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Research Article

Management of Water Resources Infrastructure in Jordan: Dams and Reservoirs

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ABSTRACT

Although Jordan has invested massively in water resources including dams, but due to climate change and to the semiarid to arid climate in most of the country, in addition to the limited water resources, Jordan faces challenges in water sector and needs to use and build new water resources including dams and to maintain the existing dams and use their storage efficiently. Climate conditions are reflected in a decrease in annual rainfall especially in eastern and southern parts of the country. The supply from surface water resources has decreased over years to reach unsafe yield charge levels for most resources. This paper aims to highlights the current situation of dams and the expected and proposed solution for scarcity of water dams in Jordan. Also, the paper aims to address the problems of dams' sector during operation such as seepage, sedimentations, and evaporation. Current paper also, will propose the possible solutions to enhance current situation of dams including operation and maintenance, in addition to water harvesting plans that aids in decreasing the scarcity of water on local level for domestic, agriculture, and 7industry needs in country.

Keywords: Dam infrastructure, dam management, efficiency use of resources.

INTRODUCTION

Jordan depends on 3 main resources of water including ground water, surface water from streams and dams' lakes and the usage of 90% of the reclaimed water from the advanced treatment of wastewater that provide plants and crops by 2/3 of its need for irrigation. Jordan, a country characterized by its arid climate and limited water resources that puts Jordan as the 4th poorest countries in the world. Jordan relies heavily on construction of dams as a critical component of its water management strategy. With an increasing population and growing agricultural demands, the effective use and management of water resources have become paramount. Jordan's uses evaluated about 1,093 MCM for the year 2021 for different uses [1]. The consumption in water supply for municipal uses will rise from 510 MCM in 2021 to 750 MCM. In addition to deficit of 70 MCM and 108 MCM in 2021 until 2040 respectively. Similarly, the demand for irrigation rose from 440 MCM in 202 to 530 MCM in 2040 in deficit of 234 MCM and 363 MCM respectively. Table 1 presents the use of surface water in Jordan.

Table 1. The Use of Source Water in Jordan [2]

Water Resource Category	Groundwater	Surface water	Reclaimed Water		
			Highlands	Jordan Valley	Industrial
Municipal	378	141			
Irrigation	210	157	31	133	
Industrial	28	4			3.2
Livestock	2	4			

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Dams in Jordan serve multiple purposes, including irrigation, flood control, and the provision of potable water [1], [2]. The big share in water budget goes yearly to municipal water supply of 47.5%, irrigation of 48.6%, in addition to industrial uses of 3.3% and others of 0.6%. Table 1 represents the uses of water sources in Jordan in 2021.Dams in Jordan collect about 250 MCM yearly to support water supply, irrigation, and industry uses. Dams in Jordan serve multiple purposes, including water supply and storage for irrigation, flood control, hydroelectric power generation, and recreational activities. Main dams such as King Talal Dam and Wadi Mujib Dam are essential for managing water resources in this arid region. For references, consider exploring reports from the Jordan Ministry of Water and Irrigation, the World Bank, and academic journals focused on water resource management. The 17 dams in Jordan provide about 320 MCM per year as storage capacity that us shrinking yearly because of sedimentation build up that affects its storage capacity. This process was involved and employed in [3, 4, 6, and 6, and 7].

One of the most significant dams is the King Abdullah Canal, which plays a crucial role in transporting water from the Yarmouk River to various agricultural areas. Another key structure is the Wadi Arab Dam, completed in 2002, which aims to enhance water supply for both irrigation and domestic use. Additionally, the Zarqa River Dam and Mujib Dam are vital for water storage and management in the region [8].The construction of these dams has been supported by various international organizations and governments, recognizing the need for sustainable water management practices in Jordan. The challenges posed by climate change, coupled with regional water scarcity, have prompted ongoing efforts to improve water conservation and efficiency [9], [10].

In summary, dams in Jordan are essential for addressing the country's water challenges, supporting agricultural productivity, and ensuring the availability of water for its growing populat.ion. As the nation continues to confront these challenges, the role of dams will remain critical in its efforts to achieve water security [6].A;so, summary is conducted based on the operation of researcj came in [11, 12, 13, 14, 15, 16, 17, and 18].

Objective of The Research

The main goal of the research is to study and evaluate the current and future situation of the water resources in Jordan focusing on Dams and reservoirs of water in Jordan. But also, the research have the objectives of the current research can be summarized as follows:

1. To explore the current situation of water sector in Jordan including the infrastructure and its management.
2. To explore the current resources for water in Jordan including the traditional and renewable resources of water budget in Jordan.

Methods of The Research

The methodology of the research based on the qualitative and the analytical approach to collect data and information about the current situation of water sector and the infrastructure of dams and reservoirs for water and its use in Jordan. Also, the methodology included the future plans for water sector and its resources and their infrastructure of dams and reservoirs and expected capacity of these infrastructure of the whole system. The study for the urpose of collecting data and information had considered the literature review and previous study and report for water sector and its infrastructure from The MWI an the reports from the supporting and financing organizations and different studies covered the subject of water sector and water resources in Jordan.

WATER RESOURCE MANAGEMENT IN JORDAN

Jordan faces significant water scarcity due to its arid climate, increasing population, and regional conflicts. The government has implemented various strategies to manage water resources effectively, focusing on sustainable practices, improving infrastructure, and enhancing water efficiency [[19], [20].

Jordan’s water sector is highly centralized, with the Ministry of Water and Irrigation (MWI) playing a central role in water governance and management. The three main institutions within the water sector are detailed below [21].

1. Established in 1988, the MWI is the main public water institution. The ministry operates at policy-making level and is responsible for outlining the country’s water strategy, creating the national master plan for water use, preparing water studies and monitoring water resources.

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2. The Water Authority of Jordan (WAJ) operates under the MWI and is responsible for the operational management of water resources and the organization of water supply and wastewater treatment in the highlands. For example, the authority has the mandate to manage threatened groundwater resources through its control of groundwater pumping licenses.
3. The Jordan Valley Authority also operates under the MWI. Its overall mandate is to create a plan and conditions for comprehensive development (farming, industrial, municipal and tourism) in the Jordan Valley and to protect all the valley's water resources.

Main Aspects of Water Management

1. **Institutional Framework:** The Ministry of Water and Irrigation oversees water resources, policies, and infrastructure development [8], [22], [23]
2. **Water Supply Sources [1], [24]:**
   - **Surface Water:** Major dams (like King Talal and Al-Wehda) and rivers (Zarqa and Yarmouk) are crucial for storing and distributing water.
   - **Groundwater**: Aquifers, particularly the Disi and Azraq basins, are vital but are being depleted due to over-extraction.
3. **Demand Management [25]:** Strategies include promoting water conservation, enhancing irrigation efficiency in agriculture (which consumes about 60% of water), and developing water reuse systems.
4. **Desalination [26]:** The government is exploring desalination as a long-term solution to meet water needs, especially along the Red Sea.
5. **Regional Cooperation:** Jordan collaborates with neighboring countries on water-sharing agreements and joint projects to optimize resource use.

MANAGEMENT OF DAMS IN JORDAN

The management of dams in Jordan is a complex issue involving water resource allocation, environmental sustainability, and socio-economic factors. Here's an overview of the management strategies and practices, along with relevant references:

1. Integrated Water Resource Management (IWRM)

Jordan adopts IWRM principles to optimize water use across sectors. This approach aims to balance competing demands while ensuring the sustainability of water resources [26]. Also, the idea of itegrated management of resources is employeed and involved in [27, 28, 29, 30, 31, 32].

2. Maintenance and Upgrading of Infrastructure

Regular maintenance and modernization of existing dams are critical to ensure safety and operational efficiency. This includes sediment management and structural assessments [33, 34, 20, 35, 36, and 37].

3. Environmental Monitoring

On-going environmental assessments help mitigate the ecological impacts of dam operations. Monitoring water quality and biodiversity around dam sites is essential [38, 39, 40, 41, 42, and 43].

4. Stakeholder Involvement

Effective management involves engaging local communities, NGOs, and governmental bodies in decision-making processes related to dam operations and water distribution [44].

5. Regional Cooperation

Jordan cooperates with neighboring countries to manage shared water resources, particularly regarding the Jordan River and the Yarmouk River Basin. Agreements focus on equitable distribution and conflict resolution [45].

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6. Climate Adaptation Strategies

Jordan is developing strategies to adapt dam management to the impacts of climate change, including altered precipitation patterns and increased evaporation rates [46].

7. Technological Innovations

The use of technology, such as remote sensing and GIS, enhances the monitoring and management of water resources related to dam operations [47]. Also, there us a need for the employment and involving of renewable energy techniques (solar system s an example) in order to improve sustainability of water use and management in dams and farms in different regions in Jordan [48] using closed transients and conveyors from dams to farms to reduce evaporation and the adaption of dripping irrigation systems in farms [49]. In addition, solar-powered irrigation reduced energy costs by 45%, benefiting both farmers economically and reducing the carbon footprint [50, 51, 52].

SURFACE WATER AND MANAGEMENT

Jordan's/ surface water resources are limited, primarily due to its arid climate and geographic characteristics. However, the country does possess several key rivers and reservoirs that play a crucial role in its water supply, irrigation, and hydropower generation.

Main surface resources distributed in different regions in Jordan [23], [53]. Also, surface water resources generally could be summed up to 650MCM during the wet season over the year and include the following regional resources in Jordan:

1. **Yarmouk River:** This is the largest river in Jordan, originating in Syria and forming part of the border with Israel. It is a vital source of irrigation and domestic water supply for northern Jordan.
2. **Zarqa River**: Flowing through the central part of the country, the Zarqa River is a crucial waterway for both agricultural and municipal use. It receives water from various tributaries and is subject to significant pollution challenges.
3. **Jordan River**: Historically significant, the Jordan River is another critical water source, though its flow has diminished significantly due to water diversion upstream and increased demand. It serves as a natural border between Jordan and Israel and is vital for local ecosystems.
4. **Wadi Mujib**: This seasonal river has significant ecological and hydrological importance, feeding into the Dead Sea. The Wadi Mujib Dam, constructed in 2002, has increased water availability for irrigation and flood control.
5. **Northern side wadies and southern side wadies**: including wadies in Yarmouk basin, Disi, and Ma'een, Zarqa-Amman in North. And Wadi Araba, and Al-Aghwar area and Karak and Tafila in South are of Jordan.
6. **Dead see side wadies**: including Ghour area, Balqa area, Wadi Arabah, and other wadies from Tafila and Karak.
7. **Hasa**: this wadi gives continues in flow from Hasa area in south of Karak to fill Tanour Dam abd its storage lake and continues as the effluent of the dam to the surface fkow wadi in the area.
8. **Azaq**: This basin is part of Disi ground water basin, but its surface one and continues to the Azraq Awasis that supports the nature life.
9. **Hammad:** This surface basin is located in Karak and recently a dam was constructed on the wadi.
10. **Sarhan**. This surface basin and wadi is found in the eastern desert in Jordan.
11. **Jafr**. Similar to Sarhan basin, Jafr surface basin is found in the eastern desert also.
12. **Southern desert**. this term surface basins are wet in winter and spring, while it turns into lakes and small awasis in southern desert.

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13. **Wadi Araba north**: this source starts from the end of Yrmouk to Dair Alla and to the north of dead sea..
14. **Wadi Araba south:** these resources are located between the south of dead sea and Aqaba area in south of Jordan.
15. **Reservoirs and Dams**: Various dams, such as the King Abdullah Canal and the Wadi Arab Dam, are constructed to store and manage surface water, facilitating its distribution for agricultural and domestic use.

What is specific about surface water in Jordan, that most of these resources are common and shared with neighbors and considered as international waterways that its streams shared between two or more countries. For example, Jordan River water is shared with Israel and Israel controls most of the water streams of the river [54]. Also, other critical shared resources in Jordan Northern region are Azraq, Yarmouk, and Amman-Zarqa basins that there recharge starts in the Syrian aide and borders. The procedures and actions in ground water resources in the Syrian side affect adversely the recharge of ground water in Jordan, specially Yrmouk River and Al-Wehdah dam and decrease the safe yield of ground and surface resources year by year. There is no comprehensive and organizing agreement between Jordan and Syria that may organize the use of water resources, and also eleven organizing arrangements were, considered between the years 1939 and 1955 and the last arrangement is Johnston in 1955 [55]. but the Syrian side compress the use of surface and ground water that affects adversely the level of ground water, surface water, and the filling of Al-Wehdah dam yearly. Also, the peace treaty that was signed between Jordan and Israel in 1994 that gives Jordan the right in getting 215 MCM of water through new dams and other structures of channels and diversions of water streams. All the required details are included in the ANNEX II of the peace treaty document, that contains seven articles about water definitions, allocation, storage, operation, maintenance, monitoring, water quality, protection, notification, agreement, and co-operation. Table 2 presents the main surface basins in Jordan.

Table 2. Surface Water Basin in Jordan [56]

No.	Surface Water Basin		Catchment Area (km2)	Average Annual Rainfall (mm/yr)
1	Basin Area	Basin Name		
2	Jordan River Basin	Yarmouk	1,426	280
3		Amman-Zarqa	3,739	220
4		Jordan Valley	780	270
5		North Valley	946	490
6		South Valley	736	370
7	Dead Sea Basin	Mujib	6,727	180
8		Hasa	2,603	130
9		Rift Side	1,508	240
10		North Wadi Arab	2,953	180
11	Eastern Desert Basin	Azraq	12,400	85
12		Hammad	18,047	85
13		Sirhan	15,733	45
14		Jafr	12,363	45
15	Southern Basin	South Wadi Arab	3,742	75
16		Southern Desert	6,296	15
		Total Catchment Area = 89,999 km2		Average = 98.21 mcm/yr

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PROBLEMS AND ISSUES IN WATER SECTOR INCLUDING DAMS

Jordan faces several challenges and problems regarding surface water management, including over-extraction, pollution, and the effects of climate change. Efficient management practices are necessary to ensure the sustainability of these vital resources. Also, dams in Jordan face several challenges that impact water management, environmental sustainability, and local communities. Here are some key problems along with references:

1. Water Scarcity

Jordan is one of the most water-scarce countries in the world. The demand for water often exceeds supply, leading to conflicts over water distribution among different sectors (agriculture, domestic, industrial) [57]. So, Jordan have limited water resources and water supply has deficits in the water yearly budget [58]. For the reason of water scarcity. Crop diversification techniques increased productivity by 30%, especially for vegetables and aromatic herbs [59].

2. Sedimentation

Many dams in Jordan, such as the King Talal Dam, suffer from sedimentation, which reduces their storage capacity and operational efficiency [60].

3. Environmental Impact

Dams can disrupt local ecosystems, affecting biodiversity and the natural flow of rivers. This is particularly concerning in areas like the Mujib River, where dam construction has altered habitats [61]. So, the functional role of dams should include a pre-action plan for the selection of dam site considering soil type, climate and metrological properties, and a pollution protection plan for water quality in dam sites and through channels and wadies [62, 63]. In addition to tjr improvement of soil conditions and soil health. Organic farming increased soil organic matter by 20% and improved water retention by 15%, reducing soil erosion [64].

4. Structural Concerns

Aging infrastructure poses risks to the safety and reliability of dams. Regular maintenance and upgrades are needed to prevent failures [65].

5. Political and Social Tensions

Water scarcity and management issues can lead to social unrest and political tensions, both domestically and with neighboring countries, especially regarding shared water resources [66]. Jordan needs for massive and continuous financial program to improve and to rehabilitate the existing infrastructure of dams in accordance with new technology in equipment and procedures of effective water use in 2 to 5 years to improve the storage capacity of dams and the efficiency a؛so. Also, to follow agricultural procedures and new effective techniques in farms in continuous programs and schedules. In addition to launching of financing programs for new construction of dams for 10 years period to update improve and to increase the storage of water surface and to increase the charging of ground water basins.

6. Climate Change

Climate change poses significant threats to Jordan's agricultural productivity and food security. Climate variability affects rainfall patterns and water availability, challenging the effectiveness of existing dam infrastructure in meeting water needs. There is a cririca needs for sustainable agriculture practices with advanced engineering management methodologies and techniques to build climate resilience across Jordan's 12 governorates [67] and through using specific techniques in irrigation systems [68].

MAIN DAMS IN JORD/AN

Jordan has several important dams that play a crucial role in managing water resources in the region. Some of the notable ones include [69]:

7. **King Talal Dam:** Located on Zarqa River about 70km north to Amman in 1977 in the first stage and the second raising stage was completed in 1987, it's one of the largest dams in Jordan wuth 108m height and 75MCM storage

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and is considered vital for water storage and flood control. It also contributes to irrigation by 85MCM yearly, in addition to the generation of 6MW of electric power.

8. **Wadi Mujib Dam:** This dam regulates water flow in the Mujib River and supports irrigation and local agriculture.
9. **Al-Wehda Dam:** was built on Yarmouk River at the Syrian-Jordanian border during 2003-2007. The dam was operated in 2006 with height of 86m and 110 MCM capacity. it serves as a joint project with Syria, primarily aimed at store water for irrigation E(30MCM) and domestic use (50MCM), in addition to the generation of electric power of 18.8 MW.
10. **Zarqa Ma'een Dam:** known for its thermal springs, this dam also contributes to water supply in the area. It was constructed from rock fill and concrete with storage capacity of the dam about 2 MCM when operated in 2017. The dam was constructed for storage purpose, control of flood and protection of the hot springs in Ma'eeen, irrigation, recharge of groundwater.
11. **Kafrin Dam:** was located 75km west of Amman, and was built in the first stage in 1968, and it was enlarged by raising its height in 1997 to reach 37m height and 8.5MCM storage capacity. Kafrin dam was constructed for irrigation and ground water aquifer rscharge.
12. **Wadi al-Arab dam:** is located in IrbId in the north of Jordan, and specifically in the west of Jordan on the border with Palestine. It was constructed from rock fill materials in 1986 with total cost of 20 Million Jordanian Dinar, and its storage capacityis about 20 MCM. It is used for drinking water mainly.
13. **Zeqlab Dam:** Sharhabeel bin Hasna Dam, known as Zaqlab, is today considered a destination for eco-tourism. Zaqlab Dam is a water dam located near the North Shouneh in the Jordan Valley region of the Irbid Governorate in northern Jordan. The storage capacity of the dam is 4 million cubic metres. The construction of the dam began in 1965 and was completed in 1967. It is the first dam in Jordan. The dam is of earthen type.
14. **KufranjehDam:** is located in the governorate of Ajloun on the Kafranja valley, and it is about 80 km north of the capital Amman, and it is a non-uniform stone dam with a height of 80.5m and a storage capacity of the dam 7.8 MCM. It was operated in 2017. The project aims to enhance the water resources available in the valley of Kafranja, for the purposes of irrigation and drinking, and to improve the surrounding environment, in addition to contributing to the risk of flooding.
15. **Al-Karamah Dam:** The Karama Dam, with a capacity of 55 MCM, was constructed in 1995 on Wadi Mallaha in the Jordan Valley area in order to store water for irrigational uses. The dam was constructed in spite of experts' warnings that this dam geologically, hydrogeologically, seismically, and from the points of view of salinity of its water, its management and the water resources to fill it is totally irrelevant, and that the dam will fail to fulfill its purposes.
16. **Wdi Shu'aib Dam:** Wadi Shoaib dam was built in 1969 at a cost of 1.8 million US dollars using soil rock fill of 900,000 CM of sediment, is 730 meters long at the top, 32 meters high, and has a storage capacity of 2.3 MCM of water.
17. **Wala Dam:** it was constructed for the purpose of irrigation and water supply 7in Madaba Region using RCC with earthfill abutments (clay core) with height above foundation of 42m and 265m length with storage capacity of 9.2 MCM, it was finished obn 2004.
18. **Tanour Dam:** it was constructed in 2001 along Wadi Al-Hasa with storage capacity of 16.8 MCM using RCC for irrigation purposes
19. **Karak Dam:** the construction of Karak Dam was started in 2017 using rocj fill in South Al-Aghar area (Mazra'a) for irrigation, development of environment, and flood control.
20. **Allajoun Dam**: the dam was constructed in Karak using rock fill and concrete coverage, with 26m in hight, 140m in length and 1 MCM storage capacity.

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21. **Wadi Ibn Hammad Dam**: the dam was constructed in Karak in 2015 with storage capacity of 4 MCM for irrigation and recharge of groundwater.
22. **Wadi Rahma Dam**: it was constructed in Wadi Araba in 2017 with 0.4 MCM for irrigation and flood control in the area. It still needs some maintenance work.
23. **Al-Fayhan Dam:** the dam is constructed in Wadi Araba in 2017 with 3.4 MCM storage capacity for irrigation and domestic uses. The dam is still under construction. Table 3 presents the main dams in Jordan

Table 3. Main DSams in Jordan, Capacity and Storage [69]

Dam	Design Capacity (MCM)	Total Inflow (MCM)	Total Outflow (MCM)	Storage End of 2017 (MCM)
King Talal	75	115.81	141.79	28.22
Wadi Mujeb	29.8	1.36	6.33	2.92
Al-Wehdah	110	72.96	93.66	4.06
Zarqa Ma'een	2	---	---	---
Kafrain	8.5	10.13	10.91	2.44
Wadi Arab	16.8	0.58	11.28	3.52
Zeqlap	4	0.49	0.36	0.37
Kufranjeh	7.8	1.16	1.17	0.86
Al-Karamah	55	1.7	6.21	13.84
Wadi Shueib	1.4	6.4	7.34	0.47
Wala	8.2	1.6	7.94	0
Tanour	16.8	7.01	20.67	5.43
Karak	2	0.44	0.28	0.16
Allajoun	1	---	---	---
Wadi Ibn Hamad	4	---	---	---
Wadi Rahma	0.4	---	---	---
Al-Fayhan	3.4	---	---	---
Total	346.1	219.64	307.94	62.29
Percentage of Storage of Design Capacity				18.6%

These dams are essential for Jordan, which faces significant water scarcity challenges, helping to manage limited water resources for agriculture, domestic use, and environmental protection.

DISCUSSION AND CONCLUSIONS

Following the updates and obstacles in water sector supply needed and the available water resources including water dams in the whole country regions implies the management of supply and the management and water demand management through the future management strategic plan including demand and supply from dam as main part of main resources in water sector to improve sustainability of existing and future uses of water dams.

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Generally, water dams in need for an improved water resource management that implies the effective use of dam water supply in dual interrelation procedures and actions with agriculture sector implying the selection of low-water consumption crops, plants and trees in Jordan valleys and other agricultural zones in Jordan.

Also, special attention and care should be paid to the procedures and techniques used in transferring water from dams and also to the techniques used in conveyance and distribution systems to and in farms sites.

Dams need increasing of storage capacity, and also decreasing of accumulated sediments through the lakes and storage tank of dams. So, specific procedures and actions are concluded and recommended:

Reduce erosion in [lakes of dams and the catchment areas that supply the dam storage during Winter season.

Prevent of flood events during winter and wet periods by mechanical means and stopping stations of flood that include heavy cobbles and boulders of stone.

Cleaning of wadies of catchment areas of loose materials, stones, old and dry trees and woods and trainge materials.

Conduct the required excavation and the construction of contour bonds, construction of gabions, in addition to the tunnel gabions, terrace, and dikes, ditches, and channels.

Increasing the depth of dam storage by cleaning sediments for existing dams and for new constructed dam and decrease the surface areas of lakes and dams to reduce evaporation through water lakes and dams.

Planting of trees and forestation in the land in front of the lake and dam areas to decrease erosion of soil in the dam site.

Conducting of steep slopes of high lands around the dam site and catchment area of the dam.

Decreasing of evaporation from the water body surface during day by using of covering materials for the water surface of dam or balls or suitable grass and plants.

Increasing the efficiency of water dam through transporting water in concrete open channels and pipe conveyor to farms instead of existing classic transporting system in nature.

Improving of irrigation procedures and the use of new technology in the field through adaption of new methods and techniques for sustainable agriculture and irrigation systems in Jordan.

Increasing of water harvesting projects to support dam storage and efficiency of water use.

The expanding in using solar energy system for power generation in dam site and farms to reduce the operation cost and increase efficiency of procedures in many of the agricultural areas.

Desalination of sea water in Aqaba and transmitting of water through a conveyor channel to Aqaba city and other areas in Jordan Valley and pther governorates. This project will support the sea level in dead sea in sustainable method.

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