represents 95% of Egypt's total amount of water. Egypt highly depends on Nile water because the rainfall is rare. The per capita share of water in Egypt is 690 cubic meters which are below the water poverty line (1000 cubic meters) (Ministry of Water Resources and Irrigation (MWRI), 2013, P.22). It is going to be reduced in the coming years as a result of the increasing population.

In the coming years, Egypt will suffer from serious water shortage and water quality degradation, which results from the population growth and the economic and agricultural expansion. Moreover, disputes about the share of each Nile basin state in water and building Grand Ethiopian Renaissance dam (Millennium dam) increase water crisis (Soliman et al., 2016; MIT's Abdul Latif Jameel World Water and Food Security Lab, 2014; Amer, 2013; Telegraph foreign-staff, 2017). Thus, the officials of water resources management in Egypt need to know the optimal allocation of limited water resources.

This research aims to appraise the sustainability of the water resources system. An integrated approach based on DPSIR-ANP method and SD model proposed by (Xu, 2011) was applied. This approach identifies the interrelationship between different factors of a water problem. It enables decision-makers to investigate the sustainability problems of water resources system at present and in the future.

2. BACKGROUND

The modeling of water resources that can serve as a decision support system tool is very important in the planning and management of water within the boundaries of states and abroad. It can support the analysis and evaluations of projects concerning with water resources, where it is useful in visualizing and predicting the changes in water supply and demand over time. Modeling of sustainable water resources management can be conducted by different methods; such as using System Dynamic Simulation Modeling (Xi and Poh, 2013; Adamowski and Halbe, 2011; Zhang et al., 2009; Duran-Encalada et al., 2017; Kotir et al., 2016), Expert Knowledge (Safavi et al., 2015), Fuzzy Logic (Sharma et al., 2012; Raju and Kumar, 2003), Mathematical Programming (Afify, 2010; Georgakakos, 2012; Anyata et al., 2014), the Geographic Information System (GIS) and Remote Sensing (Guo et al., 2010), DPSIR Approach (Sun et al., 2016).

Xi and Poh (2013) developed an SD model called Singapore Water to demonstrate that SD is a powerful decision support technique to help achieve sustainable water resource management in Singapore. Zhang et al. (2009) developed a dynamic model based on water resources carrying capacity theory for water resource management using the SD technique.

Among all possible desalination alternatives for Egypt, considering sites of the plants, their capacity, sources of feed water, the consumption of desalinated water, and the desalination technology, Afify (2010) used Multi-criteria Decision Analysis for ranking and selection. Georgakakos (2012) used linear programming to formulate the objective functions and constraints of water allocation problem to assist Castaic Lake Water Agency with decisions to meet annual water demands. Anyata et al. (2014) applied a mathematical model of discrete dynamic programming problem for forecasting the water demand, water uses, and net benefit of the conjunctive use of groundwater and surface water resources at the University of Benin, Benin City, Edo state, Nigeria.

(Xi and Poh, 2014) Proposed an innovative approach from integrated SD and named Analytic Hierarchy Process (AHP) for quantifying the priorities of various development plans to augment water supply in Singapore. (Razavi Toosi and Samani, 2012) using the ANP for ranking ten water transfer projects in Karun River-Iran. (Sun et al., 2016) designed an indicator framework based on the DPSIR model and AHP method to assess the sustainability of water resource systems in the city of Bayannur, China.

As a summary, the different methods stated above could offer useful tools for sustainability assessment of the water resources system. Also, previous works not considering predicting the water resources in the future, sustainability aspects, and assesses the sustainability of water resources in one approach. So, this research will conduct the sustainability assessment of the water resources system using an integrated approach based on DPSIR-ANP method and the SD method. DPSIR is an analytical framework for describing the interactions between the economy, society and the environment, while ANP is a method accepted and widely used in the appraisal of the decision-making process with variable comparison and feedback. SD is a computer simulation model to understand the structure and dynamics of complex systems. The advantages of using such an approach are the following:

1- From using the outcomes of the SD model, the decision makers will enable to investigate water resources problem and achieve the optimal allocation of limited water resources.
2- Evaluating the sustainability of water resources with Multi-temporal data and showing feedback between different variables.
3- Multi-temporal data will be used to figure out the dynamic changes in water resources.
4- Multiple stakeholders share in building participatory dynamic modelling framework.
5- The integrated approach enables decision policers to view the sustainability problems of water resources system more comprehensively.

Moreover, a real case study of the sustainable water resources system in Egypt will be considered in the research.

This paper develops a subsystem diagram of water resources management in Egypt based on previous researchers, studies and experts, mainly (Xi and Poh, 2013), (Zhang et al., 2009) and (MWRI, 2013). The configuration of this subsystem involves 4 major subsystems and minor 7 subsystems as shown in Fig. 1. The major subsystems are water demand, water supply, water uses and water surplus/shortage. Water demand determines the quantity of water that Egypt needs per year. Water supply determines the quantity of water available annually. Water uses to define the amount of water uses yearly. Finally, water surplus/shortage shows the abundance or deficits of water per year. When there are some deficits in water, the government should increase the funding for the water sector to build more wastewater and desalination water plants. Also, the increase in GDP leads to an increase in economic activities and standard of living, thus increasing the water demands.

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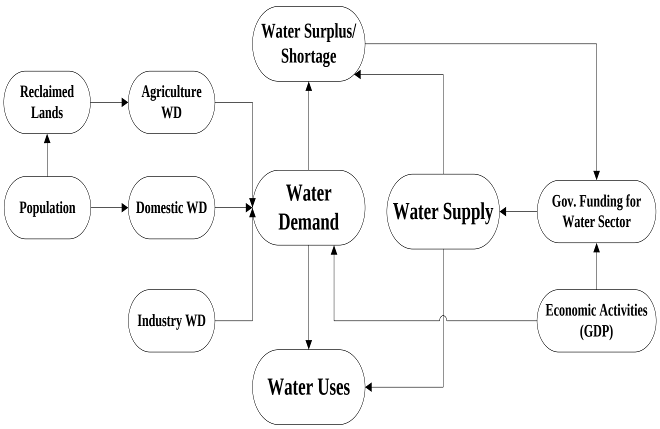

Fig. 1. Subsystem diagram for water resources management in Egypt.

3. METHODOLOGY

The methodology of this work is based on an integration approach proposed by (Xu, 2011). It is built on identifying indicators of sustainable assessment of water resources system, determine the weight of each indicator using ANP method, building SD model, and calculate the sustainable index. Fig. 2 represents the methodology flowchart.

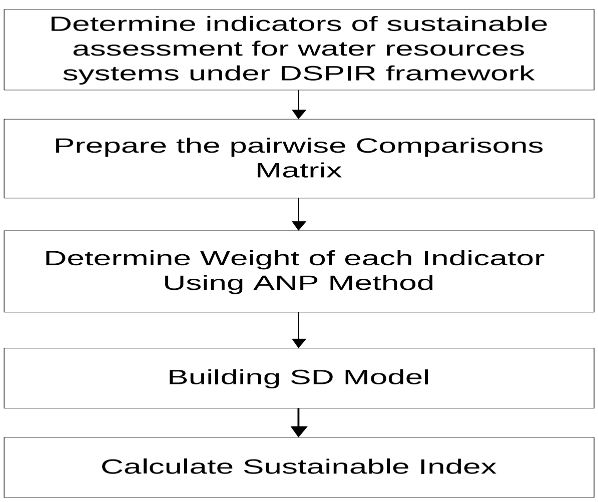

Fig. 2. Methodology flowchart of the integrated approach (Adopted from (Xu, 2011))

3.1 DPSIR Framework

Out of the Pressure-State -Response (PSR) framework the DPSIR framework originated. The PSR was established by the Organization of Economic Cooperation and Development and then adopted by the European environment agency. It organizes the indicators according to the cause-effect schema under the following categories: Driver Forces, Pressure, State, Impact, and Response. DPSIR is instrumental for describing the interactions between the socio-economic and environmental sectors. Also, it's investigating framework to clarify the complexities of the system relations in sustainable development. DPSIR framework is a widely approach using for sustainable assessment of water resources systems (Zhao and Bottero, 2009; Kristensen, 2004; Pires et al., 2017; Sun et al., 2016).

The evaluation framework for sustainable water resources management in Egypt is based on the DPSIR approach (Fig. 3). The driving forces index reflects the effects of changes in the agriculture area, population, GDP, and per capita GDP on sustainable water resource development. The per capita GDP can be used for reveals the standard of living in the Egyptian country. The pressure index indicates the factors which cause changes in the water system and act on the water resource system, and it is caused by the influence of the driver. In this study, the pressure index indicates the need for water resources and it impacts on the water quantity. It includes changes of agriculture water demand, changes of domestic water demand, changes of industrial water demand, and total water withdrawal. The state index refers to the state of the water system under the pressure of the driver. The state of the water system in this research includes water availability, and water adequacy index. The impact refers to the changes in the water system caused by the driving forces and pressure and contains the quality and quantity of water. These impacts include deficits in the amount of water availability Water Shortage), and salinization in the cultivated area. Finally, response denotes to the different measures adopted during the process of development and utilization of the water resource to warranty higher efficiency and sustainability of national water resources system. The response measures in this research include the following: wastewater treatment, desalination water, and elimination of subsidies water prices.

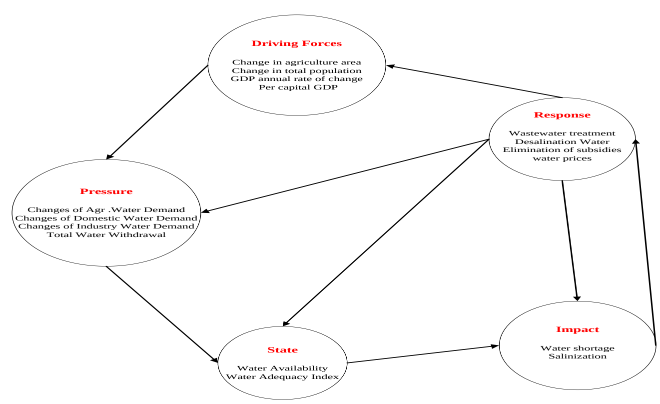

Fig. 3. DPSIR framework for water resources management in Egypt

3.2 ANP Method

The Analytic Network Process (ANP) proposed by Saati in 1999 and built on AHP. ANP is a decision finding method and is a more general of the AHP. It is considering the dependence and the interaction between the elements of the hierarchy (Piantanakulchai, 2005; Saaty, 1999). Therefore, ANP is represented by a network, rather than a hierarchy. Elements, clusters, and relationships compose the ANP network structure. The elements (nodes) in a cluster may influence some or all of the elements in another cluster. The ANP method is used to determine the weight of each indicator. The following subsection describes the stages of a developed ANP model.

3.2.1 Problem Structuring

In this research, the clusters in ANP network corresponds to the five categories of DPSIR framework framework which are Driving Forces (D), Pressure (P), State (S), Impact (I) and Response (R), as shown in Fig. 3. The elements in each cluster refer to the sustainability indicators of water resources system. The cluster and the Indicators considered in this study are represented in table 1.

Table 1: Clusters and elements of the ANP model

Cluster	elements
Driving Forces (D)	D1- Change in the agriculture area
	D2- Change in total population
	D3- GDP annual rate of change
	D4- Per capita GDP
Pressure (P)	P1- Changes of Agr. Water Demand
	P2- Changes of Domestic Water Demand
	P3- Changes of Industry Water Demand
	P4- Total Water Withdrawal
State (S)	S1- Water Availability
	S2- Water Adequacy Index
Impact (I)	I1- Water shortage
	I2- Salinization
Response (R)	R1- Wastewater treatment
	R2- Desalination Water
	R3- Elimination of subsidies water prices

3.2.2 Pairwise Comparison Matrices and Priority Vectors

In this step, In this step, a series of pairwise comparisons are made to conform to the relative importance of the different elements. In pairwise comparisons, a ratio scale of 1-9 used to compare any two elements as represented in table 2. Table 3 gives an example of the pairwise comparison matrix.

Table 2: The fundamental scale for pairwise comparisons

Value	Definition	Explanation
1	Equal importance	Two elements of decision similarly impact to the objective.
3	Moderate importance	One element of decision is moderately more affecting than the other.
5	Strong importance	One element of decision has a strong impact than the other.
7	Very strong importance	One element of decision has a very strong impact than the other.
9	Extreme importance	The difference between the impacts of the two elements to the objective is highly significant.
2,4,6,8	Judgment values between equal, moderate, strong, very stronge and extreme importance.	

Table 3: Change in agriculture area (D1) with respect to pressure criteria

D1	P1	P2	P3	P4	Priority
P1	1.00	3.00	5.00	0.33	0.26
P2	0.33	1.00	3.00	0.20	0.12
P3	0.20	0.33	1.00	0.14	0.06
P6	3.00	5.00	7.00	1.00	0.56
					1.00

3.2.3 Supermatrix Formation

The supermatrix (table 4) is constructed with priority vectors obtained from all comparison matrices. The supermatrix is a 15×15 elements matrix composed of a 5×5 clusters matrix (blocks). The local priority vectors of element comparison form the initial supermatrix (unweighted supermatrix). After formulating the initial supermatrix, the sum of each column of the matrix normalized to formulate weighted supermatrix (table 5).

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Table 4: Initial matrix (unweighted Supermatrix)

	D1	D2	D3	D4	P1	P2	P3	P4	S1	S2	I1	I2	R1	R2	R3
D1	0	0	0	0	0	0	0	0	0	0	0	0	0.08	0.05	0.39
D2	0	0	0	0	0	0	0	0	0	0	0	0	0.40	0.50	0.46
D3	0	0	0	0	0	0	0	0	0	0	0	0	0.36	0.27	0.07
D4	0	0	0	0	0	0	0	0	0	0	0	0	0.16	0.17	0.07
P1	0.26	0.11	0.08	0.16	0	0	0	0	0	0	0	0	0.06	0.07	0.20
P2	0.12	0.43	0.26	0.08	0	0	0	0	0	0	0	0	0.36	0.27	0.20
P3	0.06	0.06	0.16	0.26	0	0	0	0	0	0	0	0	0.11	0.13	0.18
P4	0.56	0.40	0.50	0.50	0	0	0	0	0	0	0	0	0.47	0.53	0.43
S1	0	0	0	0	0.17	0.25	0.25	0.3	0	0	0	0	0.25	0.25	0.25
S2	0	0	0	0	0.83	0.75	0.75	0.8	0	0	0	0	0.75	0.75	0.75
I1	0	0	0	0	0	0	0	0	0.25	0.17	0	0	0.83	0.83	0.88
I2	0	0	0	0	0	0	0	0	0.75	0.83	0	0	0.17	0.17	0.13
R1	0	0	0	0	0	0	0	0	0	0	0.65	0.58	0	0	0
R2	0	0	0	0	0	0	0	0	0	0	0.12	0.11	0	0	0
R3	0	0	0	0	0	0	0	0	0	0	0.23	0.31	0	0	0

Table 5: Weighted Supermatrix

	D1	D2	D3	D4	P1	P2	P3	P4	S1	S2	I1	I2	R1	R2	R3
D1	0	0	0	0	0	0	0	0	0	0	0	0	0.021	0.013	0.098
D2	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.126	0.116
D3	0	0	0	0	0	0	0	0	0	0	0	0	0.089	0.069	0.018
D4	0	0	0	0	0	0	0	0	0	0	0	0	0.04	0.042	0.018
P1	0.263	0.111	0.077	0.159	0	0	0	0	0	0	0	0	0.015	0.016	0.049
P2	0.122	0.431	0.263	0.077	0	0	0	0	0	0	0	0	0.09	0.068	0.049
P3	0.057	0.059	0.159	0.263	0	0	0	0	0	0	0	0	0.028	0.033	0.044
P4	0.558	0.399	0.501	0.501	0	0	0	0	0	0	0	0	0.117	0.133	0.108
S1	0	0	0	0	0.167	0.25	0.25	0.25	0	0	0	0	0.063	0.063	0.063
S2	0	0	0	0	0.833	0.75	0.75	0.75	0	0	0	0	0.188	0.188	0.188
I1	0	0	0	0	0	0	0	0	0.25	0.167	0	0	0.208	0.208	0.219
I2	0	0	0	0	0	0	0	0	0.75	0.833	0	0	0.042	0.042	0.031
R1	0	0	0	0	0	0	0	0	0	0	0.648	0.581	0	0	0
R2	0	0	0	0	0	0	0	0	0	0	0.122	0.11	0	0	0
R3	0	0	0	0	0	0	0	0	0	0	0.23	0.309	0	0	0

3.2.4 Find priorities

For obtaining the global priority vector, the weighted supermatrix raises to limiting powers to form the limited supermatrix (table 6). Table 7 shows the final priority deriving from limited supermatrix.

Table 6: Limited Supermatrix

	D1	D2	D3	D4	P1	P2	P3	P4	S1	S2	I1	I2	R1	R2	R3
D1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
D2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
D3	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
D4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
P1	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
P2	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
P3	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
P4	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
S1	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
S2	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
I1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
I2	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
R1	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17	0.17
R2	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
R3	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08

Table 7: Final priority

Cluster	Elements	Priority Value
Driving Forces (D)	D1- Change in the agriculture area	0.01
	D2- Change in total population	0.03
	D3- GDP annual rate of change	0.02
	D4- Per capita GDP	0.01
Pressure (P)	P1- Changes of Agr. Water Demand	0.02
	P2- Changes of Domestic Water Demand	0.04
	P- Changes of Industry Water Demand	0.02
	P4- Total Water Withdrawal	0.07
State (S)	S1- Water Availability	0.05
	S2- Water Adequacy Index	0.16
Impact (I)	I1- Water shortage	0.1
	I2- Salinization	0.19
Response (R)	R1- Wastewater treatment	0.17
	R2- Desalination Water	0.03
	R3- Elimination of subsidies water prices	0.08

3.3 Simulation Modeling

The developed model is a dynamic model for sustainable water resource management in Egypt. The authors use the system dynamic modeling software "Powersim" for developing the model. It is a simulation software based on the system dynamics technique for providing the modelers with higher capabilities to make complex business simulators. Fig. 4 shows the flowchart of the steps to build a simulation model. The presented model applies SD as a decision support tool to help achieve sustainable water management in Egypt and analyze the long-term impacts of various investment plans. In addition, the model presents the feedback between various variables.

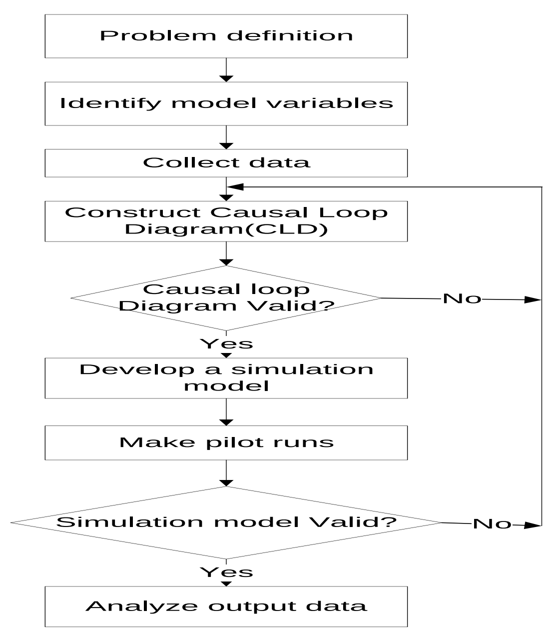

Fig. 4. Flowchart of building a simulation model.

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The authors collected the required data from the year 2004 to 2015. The data were collected from different sources (e.g. Central Agency for Public Mobilization and Statistics (CAPMAS, 2009-2017, 2013; Planning ministry, 2016; Trading Economics, 2016). The elements of system dynamics are feedback loops (Causal loop diagram), accumulation of flows into stocks and time delays. Fig. 5 shows an example of Causal loop diagrams which presented in the model.

In order to use the causal loop diagrams, a stock and flow diagram need to be developed for building a simulation model. Fig. 6 shows an example of the stock and flow diagrams which is presented in the model.

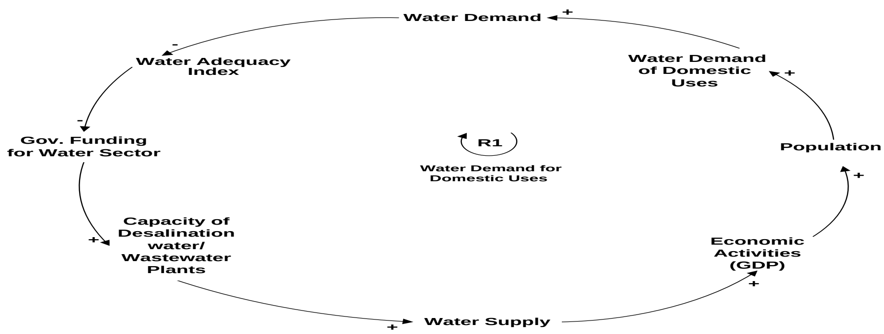

Fig. 5. Water demand for domestic uses loop

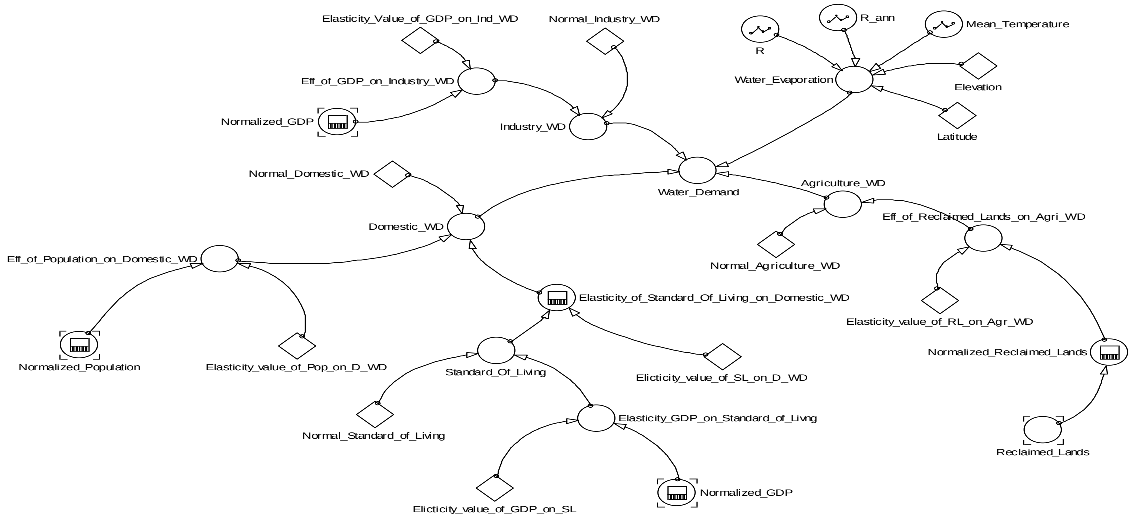

Fig. 6. Stock and flow diagram of water demand

3.3.1 SD Model Outputs

The model was constructed to interpret and simulate water demand, supply, and uses in Egypt. The model was run from the year 2004 to 2035. The outcomes are presented (Figs. 7-12).The results showed that Egypt's population would increase from about 69 million in the year 2004 to 160 million in the year 2035 as shown in Fig. 7. This increase leads to rising domestic water demand per year from about 5.6 billion m^3 in the year 2004 reaching 18.9 billion m^3 in the year 2035 as indicated in Fig. 8. The increase in population requires increasing agricultural land, establishing new factories, and expanding services and therefore increasing demand for water. Also, this increase in population leads to increasing total water demand from about 73.1 billion m^3 in the year 2004 to 93.84 billion m^3in the year 2035 as shown in Fig. 8.

Fig. 8 shows that the agriculture sector represents the largest share (82 %) of water demand in Egypt between the different sectors. Fig. 9 represents the water resources in Egypt. This Figure indicates that all water resources seem-fixed except for agricultural drainage water that expected to increase from about 4.8 billion m^3 in the year 2004 to 23.68 billion m^3 in the year 2035. This means that officials should find unconventional ways to increase the amount of water available. From analyzing the results of water demand and water supply, the authors found that there is a water shortage, thus inadequacy in water as indicated in Fig. 10 and 11.

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As shown in Fig. 12, the water withdrawal (uses) incremental over time. This increase results from the rapidly growing population, the agricultural extension uses as well as industrial development and a rise in the standard of living.

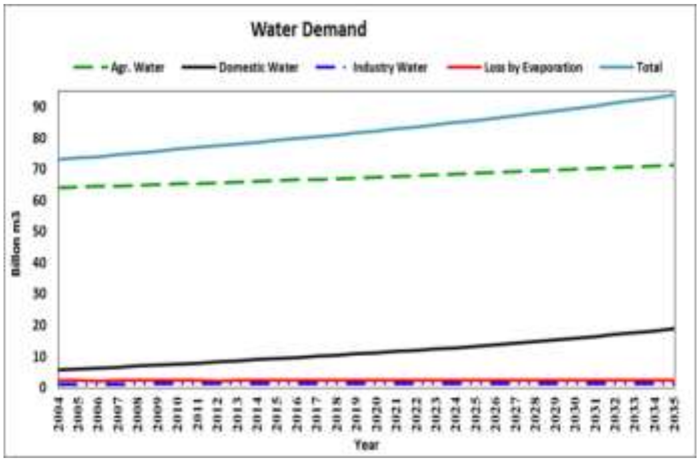

Fig. 7. Egypt's population

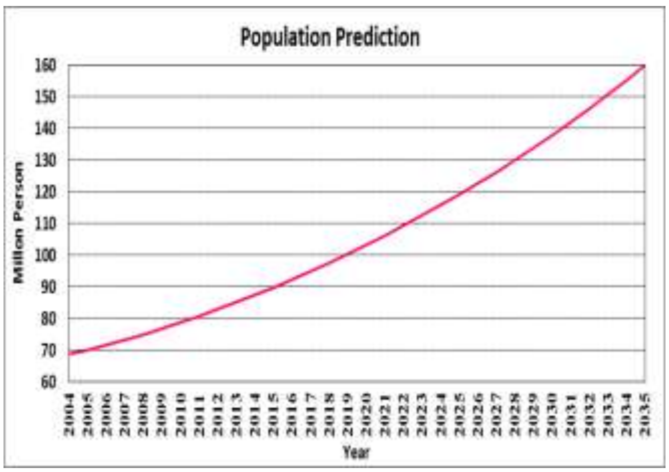

Fig. 8. Water demand

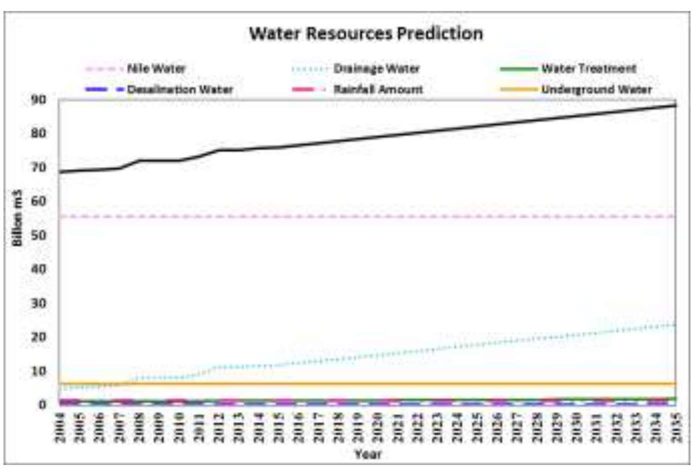

Fig. 9. Water resources

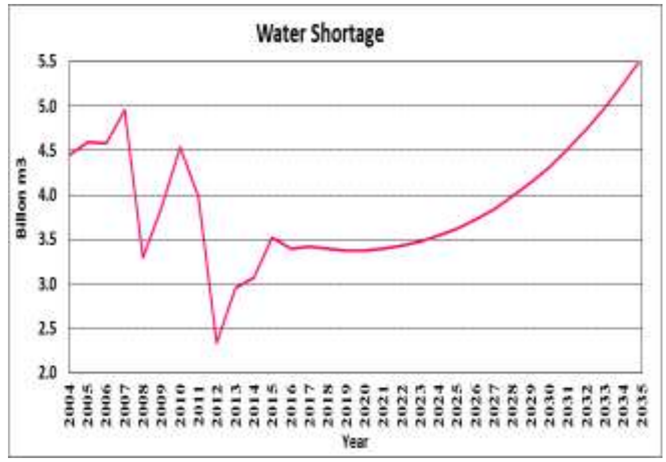

Fig. 10. Water shortage

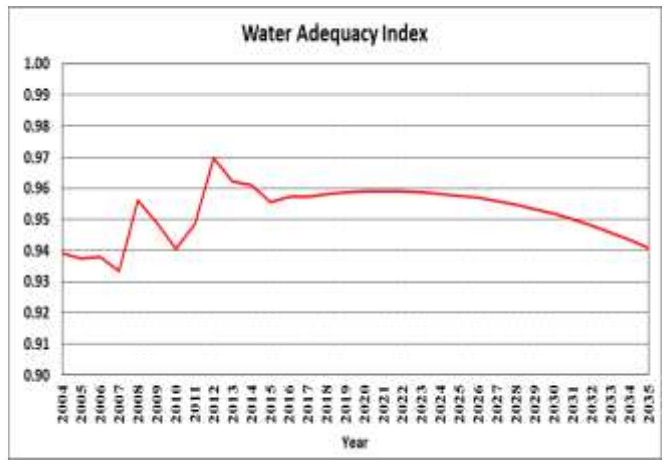

Fig. 11. Water Adequacy Index

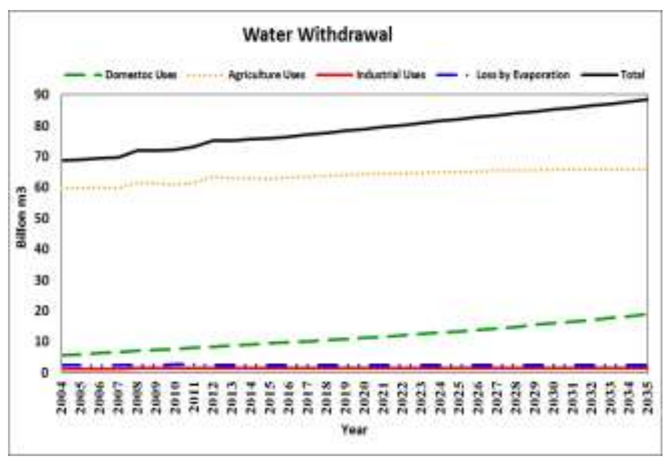

Fig. 12. Water withdrawal (Uses)

3.4 Sustainability Assessment Of Water Resources System

Sustainable water resource systems are those designed and managed to best serve people living in the future as well as those of us living today. The goal of sustainability assessment is to pursue that plans and activities make an optimal contribution to sustainable development. So, there are needing to have an index to show the sustainability degree. The following equations depict how computing the sustainability index (Xu, 2011):

1- The standard value of each indicator

$$y_{IJ} = (x_{IJ} - \min x_{IJ})/(max\ x_{IJ} - \min x_{IJ}). \quad (1)$$

Where x_{ij} is the index value of the ith indicator in jth year. m means the number of the indicators in the model, and n points out the sample years considered. In this study m= 15 and n=31 (from 2005-2035). y_{ij} is the standardization index value of index x_{ij}, min x_{ij} means the minimum value of ith index in the sample period, max x_{ij}, means the maximum value of ith index in the sample period.

2- Sustainability index of each layer (category)

$$Y_j = \sum_{i=p}^{q} w_i\ y_{ij}. \quad (2)$$

Where Y_j is the value of sustainability index of the subsystem layer (category) in jth year, i.e. “Pressure”, “State”, “Impact” and “Response”. w_i is the weight of ith index (Table 7). p and q refer to the indicators involved in the subsystem.

3- Sustainability index of the system

$$Z_j = \sum_{i=1}^{m} w_i\ y_{ij} (1 \le j \le n). \quad (3)$$

Zj is the final value of sustainability index of the system in jth year which index obtained from the value of the Driving Forces, Pressure, State, Impact and Response categories. y_{ij} is the standard index value of the ith indicator in jth year. wi is the weight of ith index, m is the number of indicators in the model, n=31 here which indicates the years considered from 2005 to 2035.

4. RESULTS

The identification and analysis of the five overall indexes in the DPSIR are depended on the weight of each indicator. The DPSIR categories and sustainability index of water resources systems (WRS) in Egypt are shown in Figs. (13-18) as a line chart.

4.1 Driving Forces Index

The driving forces index of water uses increased overall the research period (Fig. 13) because of population growth, an increase in the area of cultivated land, economic activities, and an increase in living standards of the inhabitants. This point out an increase in driving forces for Egyptian water consumption because of socio-economic development and a change in housing consumption.

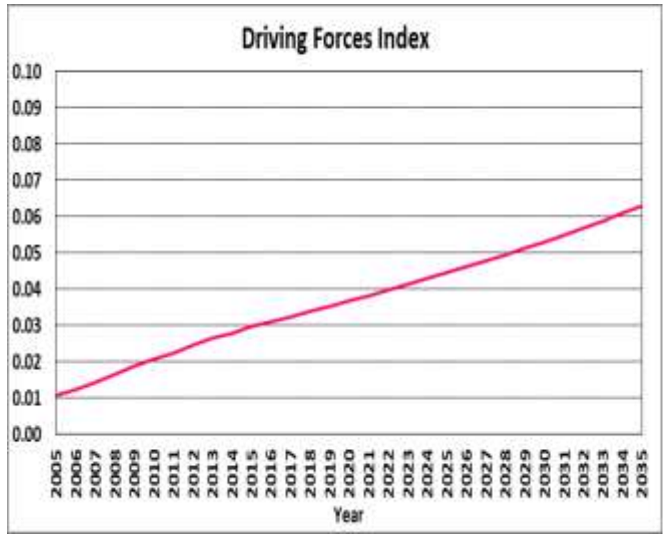

Fig. 13. Driving forces index of WRS in Egypt

4.2 Pressure Index

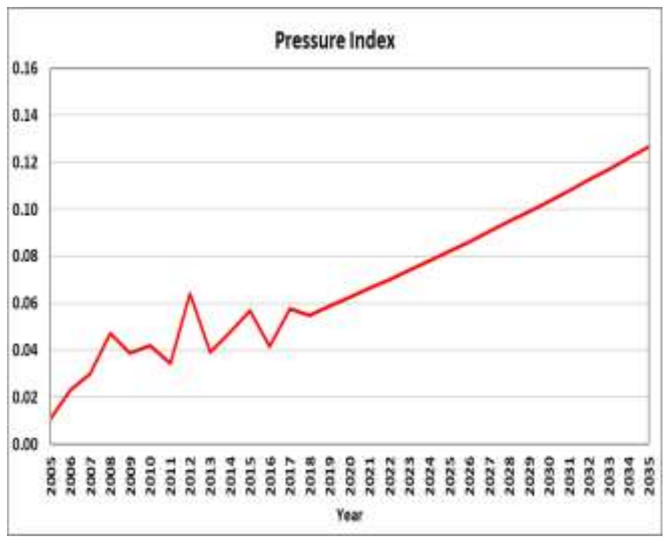

Fig. 14. Pressure index of WRS in Egypt

The pressure on water systems increased during the study period because of the increase in the driver indicators. The water resources system faced pressure due to the increase in water demand of domestic uses, agriculture, and industry (Fig. 14).

4.3 State index

Fig. 15; represents the changes in the state of water resources over time. The figure indicates an increasing trend in the first 8 years while decreasing in the following period. This increase occurs due to an increase in the amount of water availability which resulting from agriculture drainage reuse, while the decrease in the following period is related to increasing pressure on water resources.

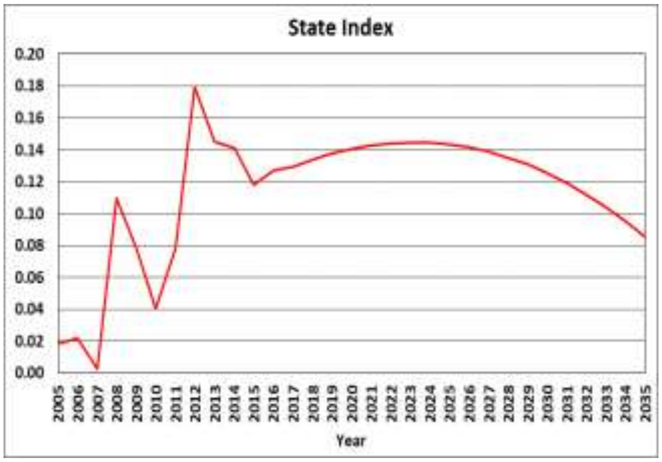

Fig. 15. State index of WRS in Egypt

4.4 Impact index

Driver and pressure have a significant influence on water resource systems. The impact indicators of the water system increased in most of the time during the study period (Fig. 16). This is attributed to the gap between water demand and water availability, and the increase in the rate of salinization.

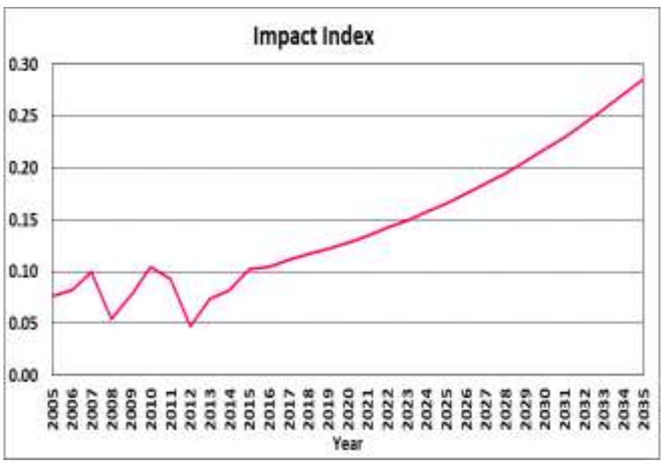

Fig. 16. Impact index of WRS in Egypt

4.4 Response index

As indicated in Fig. 17, there is an incremental change in response over time. This is attributed to the measures that were taken by officials. These measures are increasing the capacity of wastewater plants, and elimination of subsidies water prices.

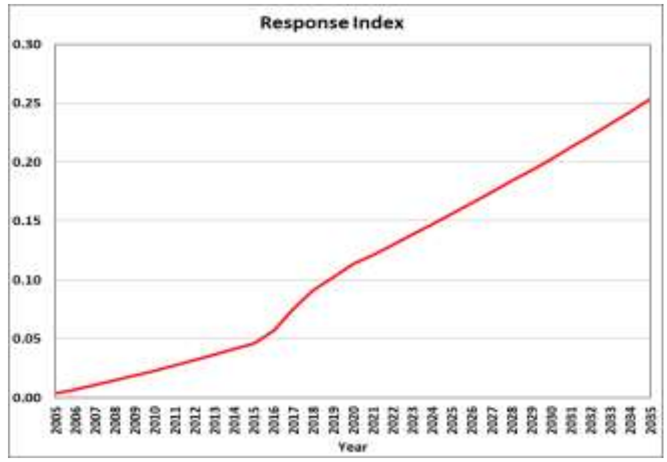

Fig. 17. Response index of WRS in Egypt

4.5 Sustainability Index

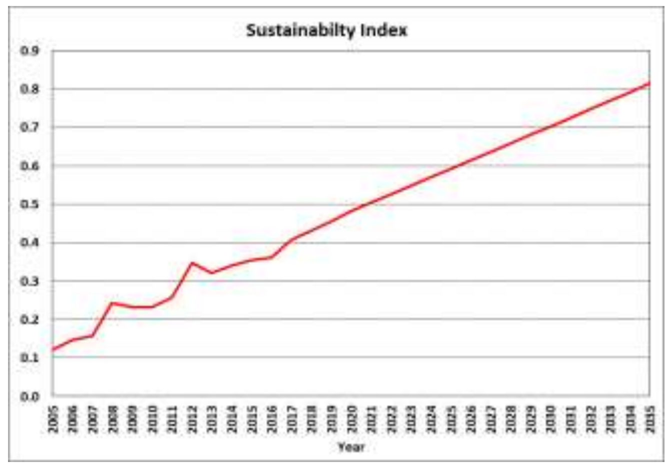

Fig. 18. Sustainability index of WRS in Egypt

Generally, there is an increasing impact on the sustainability of water resources systems in Egypt over the research period (Fig. 18). This is attributed to the increase in water resources consumption due to the increase in population, agriculture expansion and an increase in the value of GDP. At the same time, the response measures taken to increase the amount of water availability. Finally, the officials for managing water resources in Egypt should take actions to increase the efficiency of water use and increasing the renewable water resources for compensating the gap between water demand and water supply.

Fig. 19, shows changes of DPSIR categories and sustainability index of WRS in Egypt over time in one graph.

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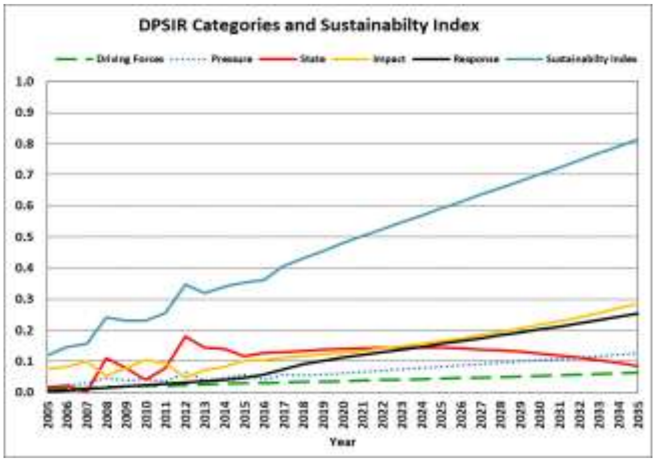

Fig. 19. DPSIR Categories and sustainability index of WRS in Egypt

5. CONCLUSION

Sustainability evaluations of international/ local water resources help to realize the evolution of the water system and its impacts. This accelerates the achievement of sustainability and management of water resources. This kind of evaluations is necessary as it guarantees the combination of socio-economic and environmental themes into all aspects of water resources management (Sun et al., 2016).

To assess the sustainability of water resources systems, this research is applying an integrated approach was developed by (Xu, 2011). It is built on using DPSIR-ANP method and the SD model. This integrated approach enables decision makers to view the sustainability problems of water resources system more comprehensively. The conclusion of applying the integrated approach to appraise sustainability in Egypt can be drawn as follows:

There is an increase in the driving forces overall in the research period. This is attributed to population growth, an increase in the area of cultivated land, economic activities, and an increase in living standards of the inhabitants. Also, overall the study the pressure on the water system incremented, while the status of the water resources declined as a result of driving forces indicators increase. Water system impact indicators increased in most of the time during the study period. This is attributed to the gap between water demand and water availability, and the increase in the rate of salinization. The Egyptian government adopted a set of response measures to improve water use efficiency and increase the amount of water. The procedures are increasing the capacity of wastewater plants, and elimination of subsidies water prices.

Finally, there is an increasing impact on the sustainability of water resources systems in Egypt over the research period. This is attributed to the increase in water resources consumption due to the increase in population, agriculture expansion and an increase in the value of GDP. So, the officials for managing water resources in Egypt should take actions to increase the efficiency of water use and increasing the renewable water resources for compensating the gap between water demand and water supply.

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