MSA Engineering Journal
MSA Engineering Journal (ekb.eg)
ISSN 2812-5339 (print); ISSN 2812-4928 (online)
E-mail: engjournal@msa.edu.eg

Integrated Water Resources Management (IWRM) Plan as a Tool to Achieve Sustainable Water Management: Applying on Fouka Basin

Walid A. Abdellatif [†*] , Shimaa Samer Abdel Kader [†]

[†]Department of Environmental Planning and Infrastructure, Faculty of Urban and Regional Planning, Cairo University, Giza, Egypt, walid_3amer@cu.edu.eg, eng_shimaa_samer@cu.edu.eg

Abstract

Integrated Water Resources Management (IWRM) has emerged as a key approach for achieving sustainable water management worldwide. This research focuses on applying the IWRM framework in the context of the Fouka Basin, a region known for its complex water resource dynamics and diverse socio-environmental challenges. **The study aims** to assess the effectiveness of IWRM as a tool for sustainable water management in the Fouka Basin, and to contribute to the broader knowledge base on IWRM and its potential to achieve sustainable water management, providing guidance for policymakers, water managers, and stakeholders involved in water resource planning and management in the Fouka Basin and similar regions worldwide. **The research examines** the application of IWRM principles in the basin. It assesses the integration of various water-related sectors, such as agriculture, industry, and domestic use, and evaluates the effectiveness of coordination mechanisms among stakeholders, including government agencies, local communities, and non-governmental organizations. Based on the assessment findings, **the research develops a IWRM plan** that outlines strategies and actions for sustainable water management in the Fouka Basin. **The plan addresses issues** such as water allocation, water conservation measures, and stakeholder engagement.

Keywords : Integrated Water Resources management, Sustainable Water Management, Integrated Water Management (IWM), water situation in Fouka basin

1 Introduction

Water is a vital resource that covers a significant portion of the Earth's surface. It is essential for sustaining life and provides natural energy and useful substances. However, as human efficiency in water usage has improved, the conservation rate has decreased. Increasing water conservation and promoting its efficient use can benefit many individuals. Integrated Water Management (IWM) is an approach that combines various strategies to conserve and sustainably manage water resources. [1]

IWM is an integrated management approach that focuses on all aspects of water resources management, including planning, implementation, and monitoring. Unlike other approaches, IWM does not prescribe a specific strategy for water resource management. Instead, it provides a collaborative platform for experts from different fields to contribute their knowledge and expertise. It also encourages collaboration between non-governmental organizations and governments to promote responsible water conservation and usage.

2 Literature review:

2. 1 Definition of integrated water resources management (IWRM)

Integrated water resources management (IWRM) is a process of managing the use of water resources in an integrated manner, taking into account the interrelationship between human activities and natural processes. It is a new concept that emerged from the need to manage all aspects of water resources in an integrated manner. The term was first used by UNESCO in its 1972 Stockholm Conference on the Human Environment. [2]

The concept of IWRM was first articulated in the 1992 United Nations Conference on Environment and Development (UNCED), also known as the Earth Summit. UNCED recognized that water is a limited resource that must be managed carefully to meet human needs while preserving ecosystem health. The Earth Summit called for an integrated approach to water resources management that would consider all aspects of the water cycle.

2. 2 Why IWRM is important: Benefits of Integrated Water Resources Management

In order to avoid water waste and preserve the ecosystem, integrated water resources management (IWRM) is essential. A number of issues, including flooding, salt in drinking water, and increased disease risks, can result from excessive water use. Because it offers advantages like food production, recreational opportunities, and biodiversity, the ecosystem is essential. In addition to harming people, excessive water use also has an impact on plants and animals. IWRM implementation is crucial as a result.

IWRM offers numerous benefits, with conflict resolution being a key advantage. When different stakeholders participate in water management decisions, they are more likely to be satisfied with the outcomes and less inclined to engage in disputes over limited resources. Overall, IWRM provides a framework for informed decision-making regarding the efficient and sustainable use of water resources. It can enhance water security, improve water usage efficiency, and lead to better environmental outcomes.

Water is a fundamental resource for human survival, health, and dignity. However, global freshwater resources are under increasing pressure, and many people still lack access to sufficient water for their basic needs. Population growth, economic activities, and improved living standards contribute to competition and conflicts over limited freshwater resources [3].

Benefits from IWRM [3]

Environment benefits

Ecosystems can gain from using an integrated water management strategy by include environmental needs in the discussion of water distribution. At the moment, these needs are frequently not taken into account when bargaining.

IWRM can help the industry by increasing other users' knowledge of ecosystems' demands and the advantages they provide. These are frequently overlooked and not taken into account while making plans and decisions.

The ecosystem approach offers a fresh framework for IWRM that gives systemic water management more consideration.

Agriculture benefits

Agriculture has a bad reputation since it is the single largest consumer of water and the main non-point source polluter of surface and groundwater resources. When combined with the poor value added in agricultural output, this typically implies that water is diverted from agriculture to other purposes, especially in water-scarce situations.

IWRM can represent the overall "value" of water to society in challenging decisions on water allocations by include all sectors and stakeholders in the decision-making.

IWRM encourages integrated planning to ensure the sustainable use of water, land, and other resources. IWRM aims to boost water production for the agricultural sector.

Water supply and sanitation benefits

Over all, properly implemented IWRM would ensure the water security of the underserved and disadvantaged.

Recognizing that everyone has the right to a fair share of water resources for domestic and household-based productive purposes necessitates ensuring that these groups are properly represented on the bodies that decide how to distribute these resources. This is especially true for women and the poor.

The emphasis on integrated management and efficient use should encourage the industry to promote waste reduction, recycling, and reuse.

As a result, human domains were kept healthy. However, previous sanitation systems focused on only replacing the garbage problem, with frequently negative environmental impacts

On a practical local level, better water resource management integration could result in much lower costs for delivering home water services.

2. 3 The integrated water resources management as an iterative process

Making policies, planning, and managing them could all be seen as consecutive processes in basin management. Creating broad policy goals (where we want to go) is the first step. The following steps involve defining the water management problems that need to be solved (identifying the issues), listing potential strategies (how we're going to get there), evaluating each one, choosing a strategy or set of strategies, putting the strategy into practise, evaluating the results, taking lessons from the results, and revising our plan to make it work better in the future. The actions create a cycle. The "learning-by-doing management cycle" enables us to incorporate what we learn during the planning and management processes, even though in practise this cycle may be disrupted by outside influences. [1]

Figure 1 The learning-by-doing management cycle of planning and implementation
Source: By Authors

2. 4 Entry levels for integrated water resources management

Various levels of water resource management exist, including the local, implementation, and policy levels. At the **local level**, plans are created for managing aquifers and allocating water within user districts. **The implementation level** involves the development of management plans at the basin or provincial scale. **The policy level** encompasses national and international processes for creating water policies, treaties, and laws. The specific entry level for water resource management depends on factors such as the nature of the resources, whether they are within one or multiple countries, the scale of planning, the development stage of the basin organization, the stage of water resources development, and the main challenges in water management.

Table 1 water resources management framework

	Policy/National	Implementation	Operational
Type of water resources organization	Cross-border commission	National, inter-state water resources commission, authority, association)	Local (such as a group for land and water management)
Plans and strategies for the management of water resources	National water resources management plan; transboundary compact; agreement or plan for the	Plan or strategy for managing sub-water resources, a big sub-watershed, a sub-aquifer, or a lake	Local planning scheme (run by local government), local land and water management

	Policy/National	Implementation	Operational
	management of transboundary water resources		plan, and storm water management plan
Size of the decision	Highest political decision-making level, transboundary agreements	State, territory, district, or country (in the case of minor states)	Farm, factory, woodland, local government, water use district, and cooperative village
system of natural resources	A component of a physical area, such as a river, lake, or body of water, or an aquifer	Lake, river valley with regard to water resources, or sub-aquifer with regard to an aquifer province regional or local biological system	places where ecological and hydrological characteristics are generally the same

Source: By authors

2. 5 Challenges to Implementing Integrated Water Resources Management.

Implementing Integrated Water Resources Management (IWRM) faces challenges due to unclear jurisdictional lines among government levels, conflicting stakeholder interests, limited resources, and changing weather patterns from climate change. Water resources management is often divided among various agencies at different levels, hindering coordination and consistent application of IWRM principles. Balancing competing interests, like agricultural irrigation versus environmental conservation, poses difficulties in IWRM implementation. Limited financial and human resources in many countries impede the comprehensive execution of IWRM plans, which should encompass infrastructure development and watershed protection. Climate change-induced weather pattern changes, such as floods and droughts, intensify pressure on water resources, exacerbating issues like water scarcity and pollution. Therefore, adaptable IWRM plans are crucial for effectively responding to these evolving conditions.

2. 6 Linkage of integrated water resources management to the sub-sectors:

Integrated Water Resources Management (IWRM) is closely linked to various subsectors that are directly or indirectly dependent on water resources. **Here are some key subsectors and their connection to IWRM:**

Agriculture: Agriculture is one of the largest water-consuming sectors. IWRM promotes efficient and sustainable agricultural practices, such as precision irrigation, water-saving technologies, and crop selection based on local water availability. It also encourages integrated planning between water resource managers and agricultural stakeholders to balance water allocation and agricultural production.

Industry: Industrial processes require water for manufacturing, cooling, and other purposes. IWRM emphasizes water use efficiency, pollution prevention and control measures, and the adoption of water recycling and reuse systems in industrial operations. Integrated planning between water managers and industries helps ensure sustainable water supply for industrial activities while minimizing their impact on water resources.

Domestic and Municipal Water Supply: IWRM considers the water needs of households and municipalities. It promotes equitable access to safe and reliable water supply, sanitation, and hygiene services. Integrated planning between water service providers, local authorities, and communities helps ensure efficient water allocation, infrastructure development, and effective water demand management.

Hydropower and Energy: Hydropower generation relies on water availability and suitable infrastructure. IWRM supports the development of hydropower projects while considering environmental and social impacts. It promotes integrated planning between energy and water sectors to optimize water use, mitigate ecological disruptions, and assess the trade-offs between energy production and other water-related needs.

Ecosystems and Environment: IWRM recognizes the importance of maintaining healthy aquatic ecosystems and biodiversity. It emphasizes the protection and restoration of ecosystems, including rivers, wetlands, and groundwater systems. Integrated planning between water managers, environmental agencies, and conservation organizations helps ensure ecological flow requirements, water quality protection, and sustainable management of natural resources.

Disaster Risk Reduction: IWRM contributes to reducing the impacts of water-related disasters, such as floods and droughts. It promotes integrated approaches that combine infrastructure development (e.g., reservoirs, flood barriers) with land-use planning, early warning systems, and emergency response mechanisms. These efforts enhance resilience and minimize the socio-economic and environmental consequences of water-related disasters.

By integrating these subsectors into water resources management, IWRM aims to achieve a balanced and sustainable approach that optimizes water use, minimizes conflicts, protects ecosystems, and meets the diverse needs of different sectors and stakeholders.

3 INTEGRATED WATER RESOURCES MANAGEMENT PLANS:

The following figure shows the 6 steps of integrated water resources management plans .

Figure 2 INTEGRATED WATER RESOURCES MANAGEMENT PLANS
Source: By Authors

3. 1 Initiation

IWRM planning necessitates a team to plan, coordinate, and lead routine stakeholder consultations. Understanding IWRM and water resource management principles for sustainable development is a crucial first step for government commitment.

Understanding and identifying water resources in the study area are the first methodological steps towards sustainable water resources management, the study area includes:

The **Fuka** Basin is considered one of the most important basins in the northwestern coast, where the surface flow volume reaches approximately 3.4 million m^3 in an area of a catchment zone of up to 500 km^2. The annual precipitation amount reaches 45 million m^3, which increases the significance of the basin in providing water resources for urban settlements, service projects, and economic activities [4]

The study area is also considered one of the promising developmental areas, as the development plan provides for intensive tourism and urban development and national projects for power generation in Dabaa.

Figure 3 the proposed strategy for the study area sector

Investment opportunities in the study area (the proposed strategy):

The urban development strategy for the coastal façades (the northwestern coast range) stipulates several investment axes and the proposed dealing strategy as follows [5]:

Tourist centers along the coast, except for the environmental conservation areas in Ras al-Hikma and the nuclear power plant area

Development of natural pastures - fish farming

Various social services in the existing and proposed urban communities

Urban development in existing cities and small communities

Building and construction materials and supplies industries - agricultural and packaging industries

Overview and Water Situation of the Study Area (Fuka Basin)

The study area is located within the borders of Matrouh Governorate on the northwestern coast (Alamein-Dabaa Basin), specifically the Fuka Basin. Fuka Basin is one of the five basins in the northwestern coast.

Climate of the Study Area

There are three interrelated factors that shape the climate of the western Mediterranean region in Egypt [4]:

(a) The location with respect to the general atmospheric circulation.

(b) Proximity to the Mediterranean Sea.

(c) Coastal orientation.

The coastal region of western Egypt experiences a "Hot Coastal Deserts" climate, with varying temperatures throughout the year. The warmest months have an average temperature exceeding 30°C, while the coldest months remain above 10°C. The Mediterranean climate pattern shows peak temperatures in July/August, reaching up to 23-30°C, and lowest temperatures in January/February, dropping to 9-17°C. The maximum recorded temperature in the region is 42.4°C, while the minimum in the past two decades was 6.7°C [4].

Geography and Topography of the Study Area

The western coastal desert of the Mediterranean can be divided into two sectors: the eastern sector, stretching from Alexandria to Ras El Hekma, and the western sector, extending from Ras El Hekma to Sallum. The eastern sector is characterized by parallel white limestone sand dunes that create an ecosystem supporting plant growth in the low valleys between the dunes. South of the dunes, there are parallel rocky cliffs separated by flat areas. These cliffs, composed of compacted limestone sands and fossilized shells, reach a height of about 20 meters and contain fertile depressions cultivated along the coast. Further south, an extensive flat rocky plain covered by a thin layer of sediment serves as a grazing area for large herds of sheep and goats. [4].

Fouka Basin as one of the Northwestern Coastal Basins:

The northwestern coastal area has been divided into five main basins: Fouka, Bajos, Matruh, El Nakhila, and Saloum-Barani. This division is done to assess the water balance for each basin separately, as each basin receives a group of wadis (seasonal rivers). The following table illustrates the boundaries of each basin, along with the wadis that flow into them [6].

Table2 the boundaries of each basin, along with the wadis that flow into them.

	Northerners		**Easterners**	
	To	**from**	**To**	**from**
Fouka	31 08 00	30 50 00	28 07 00	27 52 00
Bajos	31 12 00	31 07 00	27 52 00	27 32 00
Matruh	31 26 00	31 13 00	27 32 00	26 58 00
El Nakhila	31 32 00	31 22 00	26 58 00	26 30 00
Saloum-Barani	32 00 00	31 10 00	26 20 00	25 10 00

Source: [6]

3. 2 Work planning and stakeholder participation

Planning for IWRM necessitates a steadfast dedication to a future in which water resources are managed sustainably. It implies political will and initiative on the part of key decision-makers and stakeholders.

Stakeholder commitment is required since they are the ones who have the most impact on water management through collaborative efforts and/or altering their behaviour. Thus, despite their various and frequently at odds objectives, important stakeholders must be identified and mobilized in planning.

Politicians are a unique kind of stakeholders because they are liable for both the approval of a plan and its success or failure. Thus: Process management, political commitment, effective stakeholder participation, and raising knowledge of IWRM concepts are all important.

Stakeholders in the study area are considered important supporting factors due to the availability of cultural and knowledge heritage among the Bedouin community. They have the ability to identify and articulate their issues. In addition to the Ministry of Water Resources and Irrigation and the Desert Research Center.

3. 3 Building of a strategic vision

A country's collective objectives, hopes, and dreams regarding the condition, usage, and management of its water resources are captured in a national water vision. In this way, a vision directs future actions regarding water resources and, in particular, the planning process. It also gives guiding principles. Although it's possible that the vision won't be turned into a water policy, it's believed that it would cover sustainable water resource usage.

To achieve sustainable development, especially Goals No. 1, 2, and 6, the water sector must meet the strategic pillars and pillars of the study area, achieving food security, water security, and energy security, in light of climate changes [7].

In light of the foregoing, the proposed development vision for the northwestern coastal zone of the Mediterranean states that "the coastal zone of the northwest coast is a diversified zone with its resources and potentials that achieves balanced development between the requirements of urban and economic growth on the one hand, and the requirements of resource conservation and social development on the other hand. [5]"

The objectives of the strategic vision:
[5]**:**

Providing new job opportunities, attracting residents and various investments, and thus upgrading the local communities in the coastal zone in the form of a green knowledge economy.

Exploiting the economic, social and cultural diversity available in the coastal area as well as the potential resources and the strategic location regionally and internationally in making a quantum leap for the economy and urban settlements from entities based on exploitation of resources (resource-based settlements) to entities and settlements based on the acquisition of knowledge (knowledge-based settlements.(

Achieving integration and interdependence between development in the coastal zone and the capabilities available in the desert hinterland.

Reducing the economic and social disparities between the different constituent sectors of the area and between the urban agglomerations along the coast and the Bedouin agglomerations in the depths of the desert.

Upgrading the environment and preserving natural resources to ensure the continuity of development processes and maximizing their benefits.

Organizing urbanization to get rid of the problem of overlapping in the states of lands in the coastal strip, which threatens development and investment opportunities.

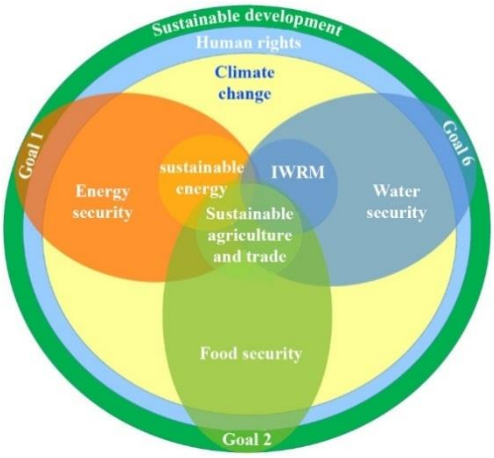

Figure4 an approach to support the energy-water nexus through integrated water resources management

Source: [7]

3. 4 Situation analysis

Knowing the current condition is crucial for defining the course of action required to achieve such a vision. Understanding conflicting requirements and goals in respect to the availability of water resources is crucial to this process, which requires consultation with stakeholders and various government agencies. When the water vision or IWRM concepts are applied to the water-related issues that come up during this analysis, it instantly starts to show what kinds of solutions might be required or feasible.

This phase identifies the positive and negative aspects of the management of the water resources as well as the areas that need to be improved in order to go forward with the vision. Goals may be written as a final product in accordance with the concerns and challenges noted, as well as the priorities of the country.

The general equation for hydrological equilibrium.

The analysis of water balance for any region relies on the general equation of hydrological equilibrium, where the inflow to the region equals the outflow from it, in addition to the change in storage. This equation can be expressed as follows [6]:

$$I = O \pm dS$$

where

I= Total inflow to the study area.
O= Total outflow from the study area
dS= Change in storage

This means that there are three main components for water balance in the North West Coast region, which are:

(Inflow component)

The inflow components for each basin in the region can be summarized as the precipitation and the surface runoff entering from each valley of the contributing watersheds.

(Out Flow Component)

The outflow components from each basin are the surface runoff exiting the basin and the evaporation, which are the primary components.

(Storag Component)

Storage compounds are divided into three types: changes in groundwater storage, changes in surface water levels, and changes in soil moisture content.

The equation for equilibrium can be simplified into its different components as follows:

$$= E + R_2 \pm dS \pm error \quad P + R_1$$

where

P the amount of rainfall
R_1 surface runoff from the valleys.
R_2 surface runoff exiting from the valleys
E Evaporation includes: evaporation + evaporation of transpiration .
dS change in groundwater storage

If we consider that all the variables in the equation are available and can be calculated, it is possible to compute the value of the change in groundwater level. In this case, the equation can be written as follows:

$$dS = (P + R_1) - (E + R_2) \pm error$$

The following are the calculation methods for each component of the hydrological balance equation for the study area.

Rainfall (P)

Measurements from five meteorological stations (Marsa Matruh, El Tabqa El 'Alya, El Negila, Burani, and El Saloum) located in the Northwestern Coastal area were used for a period of 50 years to calculate the annual average depth of rainfall. Several necessary corrections were made to these measurements, including the first correction related to the distance of the region from the sea and the second correction related to dispersion. Using the Soudan equation of 1969, the annual average was calculated for different regions.

$$Pa = (Ca \times Cd)\, P_{St}$$

where

Pa annual average of rainfall
Ca, Cd design coefficients for distance and dispersion
P_{St} measured depth of rainfall at a specific station

(Inflow Run off R_1)

The internal surface runoff for each basin in each region is the sum of the surface runoff exiting from each valley that drains into the basin

It has been calculated using the equation S C S

$$R = \frac{(P - 0.25)^2}{P - 0.8\,S}$$

where

R = Surface Sanin off
P= amount of Sanin off
S= Potential Maxine Ret mew

Total Evaporation E

Evaporation has been calculated as a combination of all components, including surface evaporation, transpiration evaporation, and evaporation from groundwater, using the following equation

$$E = Eg + Et$$

$$E_g=(P-w)$$

where
average amaull
P = Rain Fall
W = effective average of Acceleration That Contributes to the water table(m m)

The W was calculated for each region using the Jacob equation (Sudan, 1978). The average transpiration evaporation (Et) was determined by identifying the cultivated areas and crop types, and quantifying the transpiration evaporation rates (Sudan, 1978). Using satellite imagery from 1999, the cultivated portions were identified specifically for the Sidi Barrani - Saloum area.

(Outflow Runoff R_2)

"The surface runoff exiting to the sea has been calculated for each study area as 10% of the internal surface runoff (FAO studies, 1968) and L'Amouroux (1970)."

Error factor:

Sudán (1978) applied the water balance equation to each of the previous areas and applied different component equations, either developed for each region or already applied. It was found that there is an error that varies from one region to another, and this error is a percentage of the Inflow components.

dS change in groundwater storage.

by applying the hydrological balance equation

$$P + R_1 = E + R_2 \pm dS \pm \text{error}$$

The change in groundwater storage can be inferred/concluded

$$dS = (P + R_1) - (E \pm R_2) \pm \text{error}$$

The water situation of the study area (Fouka Basin)

Forecasts in the field of water resources in the northern coastal area rely on studying the water balance, which considers factors like rainfall, surface runoff, groundwater recharge, evaporation losses, and the available groundwater for careful utilization. The quantity of groundwater in this region can be utilized in limited amounts through different methods like ditches, shallow wells, and medium-depth wells, such as in the Fouka Basin [4].

Currently, groundwater is mainly used by the Bedouin community for irrigating small coastal areas and livestock rearing. However, the unwise use of water sources for garden irrigation in tourist villages can lead to the loss of potable water, agricultural water, and the intrusion of saline water from the sea.

Regarding surface water, only a small portion, around 15%, is utilized, primarily for irrigation in coastal farms or stored in underground reservoirs. Water storage is achieved using ancient cisterns from Roman or Arab times. Groundwater is extracted through wells or ditches in sandy areas, equipped with lifting pumps for various purposes. [4]

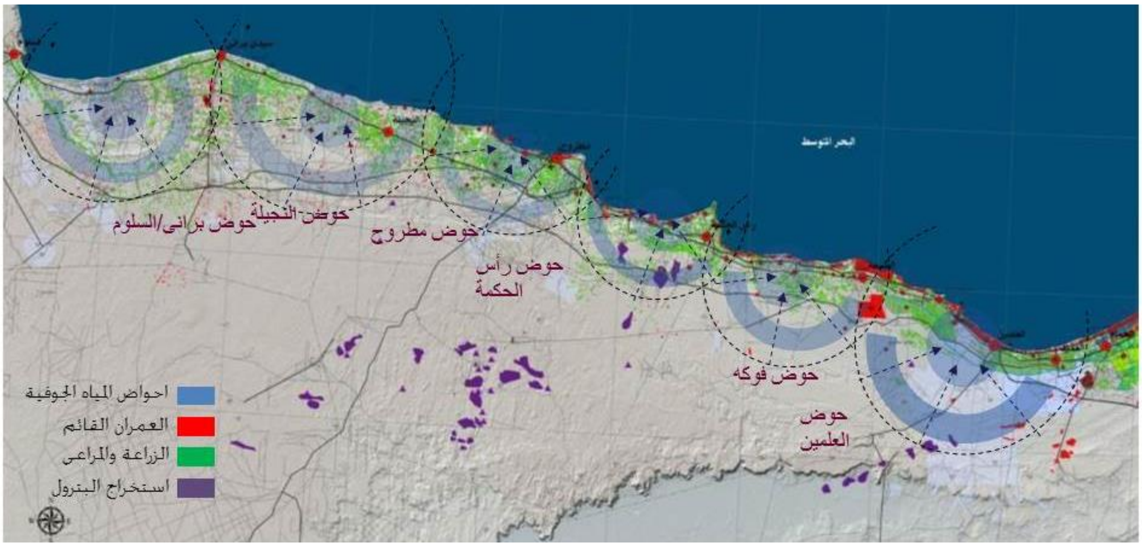

Figure 5 the location of groundwater basins in the coastal region of Matrouh Governorate

The Fouka Basin is located 80 kilometers east of Marsa Matrouh city. It stretches southward from the Mediterranean coast for about 15 kilometers, towards the southern plateau. The upper rock layers of the basin contain groundwater. The limestone reservoir in the basin is recharged through infiltration from the annual surface runoff. Groundwater movement is predominantly towards the general northward slope. Pumping from a groundwater well for agricultural purposes is conducted at a rate not exceeding 4,000 cubic meters per year. The salinity of the groundwater ranges between 2,700 and 4,000 parts per million. The following table illustrates estimates of rainfall, surface runoff, and annual groundwater recharge in the Fouka Basin [4].

Table3 estimates of rainfall, surface runoff, and annual groundwater recharge in the Fouka Basin

	Fuka Basin
Area of the catchment area	500 KM^2
Average annual rainfall	84 mm
Annual rainfall volume	45 milion m^3
Annual surface runoff volume	3.4 milion m^3
Annual groundwater recharge	2 milion m^3

Source: [4]

Table4 The water resources utilized in the Fuka Basin and rainwater maintenance systems.

Type	**Total storage capacity / withdrawal from wells (thousand m3/year)**	**Average storage capacity (m3/year)**	**No.**
Underground reservoirs	**117.2**	**148**	**789**
Roman water cisterns	**0.3**	**60**	**5**
Groundwater wells	**3.7**	**10**	**6**
Windmills (Sinnawi)	**0.3**	**150**	**2**
Cement surface reservoirs	**3.3**	**330**	**10**
Cement dams	**-**	**-**	**2**
Earthen dams	**-**	**-**	**2**
Rock dams	**-**	**-**	**250**
Desalination plants	**-**	**-**	**-**

Source: [8]

The water balance of the Fouka Basin

The total area of the Fouka Basin is 275 km2. It receives water from several rivers, the largest of which are Jarrara, Ajra, Medali, and Akma. Table -- provides information about the hydrological characteristics of these rivers in the Fouka Basin, including their maximum surface runoff and average surface runoff estimated in million cubic meters over a 50-year period by the meteorological department [6].

Using water balance equations, it was possible to calculate all the components, both inflows and outflows. Through the hydrological balance equation, it was possible to estimate the variation in groundwater storage in the Fouka Basin. The following table provides some basic statistical analyses of all the components, including the minimum and maximum values, as well as the mean and standard deviation. From the table, it is evident that the minimum value of groundwater storage variation is -5.683 million cubic meters per year, while the maximum value is 18.747 million cubic meters per year. The annual average variation in groundwater storage is 0.1364 million cubic meters. Table -- presents some simple statistical analyses of the hydrological balance components in the Fouka Basin [6].

Table 5 Hydrological characteristics of the valleys in the Fouka Basin

Name of the Valley	Average Surface Runoff (million m3)	Maximum Surface Runoff (million m3/year)	Area (km^2)
Jarrara	1.11	4.93	34.81
Ajra	2.53	10.92	76.12
Medali	0.77	3.05	18.8
Akma	1.91	8.8	67

Table 6 some simple statistical analyses of the hydrological balance components in the Fouka Basin.

Item	Preceptation (MCM/Year)	Inflow runoff (from wadies) MCM/Year	Evaporation (MCM/Year)	Outflow runoff to Sea MCM/Year	Storage in ground water Aquifer MCM/Year
Mean	87.05	6.6917	42.1964	0.669	0.1364
Std deviation	15.508	6.1004	15.1637	0.61	5.3912
sample variance	240.49	37.215	229.93	0.722	29.0656
Min Value	8.621	0.87	14.269	0.009	-5.683
Max Value	84.802	27.746	89.56	2.775	18.747
N (n missing)	49(0)	49 (0)	49 (0)	49 (0)	49 (0)

The cumulative water balance of the North Coast basins.

By combining all the previous areas, it was possible to calculate the hydrological balance components for the Northwestern North Coast, especially the area extending from the Fuka Basin to the western boundary of the Barrani-Sallum Basin. Table number... provides a summary of the hydrological balance for the five basins, including the annual rate of change in groundwater storage, as well as some basic statistical analyses.

Table 7 a summary of the hydrological balance for the five basins

	Area	Barrany Saullom	Negila	Bagosh	Kasser	Fuka	Total
Preceptation MCM/year	Mean	270.6072	29.8867	13.4742	32.589	87.05	433.61
	Std deviation	111.7275	12.5083	5.639	13.561	15.508	158.94
	Min	102.83	6.954	3.132	7.524	8.621	129.06
	Max	521.108	68.399	30.837	74.009	84.802	779.16
	N (N missing)	45(0)	49(1)	49(0)	48(0)	49(0)	
Inflow from Wadies runoff MCM/year	Mean	5.54	15.614	12.988	110.937	6.6917	151.77
	Std deviation	10.9757	19.4335	12.5277	110.259	6.1004	159.3
	Min	0	0	0.083	0.038	0.87	0.991
	Max	69.702	87.916	57.035	49.721	27.746	292.12
Evaporation MCM/year	Mean	236.9186	30.618	14.5192	37.945	42.196	362.2
	Std deviation	111.7175	12.508	5.6393	13.5618	15.164	158.59
	Min	69.141	7.685	4.18	12.88	14.269	108.16
	Max	487.419	69.13	31.882	79.365	89.56	757.36
Runoff Outflow MCM/year	Mean	0.554	1.5612	1.2989	1.0937	0.669	5.1768
	Std deviation	1.0976	1.9434	1.2528	1.1259	0.61	6.0297
	Min	0	0	0.008	0.004	0.009	0.021
	Max	6.97	8.792	5.704	4.972	2.775	29.213
Storage MCM/year	Mean	11.0599	8.679	9.66	2.0065	0.1364	31.542
	Std deviation	10.1703	14.42	10.619	8.821	5.3912	49.422
	Min	-16.239	-2.318	-1.16	-6.16	-5.683	-31.56
	Max	41.9882	63.603	47.536	32.34	18.747	204.21
	N (N missing)	45 (0)	49 (1)	49 (0)	48 (0)	49 (0)	

Source: [6]

3. 5 The most important environmental problems in the coastal area of the Fuka Basin

By reviewing the environmental features of the Fuka Basin and its water situation, the following table highlights the most significant environmental problems in the Fuka Basin [4]:

Table 8 The most important environmental problems in the Fuka Basin.

	The main problems	Aspects of the problem
1	Depletion and pollution of water resources.	Excessive use of groundwater. Water pollution. Shortage of water supply services.
2	Degradation of ecosystem services and goods due to excessive use.	Soil erosion. Deforestation. Degradation of agricultural lands and pastures. Loss of agricultural land due to urban expansion.
3	Habitat degradation and loss of biodiversity.	Degradation of natural habitats (wetlands, coastal areas). Loss of biodiversity (extinction of native species). Lack of management in the tourism sector.
4	Waste management.	Treatment of wastewater from tourist villages. Management of solid waste generated by tourist villages and investment projects.
5	Land use change	Changes mostly attributed to human activity that affect the quality of the environment and natural habitats.
6	Impacts of climate change.	Rising temperatures and increased evaporation rates. Rising sea levels, changing rainfall patterns, exposure to storm hazards.

Source: [4]

4 Results

4. 1 Water management strategies

Solutions may be proposed concurrently with or immediately following the formulation of problems. Such solutions must be examined, taking into account the needs, benefits, and drawbacks involved, as well as their viability.

Now that the scope of the issue and the challenges to be overcome are established, it is critical to set the IWRM plan's goals. The best strategy is chosen for each objective and evaluated for both its viability and compliance with the overarching objective of sustainable management. Given the complexity of the water sector, there is a lot of room for technical and management action, and at this point, priority areas for action should be determined.

Increased use of rain and floodwater, increased use of freshwater, desalination of medium- and high-salinity groundwater, and seawater desalination are the IWRM plan's top priorities. The ideal tactic for each goal is displayed in the table below.

Table 9 the most appropriate strategy for the goals for the IWRM plan

The goals for the IWRM plan	The most appropriate strategy
Increasing the use of rain and flood water	Construction of barriers, rock dams and tanks
Increasing the use of fresh water	Digging wells and using methods of raising water in small quantities (windmills)
Desalination of medium and high salinity groundwater	Conducting a study to determine the places and quantities that can be withdrawn for each level of salinity, along with determining the cost
Seawater desalination	Establishing a desalination plant and distribution network

4. 2 IWRM Plan prepared and approved

An IWRM plan could be created based on the vision, situation analysis, and water resources strategy. It may take several draughts to reach realistic and workable activities and budgets, as well as to win over lawmakers and stakeholders to the numerous tradeoffs and judgements made. For the mobilisation and application of resources, government approval is necessary.

A plan for the integrated management of the Fouka Basin's water resources through 4 axes can be created based on the development vision for the basin, an analysis of the current condition, and the water resources strategy (figure --):

Sustainability of rainwater harvesting

Sustainable use of groundwater

Water recycling

Seawater desalination

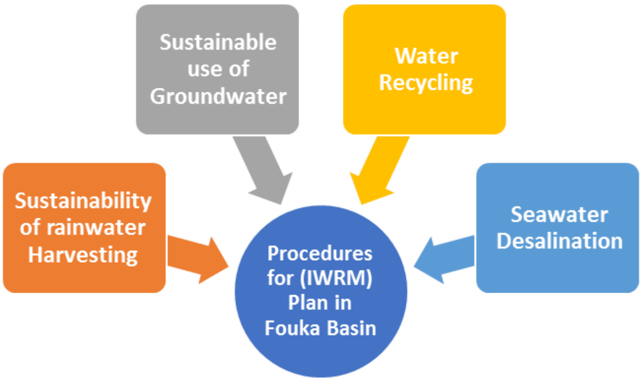

Figure 6 Axes of the Integrated Water Resources Management Plan

The following table 10 illustrate Procedures for the Integrated Water Resources Management (IWRM) Plan in Fouka Basin

Table 10 Procedures for the Integrated Water Resources Management (IWRM) Plan in Fouka Basin

Procedures for the Integrated Water Resources Management (IWRM) Plan in Fouka Basin	Sustainability of rainwater harvesting	Sustainable use of groundwater	Water recycling	Seawater desalination
Extracting a suitable map for rainwater harvesting in Fouka Basin Arrangement of rainwater harvesting methods according to the degree of applicability of the Fouka basin inputs with the criteria for applying each method				
Mandatory measurement of withdrawal quantities in Fouka Basin				
Improving the efficiency of the groundwater irrigation process: by using modern irrigation methods that save water consumption				
Determination of a maximum limit for the use of groundwater				
Groundwater pricing				

Procedures for the Integrated Water Resources Management (IWRM) Plan in Fouka Basin	Sustainability of rainwater harvesting	Sustainable use of groundwater	Water recycling	Seawater desalination
Provide incentives to save water and prevent waste in the Fouka basin, by helping to obtain modern irrigation systems that save water.				
Granting licenses, controlling pollution and activating the quota system				
Campaigns to raise awareness of farmers in the villages of Al-Jazeera, Gala station, Sedi Shabiba, Al-Hareib, Onsi Gaber and Gamisa				
The use of saline groundwater in irrigation of salt-tolerant crops.				
The use of saline groundwater in fish farming according to the degree of salinity				
Extracting the map of the integrated assessment of the use of groundwater in agricultural development in the north of the villages of Al-Jazeera and Gala station				
Determine the appropriate method for soilless culture according to the characteristics of each method.				
Smart expansion of recycled water networks from villages surrounding the Fouka Basin				
Implementation of performance-based contracts: by operating and maintaining both recycled water networks and irrigation management using recycled water				
Construction of a wastewater treatment station				
Preparing awareness, educational and organizational programs based on incentives to reduce water consumption in home gardens				

5 Discussion

5. 1 Implementation and evaluation

Having the IWRM plan is a goal, but it's not the end in and of itself. Plans are not carried out far too frequently, and the following factors should be recognized and avoided:

A lack of political support for the endeavour. Usually because key decision makers weren't involved in starting the process or because other forces were driving it.

Planning that is overly ambitious and requires resources that the government cannot provide.

Inadmissible plans. Plans were rejected by one or more powerful parties as a result of poor consultation or irrational expectations of compromise. Ample consultation is essential when it comes to water because it could alter economic gains or power dynamics.

The following table -- illustrate priorities for implementing the integrated water resources management plan in Fouka Basin

Table 11 priorities for implementing the integrated water resources management plan in Fouka Basin

Priorities for implementing the integrated water resources management plan	First priority	Second priority	Third priority
Extracting a suitable map for rainwater harvesting in Fouka Basin Arrangement of rainwater harvesting methods according to the degree of applicability of the Fouka basin inputs with the criteria for applying each method	■		
Mandatory measurement of withdrawal quantities in Fouka Basin		■	
Improving the efficiency of the groundwater irrigation process: by using modern irrigation methods that save water consumption			■
Determination of a maximum limit for the use of groundwater		■	
Groundwater pricing Provide incentives to save water and prevent waste in the Fouka basin, by helping to obtain modern irrigation systems that save water.	■		
Granting licenses, controlling pollution and activating the quota system			■
Campaigns to raise awareness of farmers in the villages of Al-Jazeera, Gala station, Sedi Shabiba, Al-Hareib, Onsi Gaber and Gamisa			■
The use of saline groundwater in irrigation of salt-tolerant crops.			■
The use of saline groundwater in fish farming according to the degree of salinity			■
Extracting the map of the integrated assessment of the use of groundwater in agricultural development in the north of the villages of Al-Jazeera and Gala station		■	
Determine the appropriate method for soilless culture according to the characteristics of each method.			■
Smart expansion of recycled water networks from villages surrounding the Fouka Basin		■	
Implementation of performance-based contracts: by operating and maintaining both recycled water networks and irrigation management using recycled water		■	
Construction of a wastewater treatment station			■
Preparing awareness, educational and organizational programs based on incentives to reduce water consumption in home gardens		■	

References

[1] t. G. W. P. (. a. t. I. N. o. B. O. (INBO)., “A Handbook for Integrated Water Resources Management in Basins,” the Global Water Partnership (GWP) and the International Network of Basin Organizations (INBO)., 2009.

[2] unesco, “/www .unesco.org/new/en/natural-science,” [Online]. Available: : http://www .unesco.org/new/en/natural-sciences/integrated-water-resources-management.

[3] C. the Canadian International Development Agency, “INTEGRATED WATER RESOURCES MANAGEMENT PLANS,” the Canadian International Development Agency, CIDA in the framework of the PAWD program, Partnership for African Waters Development , 2005.

[4] GOPP, Matrouh Governorate and Alexandria University, "Strategic Plan for Matrouh Governorate (Final Report)," GOPP, Cairo, 2015.

[5] The General Organization for Physical Planning, "Urban development strategy for coastal façades, northwestern coast range," Ministry of Housing, Utilities and Urban Communities, Cairo, 2017.

[6] Groundwater Research Institute, "North Coast Hydrogeological Maps Project," Groundwater Research Institute, Cairo, 2002.

[7] United Nation, ESCWA, "Water in the 2030 Agenda for Sustainable Development, the water-energy-food nexus in the Arab region," United Nation, ESCWA, Beirut, 2019.

[8] Muhammad Yahya Daraz, "Agricultural development in the northwestern coast and its desert hinterland, report on the current situation, issues and determinants of development," Ministry of Water Resources and Irrigation, Cairo, 2010.

[9] UNDP, “INTEGRATED WATER RESOURCES MANAGEMENT PLANS,” Canadian International Development Agency, canada, 2005.

[10] “Integrated Water Resources Management: Concept, Research and Implementation,” 5 3 2023. [Online]. Available: .https://link.springer.com/chapter/10.1007/978-3-319-25071-7_1 .

[11] “Performance evaluation of River Basin Organizations to implement integrated water resources management using composite indexes,” 5 3 2023. [Online]. Available: .https://www.sciencedirect.com/science/article/pii/S1474706512000988 .

[12] “Strategic implementation of integrated water resources management in Mozambique: An A’WOT analysis,” 5 3 2023. [Online]. Available: .https://www.sciencedirect.com/science/article/pii/S1474706511001562 .

[13] “Research article A comprehensive optimum integrated water resources management approach for multidisciplinary water resources management problems.,” 5 3 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0301479719303470.

[14] “Climate change adaptation and Integrated Water Resource Management in the water sector.,” 5 3 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S002216941300588X.

[15] “Capacity Development for Integrated Water Resources Management: Lessons Learned from Applied Research Projects.,” 5 3 2023. [Online]. Available: https://link.springer.com/chapter/10.1007/978-3-319-25071-7_14.

[16] “Effective modeling for Integrated Water Resource Management: A guide to contextual practices by phases and steps and future opportunities,” 5 3 2023. [Online]. Available: .https://www.sciencedirect.com/science/article/pii/S1364815218304456.

[17] “The implications of complexity for integrated resources management,” 5 3 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1364815206000417 .