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A METHODOLOGICAL FRAMEWORK TO SUSTAIN HYDROLOGICAL RESOURCES IN EGYPTIAN COASTAL DESERTS

W. A. ABDELLATIF[1], P. H. A. YOUSEF[2],
M. M. QORQOR[3] AND A. A. ELKHOULY[4]

ABSTRACT

The research addresses the concept of using hydrological resources in Egyptian coastal deserts, despite their availability, they are wasted and thus an impediment to the stability of urbanization. Hence, the main purpose of the research is how to reach an integrated methodological framework for the sustainability of hydrological resources in coastal deserts that will utilize these resources and be suitable for the autonomy of coastal deserts. This methodological framework is divided into three main axes: sustainable supply of water resources, their uses, and demand. The interactions between the three main axes in the methodological framework and relationship to the sustainability process has been studied; finally, the appropriate methodological framework will be determined. The main research result was identifying multiple aspects of sustainability resulting from the conducted methodological framework and the diversity of the developmental returns of sustainability on urban, environmental, economic and social benefits.

Keywords: Groundwater, Rainwater, Sustainability of hydrological resources, Coastal deserts, Methodological framework.

1. INTRODUCTION

Hydrological resources, groundwater and rainwater, are the most essential resources of the world; groundwater is considered the safest source for drinking [1]. Attention has increased to the hydrological resources in recent decades, as it is considered the main source of supply of drinking water in many countries. Groundwater and rainwater have a unique property that is reflected on how they are

[1] Assistant Lecturer, Faculty of Urban and Regional Planning, Cairo University, Giza, Egypt, walid_3amer@yahoo.com
[2] Assistant Professor, Faculty of Urban and Regional Planning, Cairo University, Giza, Egypt.
[3] Associate Professor, Faculty of Urban and Regional Planning, Cairo University, Giza, Egypt.
[4] Professor, Desert Research Center, Egypt.

treated. However, in the Egyptian coastal deserts, hydrological resources have a limited use despite of their availability. This paper discusses how to reach an integrated methodological framework for the sustainability of hydrological resources in Egyptian coastal deserts. The research questions how to achieve sustainability for hydrological resources and what is its impact on coastal deserts sustainability.

2. HYDROLOGICAL RESOURCES IN EGYPTIAN COASTAL DESERTS

Egyptian coastal deserts vary in terms of environmental and urban characteristics: the North West coastal desert, the Northern coastal desert of Sinai, and the Red Sea coastal desert. Coastal deserts environmental characteristics are well-covered [2-5].

The Egyptian coastal deserts are rainwater drainage areas where the North West coastal desert, the Northern coastal desert of Sinai (Mediterranean Sea coastal deserts) are located within the Mediterranean rainwater drainage basin. The coastal deserts on the Red Sea are located within the Red Sea and Gulf of Suez drainage basins. Figure 1 illustrates regional drainage basins in Egypt.

The aquifer systems are numerous in Egyptian coastal deserts. The North-West coast includes three aquifers (carbonate, Wadi deposits and Moghra aquifer) while the Northern coastal desert of Sinai includes two aquifers (Wadi deposits and carbonate aquifer) and the Red Sea coastal desert includes two aquifers (fractured rocks and Wadi). Figure 2 illustrates the location of the Egyptian aquifers.

3. ENVIRONMENTAL GROUNDWATER ASSESSMENT USING DIGITAL AND TECHNOLOGICAL TOOLS

Groundwater assessments are concerned about the current status of groundwater which provides the indicators for sustainable use and thus adjust the demand to suit the size and characteristics of the resource to sustain it and sustain the activity. Groundwater assessments are concerned with four components: groundwater potential, groundwater vulnerability, groundwater quality, and integrated groundwater footprint.

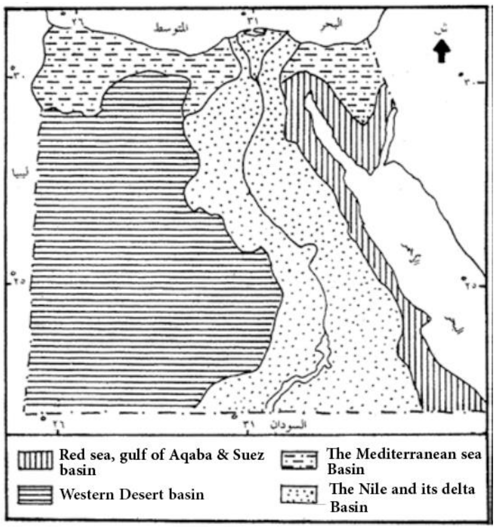

Fig. 1. Regional drainage basins in Egypt [6].

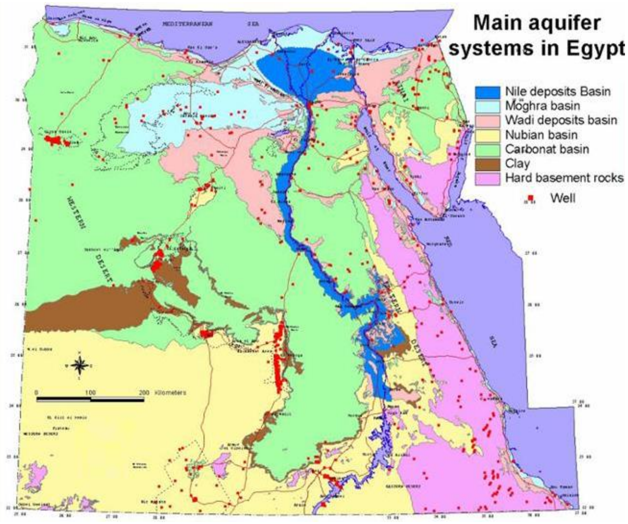

Fig. 2. Main aquifer systems in Egypt [7]

3.1 Groundwater Potential Assessment

3.1.1 Factors affecting groundwater potential assessment

The main factors in the literature affecting groundwater potential assessment [8-17] were determined in order of importance according to the relative weights given to each factor. These include geology, slop, geomorphology, rainfall, land use and land cover, drainage density, soil, runoff coefficient, and proximity to surface water bodies. The relative weight of each factor varies according to its effect on the groundwater potential zone.

3.1.2 Methodology of the generation of groundwater potential map

To generate a groundwater potential map, spatial layers of the factors are merged using the weighted overlay tool in Arc GIS [14]. It applies one of the most used approaches for overlay analysis to solve multi criteria problems such as site selection and suitability models [18]. Different features of each theme were assigned a rank according to their relative influence on the groundwater development. Based on this scale, a qualitative evaluation of different features of a given theme was performed [14]. Thus, a digital map is generated to assess the groundwater potential.

3.2 Groundwater Vulnerability Assessment

The concept of groundwater vulnerability describes the relative ease with which the groundwater resource could be contaminated. This is based on the idea that the physical and natural environment can provide the resource with various degree of contamination. It has been defined as "an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts" [19].

There are three main methods for assessing the vulnerability of groundwater to pollutants [20]. The first is process-based, through numerical modeling, and the second is the statistical method. The third is the method of overlay and index, which includes obtaining maps of the factors that affect the transfer of pollutants from the surface to the groundwater and their merging, then assigning a value for those coefficients; the end result is a spatially susceptible indicator of groundwater [21].

3.2.1 The DRASTIC method

The DRASTIC vulnerability index (DVI) is calculated by linear addition of the weights and rating. The seven hydrogeological factors used in the DRASTIC method to assess the vulnerability of groundwater resources to pollutants used in the calculation of the final indicator are: depth to groundwater, net recharge, aquifer media, soil media, general topography, impact of vadose zone, and hydraulic conductivity of the aquifer (m/day). The formula for DVI determination is given in Eq. (1) and includes the seven hydrographic parameters [20]:

$$(DVI) = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w \tag{1}$$

Where:

DVI : The DRASTIC Vulnerability Index,
D_r,D_w : Rating and weight for the depth to water table,
R_r, R_w : Rating and weight for aquifer recharge,
A_r, A_w : Rating and weight assigned to aquifer media,
S_r,S_w : Rating and weight for the soil media,
T_r, T_w : Rating and weight for topography (slope),
I_r, I_w : Rating and weight assigned to impact of vadose zone,
C_r, C_w : Rating for rates weight given to hydraulic conductivity.

The rating and weighting values for the various hydrogeological parameter are summarized [20]. The final index becomes the sum of the product of each coefficient in its relative weight.

3.3 Groundwater Quality Assessment

The water quality index (WQI) helps to evaluate the quality of groundwater and its usage for drinking considering that the groundwater chemistry is the most important part to identify the drinking water quality. The WQI is calculated by assigning the weights (w_i) to the physical and chemical parameters and their influence on water quality (TDS – HCO_3^- –Cl^- –SO_4^{2-} –PO_4^- –NO_3^- –Ca^{2+} -Mg^{2+} –EC – pH). Based on the WHO (2011) standard and the assigned weight (w_i) that ranges from 1 to 5 depending on the effect of each factor in the assessment of water quality, a five-stage category is used to classify the computed WQI [22]. The classification is excellent for water less than 50 mg/l, good water is between 50-100 mg/l, poor water is between 100-200 mg/l, very poor water is between 200-300 mg/l. Water unsuitable for drinking purposes is more than 300 mg/l.

3.4 Integrated Groundwater Footprint Assessment

The groundwater footprint can be viewed as a water balance between inflows and outflows in the aquifer system; it can be estimated by from Eq. (2) [23]:

$$GF = A\,(C/(R-E)) \tag{2}$$

Where:

GF	:	groundwater footprint,
C	:	area-averaged annual abstraction of groundwater (m^3/y) (outflows),
R	:	recharge rate (m^3/y) (inflows),
E	:	groundwater contribution to environmental stream flow (m^3/y)
A	:	aquifer area, the area of interest for which C, R and E are defined (m2).

In order to consider groundwater footprint as a comprehensive decision-making tool, the critical role of groundwater quality and its merging into the groundwater footprint should also be considered based on Eq. (3):

$$iGF = GF \times (1 + n\,[(CF_1)\,A_1/A + (CF_2)\,A_2/A + \ldots.. + (CF_n)\,A_n/A]) \tag{3}$$

Where:

iGF	:	integrated groundwater footprint, n: number of contaminants,
CF(1…n)	:	contamination factor for contaminant (j),with j=1,…, n,

A(1…n) : the extent of contamination, in terms of the area (m^2).

For a relative comparison among the various groundwater tanks, the ratio of the groundwater footprint (GF), as well as the integrated groundwater footprint (iGF), to aquifer area (A) were used. This ratio can be considered as a groundwater stress indicator. Values of the ratio [(GF or iGF)/A] > 1 indicate non-sustainable consumption of groundwater resources in that aquifer and/or evidence of contamination. Aquifers with values of [(GF or iGF)/A]≫1 are significantly stressed and/or significantly contaminated, while values of [(GF or iGF)/A] < 1, suggest that groundwater reserves are sustainably used and/or of good quality [23].

3.5 Concluding a Methodology of Environmental Groundwater Assessment

From the above groundwater assessments [14, 20, 22, 23] through the inputs, processes, indicators used and resulting outputs, the methodology was modified as presented in Fig. 3.

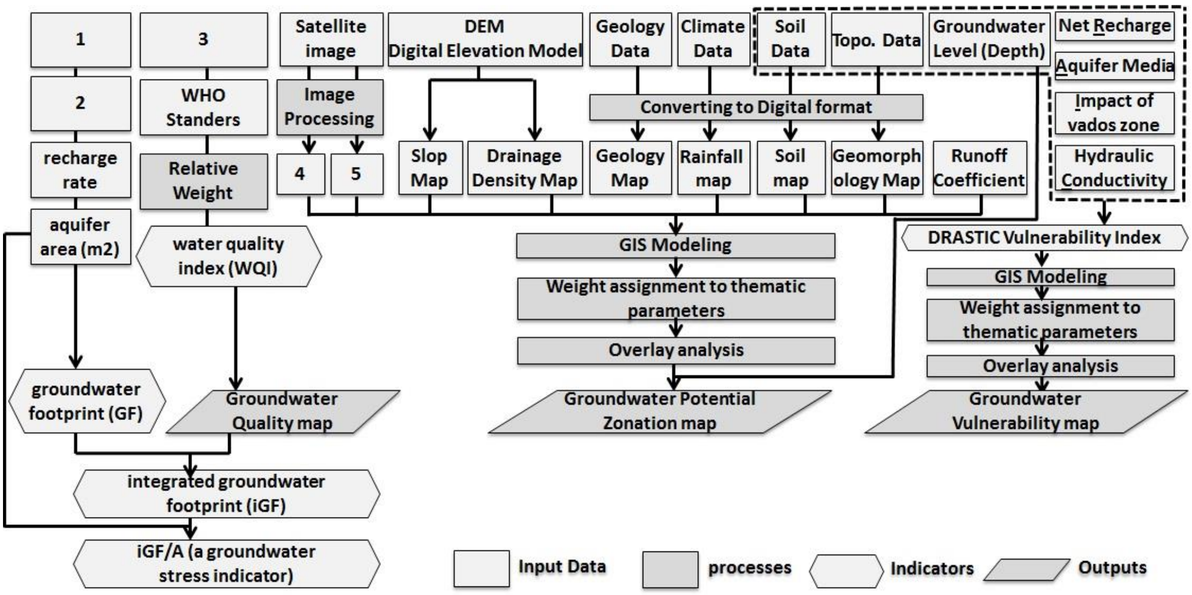

Fig. 3. Methodology of environmental groundwater assessment.
1: groundwater contribution to environmental stream flow (m^3/y), 2: area-averaged annual abstraction of groundwater (m^3/y), 3: physicochemical parameters, 4: land use and land cover map, 5: proximity to surface water bodies.

4. SUSTAINABILITY AND SUPPORT FACTORS FOR RAINWATER HARVESTING IN COASTAL DESERTS

4.1 Opportunities for Increasing Rainfall in Coastal Deserts Using Biotic Pump Theory

In deserts, despite the existence of seasonal differences between land and ocean surface temperatures, the evaporation on land is practically absent, so no sea-to-land fluxes of moisture can originate in any season. The absence of a contiguous cover of tall trees with high leaf area prevents such ecosystems from rainfall opportunity specially with increasing the distance from sea. Flux of moisture from sea to land would compensate runoff from the optimally moistened soil. Coastal desert ecosystems can thus ensure the necessary sea-to-land flux of moisture in any direction. The cumulative evaporative surface of the coast can be much higher than the open water surface of the same area [24], thus more plants can grow.

4.2 Methodology of Suitability Maps for Rainwater Harvesting

The rainwater harvesting suitability model (RSM) was developed using model builder in ArcGIS, by using the layers including (physical, ecological, socio-economic, the restrictions) influencing rainwater harvesting suitability model. As model builder works in the raster environment with grid format layers, vector themes were converted into raster themes. The rainwater harvesting suitability model includes two sub-models (potential model and constraint model). Pixel values of each physical, ecological and socio-economic layer were classified from 1 to 5 according to the influence on rainwater harvesting. The most suitable parameters were classified as 5, while the least suitable were classified as 1. The reclassification was done during the data processing using Spatial Analyst, in ArcGIS [25]. Figure 4 illustrates the methodology of suitability maps for rainwater harvesting.

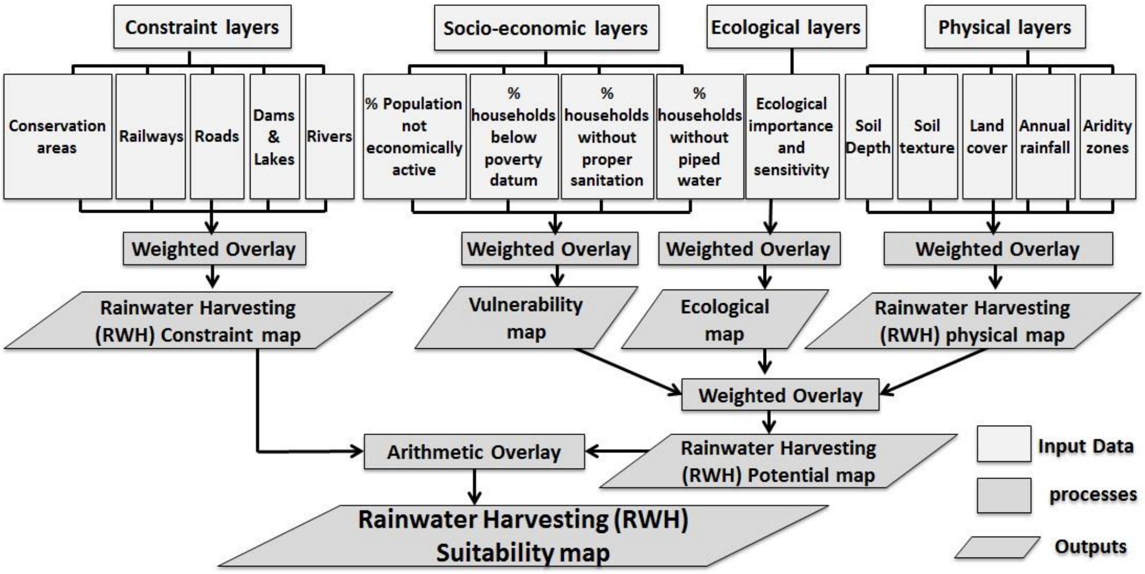

Fig. 4. Methodology of rainwater harvesting suitability maps [25].

4.3 Methods of Rainwater Harvesting

As water harvesting is an ancient tradition and has been used in most dry lands worldwide, many different techniques have been developed. Most of these are for irrigation purposes, while others are to conserve water for human and animal consumption. Water harvesting methods are classified in several ways, mostly based on the type of use or storage and the catchment size [26]. Rainwater harvesting methods can be divided into two categories:

A. Micro-catchment methods: includes on-farm systems (contour ridges, semi-circular and trapezoidal bunds, small pits, small runoff basins, runoff strips, inter-row systems, meskat, contour-bench terraces) and rooftop systems.

B. Macro-catchment and floodwater methods: includes Wadi-bed systems (small farm reservoirs, Wadi-bed cultivation, Jessour) and Off-Wadi systems (Water-spreading systems, large bunds, tanks and hafair, cisterns, hillside-runoff) [26].

5. SUSTAINABLE USE OF HYDROLOGICAL RESOURCES

5.1 Integrated Groundwater Assessment for Agricultural use in Coastal Deserts

Groundwater is the main resource in many agricultural development areas, especially in coastal deserts. Agriculture is the most water-consuming sector. The great privacy of groundwater makes the process of agricultural development depending on it unconventional. Thus, it is necessary to identify the main factors affecting the groundwater uses in agricultural development to merge these factors. These are groundwater quality map, groundwater potential map, and vulnerability map [27].

In order to merge the main factors affecting the assessment of groundwater used in agriculture, the multivariate clustering method is used. It is a classification method for merging the results of groundwater quality, potential, and vulnerability. The Maximum Likelihood Classification (MLC) method that considers both the variance of the class when assigning each cell to one of the classes represented in the main three variables was used [27].

5.2 Soilless Culture

The agricultural sector is considered the most influential sector for the sustainability of hydrological resources in terms of the percentage of water consumption. This reached 81.6% of the total uses in Egypt according to the Central Agency for Public Mobilization and Statistics in 2014/2015 (with a share of 62.35 of 76.5 billion cubic meters). The negative impact of fertilizers and materials used in groundwater based agriculture should not be overlooked. Therefore, it is necessary to rely on agriculture methods that lead to water conservation and contribute to mitigate the harmful effects on the environment resulting from traditional agriculture. It is necessary to ensure that the contaminants do not reach the soil or groundwater, and that the nutrients remain in the nutritious solution until absorbed by the plant.

5.2.1 Soilless culture systems

There are three main systems of soilless culture:

- Culture media: The importance of the soilless culture increased with the development of greenhouses [28].
- Hydroponics: is an agricultural system that relies on planting without soil using a nutrient solution that passes below the plant, which provides the plant with the

necessary nutrients so that it is easy to absorb. This system conserves water and makes plants grow faster than traditional agriculture [28].

- Aquaponics: is an integration of recirculating aquaculture systems and hydroponics in one production system [29].

5.3 Uses of Saline Groundwater Resulting from Sea Water Intrusion

The phenomenon of freshwater below saltwater is quite a complex one. In reality the two fluids are miscible and are separated by a transition zone with a continuous upward slight increase of salt concentration from below saltwater to the uncontaminated water above [30].

Saline groundwater is an important source of irrigation for salinity tolerant crops and plants, giving good production to meet the needs of farmers when fresh water is not available. Thus, saline groundwater can be included in the water budget of coastal deserts, where highly efficient use and good management lead to increased irrigated land area of coastal deserts, by using them to irrigate suitable and tolerable crops for salinity. This is positively reflected by reducing the burden on the use and supply of fresh water for drinking purposes [31]. Saline groundwater can also be used in coastal deserts in fish farming, depending on the degree of salinity [32].

5.4 Merging of Groundwater Protection with Land Use Planning

The delimitation of reserved areas can be merged into spatial land-use planning by mapping the allowed activities. This process sets a threshold value corresponding to a tolerable water environment value, based primarily on the hydrogeological and climate characteristics of the area. This can be reached by analyzing the existing pressures, which identifies the current groundwater condition.

If the condition exceeds the threshold, current new activities are not allowed. When the condition is less than this threshold, different management scenarios can be created for the activities to be allowed. This represents a management tool that accommodates different assumptions related to the implementation of new zones or changes in existing zones by evaluating the economic impact of decisions. A combination between groundwater protection and the possibility of settling economic activities makes this methodology an effective tool for sustainable development [33].

The methodology presented in Fig. 5 helps to merge planning policies effectively with resource protection. This is, therefore, a general methodology applicable with sustainable development, allowing economic activities compatible with environmental protection depending on the pressures and economic costs [34].

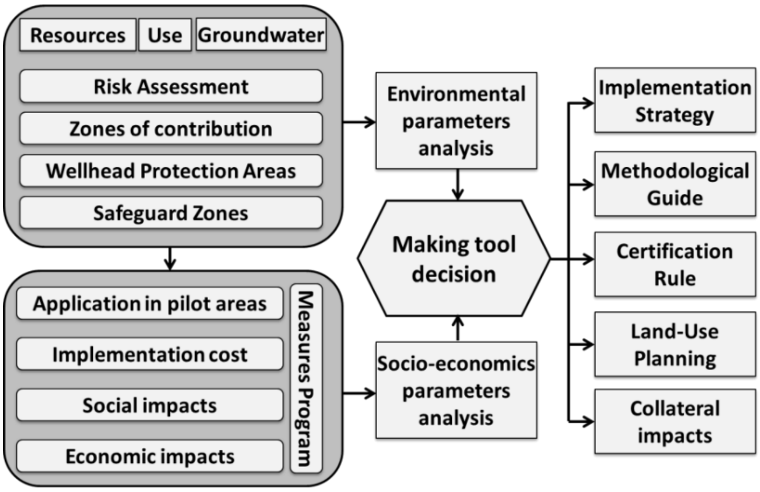

Fig. 5. Methodology for merging groundwater protection with land use planning, Research using [33].

6. TOOLS OF SUSTAINING DEMAND FOR HYDROLOICAL RESOURCES

Water demand management has been defined as "a set of actions that urge individuals in their activities to regulate the quantity and price of water, the way they reach and drainage it, reducing pressure on fresh water and maintaining quality"[34]. It can be classified into four main sections: economic tools, regulation tools, technical tools and training, and awareness raising tools.

6.1 Economic Tools of Water Demand Management

- Pricing: Water pricing is an economic tool that can contribute significantly to water demand management and reduce the gap between supply and demand. It can affect the amount of used water and reduce the waste and misuse of water [35].
- Quotas: Setting a consumption limit, which cannot be exceeded [36].
- Financial aid (subsidies, loans) for farmers: through giving aid in acquiring modern irrigation systems, which save more water, etc. [36].

6.2 Regulation Tools of Water Demand Management

- Changing legislation, including regulating policies for water rights and participation in their use, and laws to assist rural and urban water users [37].
- Giving licenses, pollution control, and quota system [35].
- Decentralization and participatory irrigation management: it requires the participation of the user community and their associations [35].
- Provisional restrictions linked to hydro-climatic fluctuations.
- Obligatory metering of off take volumes (above certain thresholds) [36].
- Water Police responsible for control and reporting offenders [36].
- Devolve units of management (basin agencies) [36].
- User and irrigator associations [36].

6.3 Technical Tools of Water Demand Management:

- Improve irrigation methods efficiency [36].
- Reduce vulnerability of agronomical models and land use systems [36].
- Merging the wastewater reuse in water demand management strategies [36].

6.4 Training and Awareness Raising Tools of Water Demand Management

- Raising awareness of water value and mechanisms to rationalize its use [35].
- Campaigns to raise awareness of farmers and the general public [36].
- Supporting agricultural advisory service [36].
- Training of agricultural professionals, technicians and engineers [36].

7. ANALYSIS

Reviewing the mentioned factors affecting the sustainability of hydrological resources leads to the methodological framework to sustain hydrological resource in coastal deserts. This is divided into three main axes: sustainable supply, use and demand. Figure 6 illustrates the main axes of the methodological framework.

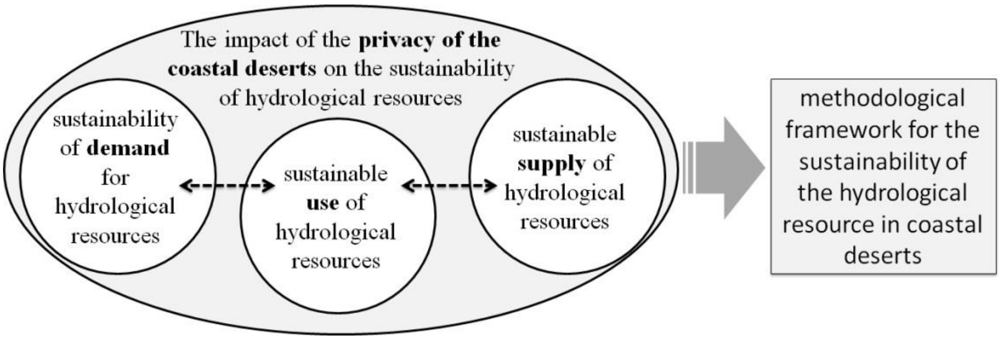

Fig. 6. Main axes of the methodological framework.

7.1 Interaction between the Main Axes of the Methodological Framework

Many of the elements of the main axes of the methodological framework overlap with each other where the use of hydrological resources cannot be sustained without sustainable supply and demand for hydrological resources. The dashed arrows in Fig. 7 illustrate these interactions and can be summarized in the following points:

- The above-mentioned groundwater assessments (quality, availability, and vulnerability) are the main factor for the assessment of groundwater in agriculture, and basic factor for generation of land use maps based on groundwater protection.
- Choosing the suitable method for rainwater harvesting effects the method of agriculture depending on the environmental characteristics of site (slope, soil, etc.).
- Technical, training and awareness-raising tools within the tools of sustainable groundwater demand affect the agriculture sustainability based on rainwater harvesting and soilless culture methods.
- Socio-economic factors affect permitted land use maps based on the protection of groundwater, affecting economic tools within sustaining demand tools.

7.2 Methodological Framework for the Sustainability of the Hydrological Resource in Coastal Deserts

Reaching the sustainability in three main axes (sustainable supply, use, and demand) for hydrological resources (groundwater and rainwater) is the basic component of the methodological framework taking into consideration the interactions between these axes, as shown in Figure 7.

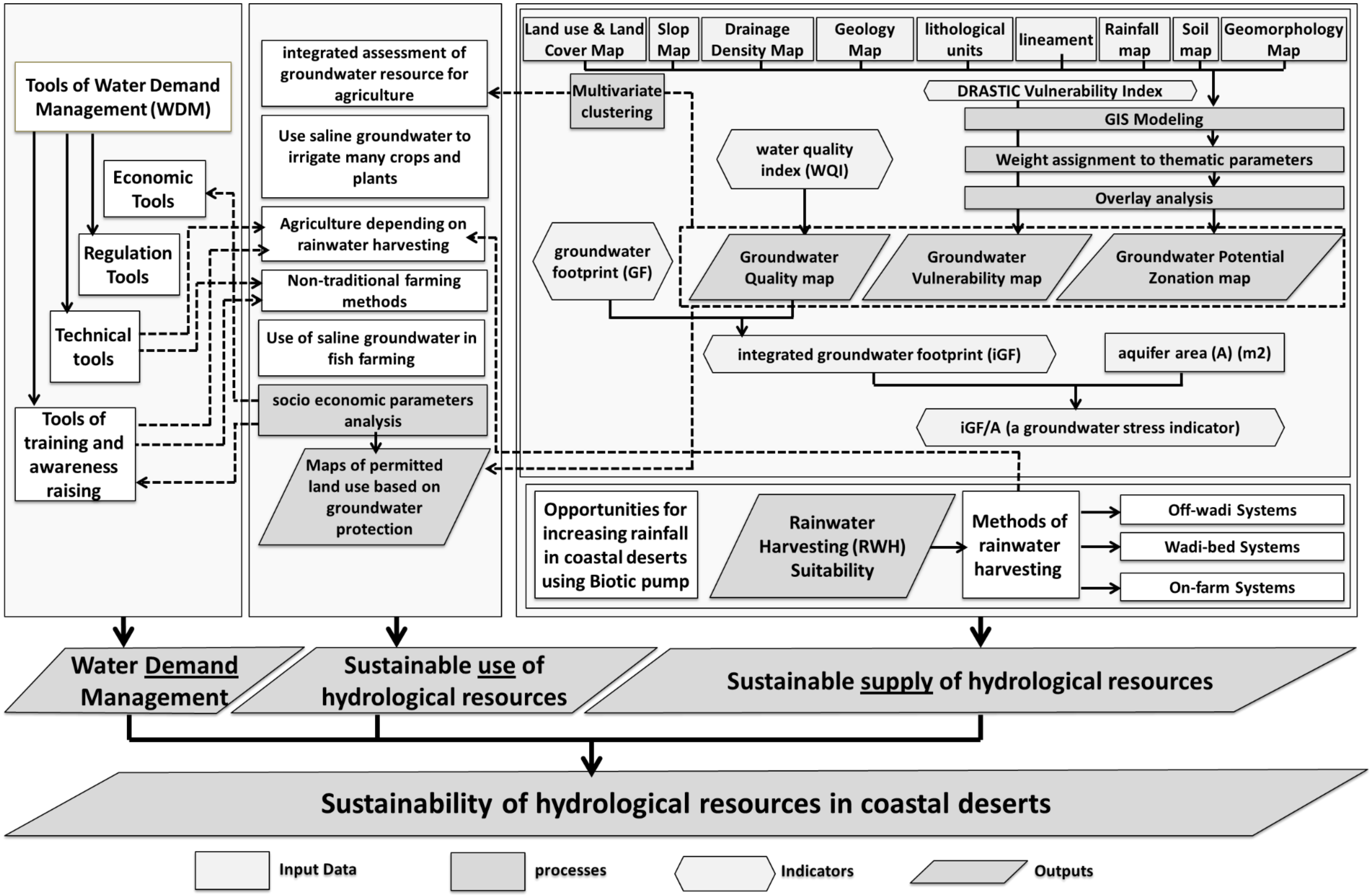

Fig. 7. Methodological framework for the sustainability of hydrological resources in the coastal deserts

7.3 Aspects of Sustainability Elements in the Methodological Framework

The aspects of the sustainability in the methodological framework are multiple according to each process within it, the outputs of these aspects vary, whether urban, environmental, economic or social.Table 1 illustrates sustainability aspects of the methodological framework and classification of outputs for each process in it.

Table 1. Aspects of sustainability methodological framework elements.

Main axes	Processes	Aspects of sustainability*	Classification of outputs**
Sustainable supply of hydrological resources	Groundwater potential assessment	Create development plans based on groundwater potential in coastal deserts to ensure that water requirements are met in the basis for sustainable development plans	Urban
	Groundwater vulnerability assessment	Ensure that groundwater contaminants are not reached in high vulnerability areas to maintain groundwater quality.	Urban
	Groundwater quality ass.	Determination of groundwater suitability for different uses according to its quality	Urban
	integrated groundwater footprint assessment	▪ Shift to less water-consuming crops in areas where iGF is rising. ▪ Identify areas where less profitable crops can be replaced by more profitable products requiring more water. ▪ Determine feasibility of transferring water from groundwater aquifers that are low in the iGF index to aquifers that rise in iGF. ▪ Mitigation of pressure in an area due to intensive agriculture or tourism activities in areas where the iGF is low. ▪ Reaching sustainable development and balance between agriculture and tourism activities in areas with limited surface water.	Urban - Economical
	Using biotic pump theory	Ensure the flow of moisture from the sea to the ground and thus more intensity of precipitation. Thus more plants can grow.	Environmental
	Suitability maps for rainwater harvesting	Ensure the sustainability and spatial suitability of rainwater harvesting depending on environmental, urban and social characteristics.	Environmental - urban - social
	Choosing suitable method for rainwater harvesting	The suitable method for rainwater harvesting is selected depending on the type of use, the type of storage and the size of the catchment to maximize utilization	Environmental–Economical

Table 1. Aspects of sustainability methodological framework elements, (Cont.).

main axes	Processes	Aspects of sustainability*	Classification of outputs**
Sustainable use of hydrological resources	Groundwater assessment for agricultural use	▪ Ensure that agriculture does not adversely affect groundwater. ▪ Ensure the suitable quality of groundwater for agriculture. ▪ Ensuring availability of groundwater for agriculture	Environmental–Economical
	Application of soilless culture systems	▪ Water retention in the system and its reuse can reduce the amount of water and costs. ▪ Possibility of applying it in places not suitable for agriculture. ▪ Reduce soil-borne diseases and pathogens, and thus reduce pesticide damage. ▪ The possibility of improving growth conditions leading to increased yield. ▪ Stability and high financial returns.	Environmental–Economical
	Use saline groundwater	▪ Reduce the burden on freshwater use ▪ Increase irrigated land by irrigating many crops and saline tolerant plants ▪ Increasing fish farming revenues and improve farmers' income	Environmental–Economical
	Merging of protected areas of groundwater into spatial planning	▪ Merge planning policies effectively with resource protection. ▪ Ensure development decisions without negative impact on groundwater ▪ Allowing settlement of compatible economic activities with groundwater protection	Urban-Environmental–Economical
Sustainable demand for hydrological resources	Economic tools	Pricing and quotas affect the amount of water used and reduce waste and misuse.	Economical
	Regulation tools	Improve the monitoring efficiency and management of water resources	Environmental –Economical
	Technical tools	▪ Improving efficiency of irrigation methods. ▪ Reduce vulnerability resulting from agricultural land and land use	Environmental–Economical-Urban
	Training and awareness raising tools	Awareness of the water value and the rationalization of its use and raise the awareness of farmers and other sectors.	Social

* Researcher analysis

** The outputs were categorized by comparison with the planning elements

8. CONCLUSIONS

Through few inputs and processes, important results can be reached on development decisions in the Egyptian coastal deserts that ensure the sustainability of their hydrological resources and thus the sustainability of urban development.

Achieving the sustainability of hydrological resources requires the three main axes of the framework (sustainable supply, use, and demand) in an integrated form.

In order to achieve the first axis (sustainable supply) of hydrological resources, the four environmental assessments of groundwater must be made in addition of applying the biotic pump theory to increase the opportunities of rainfall in the coastal deserts, and following the methodology of suitability maps for rainwater harvesting, then choose the suitable methods for rainwater harvesting. To achieve the second axis (sustainable use), the use of groundwater in agriculture must be assessed and soilless culture systems must be applied, as well as the utilization of saline groundwater. Finally, merging groundwater protection with land use planning as a mechanism to allow economic activities to be compatible with the environmental protection, which depends on the pressures and economic costs. To achieve the third axis (sustainable demand), the tools for sustaining demand for hydrological resources must be used (economic, regulation, technical, training and awareness raising tools).

By achieving the sustainability of the above three axes, the targeted methodological framework for the sustainability of hydrological resources in Egyptian coastal deserts has been reached as outlined in Fig. 7, where multiple aspects of the sustainability of the methodological framework elements and outputs vary, whether urban, environmental, economic and social aspects as shown in Table 1.

The methodological framework is applicable in the Egyptian coastal deserts. The research is considered an approach to other researches for applying the methodological framework spatially in successive stages to achieve sustainability in all aspects of the framework.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

REFERENCES

1. Elansary, A. S., Hamza, K. I., “Impact of Oxidation Pond on Groundwater Contamination”, Journal of Engineering and Applied Science, Vol. 46, No. 4, pp. 613-628, 1999.
2. Ministry of Planning, Monitoring and Administrative Reform, “Updating the Strategy and Comprehensive Development Plan for the North West Coast and its Desert Hinterland 2010-2032”, Cairo, 2010.
3. Hemdan, G., “Personality of Egypt”, Cairo, Dar Al Hilal, 1984.
4. Egyptian Environmental Affairs Agency, North Sinai Governorate, “Environmental Profile of North Sinai Governorate”, The Ministry of Environment, Egypt, 2007.
5. Egyptian Environmental Affairs Agency, Red Sea Governorate, “Environmental Profile of Red Sea Governorate”, The Ministry of Environment, Egypt, 2008.
6. Diab, M. S., “Facing the Dangers of Flooding in Egypt and Utilizing its Water”, First Annual Conference on Crisis and Disaster Management, Egypt, 1996.
7. Elnashar, W. Y.;. “Groundwater Management in Egypt”, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol. 11, No. 4, pp. 69-78, 2014
8. Singh, L. K., Jha, M. K., Chowdary, V.M., “Assessing the Accuracy of GIS-Based Multi-Criteria Decision Analysis Approaches for Mapping Groundwater Potential”, Ecological indicators, Vol. 91, pp. 24–37, 2018.
9. Al-Shabeeb, A., Al-Adamat, R., Al-Fugara, A., Al-Amoush, H., AlAyyash, S., “Delineating Groundwater Potential Zones within the Azraq Basin of Central Jordan Using Multi-Criteria GIS Analysis”, Groundwater for Sustainable Development, Vol. 7, pp. 82–90, 2018.
10. Chaudhary, B. S., Kumar, S., “Identification of Groundwater Potential Zones Using Remote Sensing and GIS of K-J Watershed, India”, Journal Geological Society of India, Vol. 91, pp. 717-721, 2018.
11. Mohammadi-Behzad, H. R., Charchi. A., Kalantari. N., Nejad. A. M., and Vardanjani. H. K., “Delineation of Groundwater Potential Zones Using Remote Sensing & Geographical Information System (GIS) and Analytic Hierarchy Process techniques (A Case Study in the Leylia–Keynow Watershed, Southwest of Iran)”, Carbonates and Evaporites, Vol. 34, pp. 1307–1319, 2019.
12. Gnanachandrasamy, G., Yongzhang, Z., Bagyaraj, M., Venkatramanan, S., Ramkumar, T., Shugong, W., “Remote Sensing and GIS Based Groundwater Potential Zone Mapping in Ariyalur district, Tamil Nadu”, Journal Geological Society of India, Vol. 92, pp. 484-490, 2018.
13. Pinto, D., Shrestha, S., Babel, M. S., Ninsawat, S., “Delineation of Groundwater Potential Zones in the Comoro Watershed, Timor Leste Using GIS, Remote Sensing and Analytic Hierarchy Process (AHP) technique”, Applied Water Science, Vol. 7, pp. 503–519, 2017.
14. Kumar, P., Herath, S., Avtar, R., Takeuchi, K., “Mapping of Groundwater Potential Zones in Killinochi Area, Sri Lanka, using GIS and Remote Sensing Techniques”, Sustainable Water Resource Management, Vol. 2, pp. 419–430, 2016.
15. Zeinolabedini, M., Esmaeily, A., “Groundwater Potential Assessment Using Geographic Information Systems and AHP Method (Case study: Baft city, Kerman, Iran)”, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, International Conference on Sensors & Models in Remote Sensing & Photogrammetry, Kish Island, Iran, pp. 769-774, 2015.

16. Nagarajan, M., Singh, S., "Assessment of Groundwater Potential Zones Using GIS", Journal of the Indian Society of Remote Sensing, Vol. 37, pp. 69–77, 2009.
17. Murthy, K. S., Amminedu, E., Rao, V. V., "Integration of Thematic Maps through GIS for Identification of Groundwater Potential Zones", Journal of the Indian Society of Remote Sensing, Vol. 31, no. 3, pp. 197-210, 2003.
18. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-weighted-overlay-works.html, (Accessed 05/06/2019).
19. Jessica, E. L., Sonia, T., "Groundwater Vulnerability Assessments and Integrated Water Resource Management", Watershed Management Bulletin, Vol.13, No. 1, pp. 18-29, 2009.
20. Gupta, N., "Groundwater Vulnerability Assessment Using DRASTIC Method in Jabalpur District of Madhya Pradesh", International Journal of Recent Technology and Engineering (IJRTE), Vol. 3, pp. 36-43, 2014.
21. http://courses.washington.edu/cejordan/SbCcMa_Presentation.pdf (Accessed 07/07/2019).
22. Kalaivanan, K., Gurugnanam, B., Pourghasemi, H. R., Suresh, M., Kumaravel, S., "Spatial Assessment of Groundwater Quality Using Water Quality Index and Hydrochemical Indices in the Kodavanar Sub-Basin, Tamil Nadu, India", Sustainable Water Resource Management, Vol. 4, pp. 627–641, 2017.
23. Kourgialas, N. N., Karatzas, G. P., Dokou, Z., Kokorogiannis, A., "Groundwater Footprint Methodology as Policy Tool for Balancing Water Needs (Agriculture & Tourism) in Water Scarce Islands - The Case of Crete, Greece", Science of the Total Environment, Vol. 615, pp. 381–389, 2017.
24. Makarieva, A. M., Gorshkov, V. G., "Biotic Pump of Atmospheric Moisture as Driver of the Hydrological Cycle on Land", Hydrology and Earth System Sciences, Vol. 11, pp. 1013-1033, 2007.
25. Kahinda, J. M., Lillie, E. S., Taigbenu, A. E., Taute, M., Boroto, R. J., "Developing Suitability Maps for Rainwater Harvesting in South Africa", Physics and Chemistry of the Earth, Vol. 33, pp. 788–799, 2008.
26. Oweis T., Prinz D., Hachum A., "Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments", Aleppo, Syria, International Center for Agricultural Research in the Dry Areas (ICARDA), 2001.
27. Mehra, M., Oinam, B., Singh, C. K., "Integrated Assessment of Groundwater for Agricultural Integrated Assessment of Groundwater for Agricultural Use in Mewat District of Haryana, India Using GIS", Journal of the Indian Society of Remote Sensing, Vol. 44, No. 5, pp. 747–758, 2016.
28. Department of Health and Agricultural Development, "Soilless Culture", The United Arab Emirates, Ministry of Environment and Water, 2016.
29. Food and Agriculture Organization, FAO., "Small- Scale Aquaponic Food Production - Integrated Fish and Plant Farming", United Nations, Rome, 2014.
30. Bobba, A. G., "Groundwater Development and Management of Coastal Aquifers through Monitoring and Modeling Approaches", Groundwater: Resource Evaluation, Augmentation, Contamination, Restoration, Modeling and Management, pp. 283-333, India, 2007.
31. Mahmoud, K. R., "Experience of the Arab Center for the Studies of Arid Zones and Dray Lands in Field of Use of Non-Conventional Water", 4th Conference Recent Technologies in Agriculture, ACSAD, Cairo, pp. 378-392, 2009.

32. Egyptian Environmental Affairs Agency, “Guide of Environmental Requirements for Fish Farming Projects”, Cairo, Ministry of Environment, 2009.
33. Jiménez-Madrid, A., Carlos M. N., and Pedro J. F., “The Integration of Groundwater Protection into Land-Use Planning, Certification and Standardization of Quality of Urban Supply Systems”, Procedia Engineering, Vol. 209, pp. 148-155, 2017.
34. Baroudi, E., Lahlou, A. A., Attia, B., “Water Demand Management - Policies, Practices and Lessons Learned from the Middle East and North Africa Region”, Arab House for Science, Lebanon, 2006.
35. Tee, A., Rehal, N., “Water Demand Management as an Approach to Sustainable Development, A Case Study of Some Arab Countries”, Conference of Sustainable Development and Efficient Use of Available Resources, Sétif, 2008.
36. Global Water Partnership, “Water Demand Management: The Mediterranean Experience”, Global Water Partnership, Stockholm, 2012.
37. Al-Ashram, M., “Water Economics in the Arab Region and the World”, Center for Arab Union Studies, Lebanon, 2001.

إطار منهجي لاستدامة الموارد الهيدرولوجية في الصحاري الساحلية المصرية

رصد البحث محدودية التعامل مع الموارد الهيدرولوجية في الصحاري الساحلية المصرية وذلك على الرغم من وفرتها في أجزاء كبيرة منها مما يعد إهدارا لقيمتها وعائقا لاستقرار العمران بها. ومن هنا فإن الغرض الرئيسي للبحث هو كيفية الوصول لإطار منهجي متكامل لاستدامة الموارد الهيدرولوجية في الصحاري الساحلية يعمل على الاستفادة من هذه الموارد ويلائم خصوصية الصحاري الساحلية. وللوصول للإطار المنهجي تم دراسة العوامل المؤثرة على استدامة الموارد الهيدرولوجية حيث تم تقسيم الإطار المنهجي لاستدامة الموارد الهيدرولوجية في الصحاري الساحلية إلى ثلاثة محاور رئيسية هي: التغذية المستدامة لمصادر الموارد الهيدرولوجية واستخداماتها المستدامة ثم استدامة الطلب عليها وتم دراسة التداخلات بين المحاور الرئيسية في الإطار المنهجي وأوجه الاستدامة الناتجة عنه، وأخيرا تم استنتاج الإطار المنهجي المناسب. وتتلخص أهم نتائج البحث في تعدد أوجه الاستدامة الناتجة عن الإطار المنهجي المستخلص وتنوع المردود التنموي لأوجه الاستدامة من مردود عمراني وبيئي واقتصادي واجتماعي.