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Dam Safety in Jordan: Factors Affecting Dam Safety, Responsibilities and Required Actions

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Abstract

Dams in Jordan are exposed to a variety of natural and manmade threats like dams worldwide, but with some peculiar threats due to Jordan's semi-arid climate, steep topography, tectonic activity, especially along the Jordan Rift Valley, position in the turbulent Middle East area, and weak socio-economic situation. In this study, the threats facing the main dams in Jordan are discussed and their sources are defined. The responsible agencies for reducing the threats and eliminating their sources are identified, as long as they are manmade. Natural threats are dealt with as superimposed and Jordan has to adapt to them by taking the necessary protective measures. The study concludes that all dams in Jordan are threatened by climate change and siltation and hence reduction in storage. The quality of stored water in dams, which are used for supplying drinking water such as Al-Wehdah, Wadi Al-Arab, Ziglab, Al-Wala and to a certain extent Al-Mujib is threatened by pollution due to urbanization, agricultural and industrial activities. All dams in Jordan are exposed to sabotage threats, which may negatively affect dams' water quantities and quality. The stability of dams due to engineering failures is observed in the cases of Al-Kafrain, the left abutment of Al-Mujib, the spillway of Wheidi and eventually Al-Wala Dam. The latter was raised based on unique construction technology. The study recommends developing and implementing, as soon as possible, rigorous action plans to eliminate or, minimize the impacts of threats facing dams in Jordan.

Keywords

Dams, Jordan, Siltation, Flood Water, Stability, Climate Change

1. Introduction

Tens of dams have been constructed in Jordan during the last few decades, many of them with capacities of a few hundred thousand to some million cubic meters. Only 14 dams have a capacity of more than one million cubic meters. The largest Jordanian dam, the Al-Wehdah Dam, is constructed on the Yarmouk River, which marks the border between Jordan and Syria with a storage capacity of 110 MCM. All dams were constructed to collect flood and base flow water to regulate the flood flow and to use the collected water for drinking, irrigation or industrial purposes, but many of these dams ended up collecting, in addition, treated wastewater such as, King Talal, Al-Kafrain, Shueib, Kufranja, Zarqa Ma'in and Al-Karak, which restricted their impaired water quality use to irrigation purposes Figure 1.

This study reviews and categorizes the threats facing the main dams in Jordan and discusses the sources of these threats. The responsible agencies for reducing the threats and eliminating their sources are identified, as long as these threats are manmade. Natural threats are dealt with as given and Jordan has to adapt to

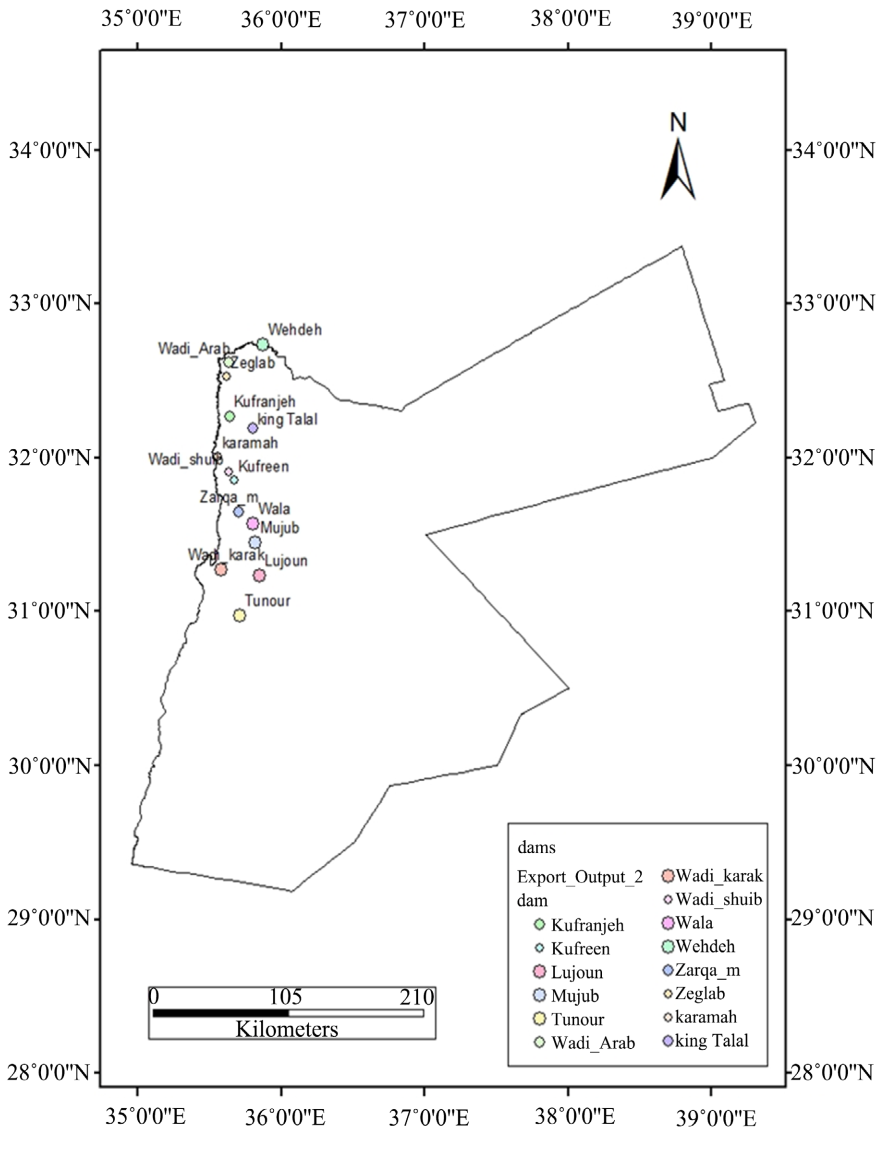


Figure 1. Locations of the major dams in Jordan.

such natural threats by taking the necessary measures to protect the dams from the threat consequences. The factors affecting dams in Jordan can be categorized as follows:

- Factors affecting the stored water quantities;
- Factors affecting the stored water qualities;
- Factors affecting dams' stability;
- Factors affecting dams' security.

2. Factors Affecting the Stored Water Quantities

Dams are designed to accommodate optimal amounts of water based on the long-term average quantities of incoming water to the planned dam sites, their seasonality, dam site storage potentials, dead storage requirements, expected siltation, geology, and other factors, which depend on climate, topography, water use, and its seasonality.

The factors leading to changes in the quantities of stored water in dams are climate changes, siltation, unexpected leakages, water diversions within the dam catchment area, and direct extractions from dams' lake water.

2.1. Climate Change

Climate change impacts are manifested in increasing temperatures, reduced precipitation, and increasing rainfall intensities, which affect the quantity of flood and base flow water along wadi and river courses as shown in **Figure 2**. In Jordan, recorded precipitation, temperatures, and intensity of rainfall show that climate change has started affecting the country's water resources and hence its water supply with all the negative impacts of such effects on the health, environment and socio-economic sectors [1] [2] [3].

A simulation study for the period 2040-2099, based on rainfall records (1961-1990) for the Middle East region, concluded that precipitation over Jordan will decrease by 17% in the middle of the 21st century and by 21% at its end [4]. A regional climate model developed to study changes in precipitation amounts in Israel and Jordan resulted in lower precipitation amounts and a reduction in the frequency and duration of rain events [5].

UNDP & GEF [6] used the Representative Concentration Pathways (RCPs) as a tool for predicting the trends of rainfall in Jordan up to 2085, as extremely likely predicted rise in mean temperature for all of the country, up +2.1˚C [+1.7˚C to +3.1˚C] for RCP 4.5, and +4˚C [3.8˚C - 5.1˚C] for RCP 8.5 (**Figure 3**).

Matouq *et al.* [7] used GIS and artificial networks for weather forecasting based on rainfall and temperature data from 1979-2008. The simulated trends up to 2018 showed continuous increases in maximum and minimum temperatures in the eastern, northern and southern regions of Jordan. They estimated that, over the last 50 years, the mean temperature has increased rapidly by 1.5˚C - 2˚C since 1991.

The theme of climate change impacts on the generation of flood water manifested itself in the extreme floods which took place in Amman in 2015 and 2013.

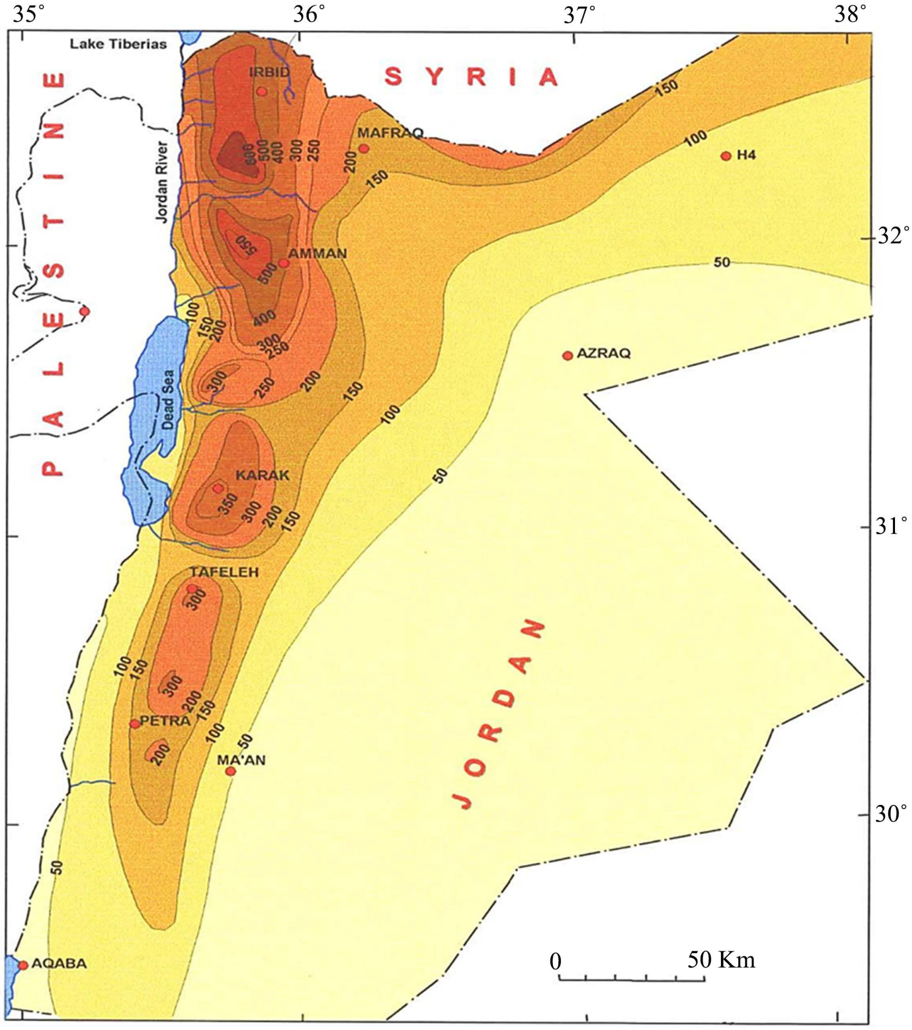


Figure 2. Rainfall distribution over Jordan [14][1].

This issue has been tackled by several studies in Jordan such as [1] [8] [9] [10] [11] [12]. Most of these studies emphasized the disproportional effect of reduced rainfall on flood flows, expecting higher percentages of reduction in flood flows than those of reduction in precipitation. According to [1] [13]; the reduction in flood flow in the different precipitation regions in Jordan as a result of a 10% reduction in precipitation will range from 14% in rain rich areas to more than 60% in the low precipitation desert areas. That is because flood flow depends on a variety of factors such as type of precipitation (rainfall duration and intensity, snow), topography, soil, geology, evaporation force of the climate, and land use.

Contrary to climate changes, global changes in urbanization due to improving living standards, rural migration to towns and cities, migration of refugees from other countries, all requiring new buildings and asphalted roads on the account of natural soil covers result in increasing flood flow generation, flood water amounts and flood intensities as Amman flooding event 2015 and 2022 (**Figure 4**).

[1]WAJ: Water Authority of Jordan Open Files.

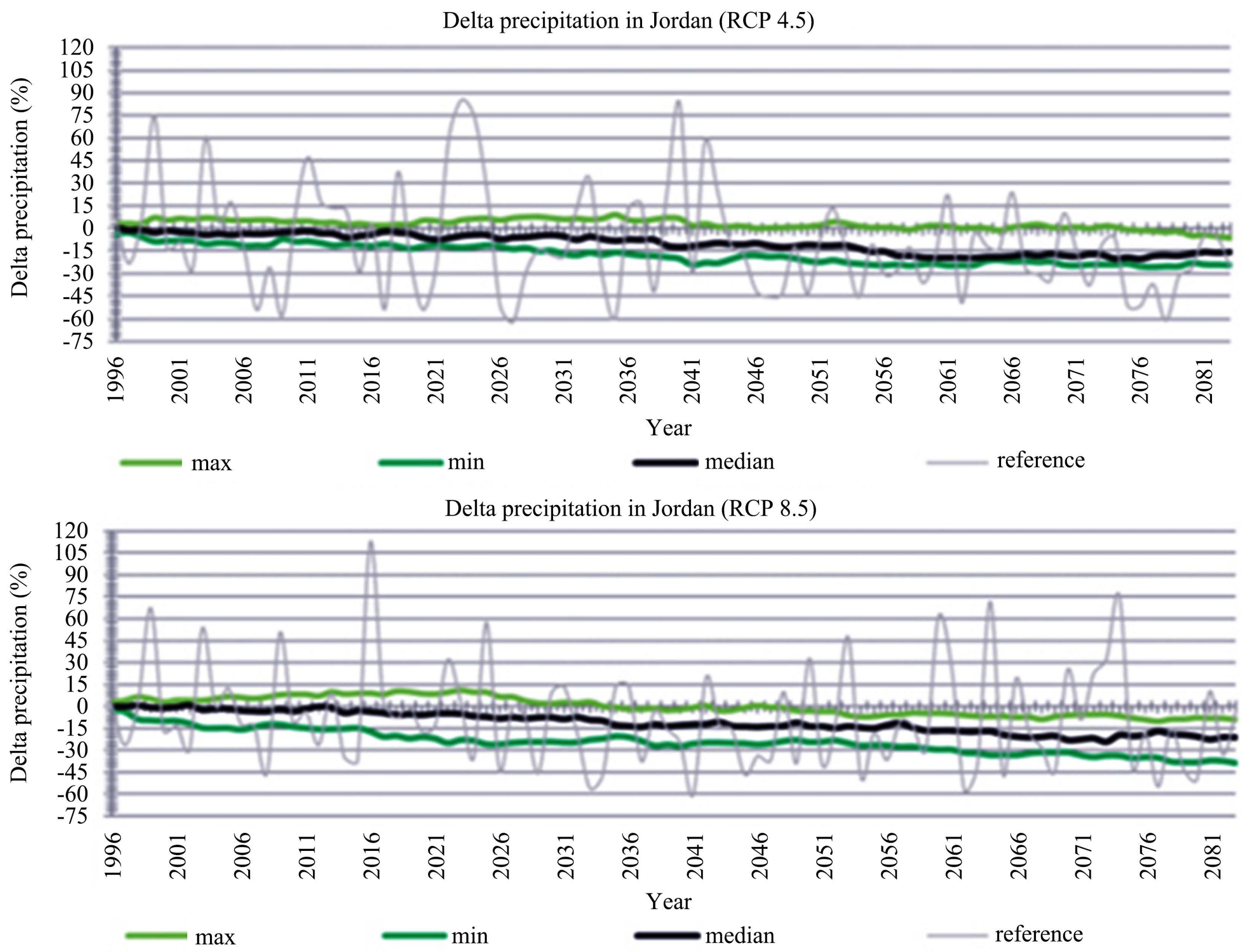


Figure 3. Projected changes in annual precipitation (%) over Jordan for RCP 4.5 and 8.5 [6].

Figure 4. Amman flooding events in 2015 & 2023 showing parts of the old city, where the designed drainage system has become undersized due to increasing urbanization and increasing rain intensities.

In Jordan, floods reaching the dams of King Talal, Wadi Al-Arab, Ziglab, Shueib, Al-Kafrain, Zarqa Ma'in, Al-Karak and Al-Wala are increasingly affected by the rapid urbanization of their catchment areas, a development which partly counteracts the impacts of climate change of decreasing flood flows. The diversion of treated wastewater to be collected in some dams is also alleviating the climate change impacts by compensating for the decreasing flood flows joining the dam's lakes.

2.2. Siltation and Lake Volume Reduction

The main dams in Jordan were constructed on wadi and river courses, which drain the high mountains east of the Jordan Rift Valley towards the bottom of the Rift Valley and into the Dead Sea which is the ultimate base level for surface and groundwater of the whole surrounding areas. The topographic gradients from the highlands to the wadi bottom range generally from 5% - 10%, which are very high gradients that allow weathering products to rapidly erode and be transported towards the base level. Dams constructed on such water courses trap these sediments, which build up with time to reduce the storage capacities of dams (Siltation of dams). No dam in Jordan is provided with check- or fore-dams to collect the flood sediment load before it reaches the dam. Therefore, dams in Jordan are silting up at a very high rate compared with dams in low-relief areas. Programs to alleviate the natural erosion, transportation, and sedimentation process in dams have been of limited extent with very low impact on the siltation processes. Even in urbanized areas and along the road net, erosion products still reach the water courses and settle in dams. The different municipalities and the ministry of public works have no adequate programs in their planning to take action to minimize the flow of such erosional products to water courses and into dams. Land sliding within dams' lakes or within their catchment areas also leads to reduced dam storage capacities. The left abutment of Al-Mujib Dam Lake, as well as, the left abutment of King Talal Dam Lake has during the last few years, witnessed the sliding of rock masses of many hundred thousand cubic meters into the dams' lakes reducing herewith their storage capacities. The natural erosion in the catchment areas of dams has, throughout the last few decades, been enhanced by mining processes of phosphate, gypsum, building stones and aggregates where mining by-products are accumulated in heaps, permitting their easy erosion and transportation towards wadi courses and dams.

Siltation is one of the main threats to dams' capacities in Jordan, The majority of dams have large amounts of sediments, which represents a higher volume of its original designed volume (e.g. 52.9%, 24%, 22.9%, 21.8%, 18.2% and 17.2% for Wadi Shuieb, King Talal, Al-Kafrain, Al-Mujib, Al-Wala and Wadi Al-Arab Dams respectively) (**Table 1**). However, when considering the date of construction, the higher sedimentation rates dams are Wad-Al-Karak, Wadi Al-Mujib, Wadi Shueib and Al-Wala Dams with 1.17%, 1.09%, 0.98% and 0.87% per year respectively (**Table 1**). This might be attributed to the semi-arid to arid climate with long summers, which makes the upper soil dry and easy to erode by runoff water. That is besides, the land sliding of large amounts of sediments into dam lakes due to steep slopes and flooding events. This threat, not only decreases the available volume for storing water, but also decreases the life of dams and causes some serious technical problems such as closing the intakes. To overcome this

Table 1. Main information on the major dams in Jordan [15][2].

Dam name & year of construction	Designed storage MCM	Real storage m³	Dead storage m³	Sediments m³	% of sediments	Annual sed. rate	Catchment km²	Lake Area km²	PPT mm/year
Al-Wehdah, 2006	110	106,362,891	3,637,109	NA			5590	3.75	350
Wadi Al-Arab; 1986	16.8	16,789,000	3,200,000	2,900,000	17.2%	0.44	262	0.8	350
Ziglab 1967	3.9	3,964,300		335,700	8.6%	0.15	106	0.3	150
Kufranjah, 2016	7.8	7,800,000	420,305	NA			99		
King Talal, 1977	75	67,003,900		18,000,000	24%	0.52	3700	4.8	250
Al-Karamah, 1997	55	55,000,000	55,000	2,000,000	3.6%	0.0005	62	5	150
Wadi Shueib, 1969	1.7	1,254,959	423,294	900,000	52.9%	0.98	178	0.3	300
Al-Kafrain, 1967	8.5	8,452,287	45,063	1,900,000	22.4%	0.4	163	0.8	300
Zarqa' Ma'in, 2017	2	2,000,000	0	NA			182	0.14	200
Al-Wala, 2002	25.3	25,105,134	422,844	4,600,000	18.2%	0.87	1770	0.86	200
Al-Muiib, 2003	29.8	24,718,788	3,774,160	6,500,000	21.8%	1.09	4380	1.6	200
Al-Tannur, 2001	14.7	14,308,400	500,000	2,500,000	17%	0.77	2160	0.84	250
Al-Lajjon, 2015	1	1,000,000	67,494	NA			46	0.13	215
Al-Karak, 2017	2	2,000,000	93,964	139,982	7%	1.17	170	0.194	

problem several solutions were adapted such as raising the dam, removal of sediments by turbidity and mechanical removal, although these solutions are very expensive, time consuming, and not necessarily always successful.

2.3. Water Diversions and Abstractions in the Dam Catchment Area

Dams were planned and designed to collect both flood and base flow water, but due to the pumping of spring water and groundwater over-pumping from all groundwater aquifers in the country, especially from those feeding springs discharging along water courses and flowing towards the Rift Valley, the discharge of springs has decreased or even ceased. Accordingly, the incoming base flow of rivers and wadis decreased and hence the stored water quantities in dams. One good example is the Al-Wehdah dam built on the Yarmouk River shared by Jordan and Syria, Unfortunately, Syria has developed almost all the surface and groundwater resources in its part of the Yarmouk River catchment, which deprived the dam of its water. Therefore, this dam has never filled or reached its designed capacity (**Figure 5**).

Springs' water extractions have led to their dryness and deprived dams of their discharges. In addition, blocking of Wadi courses by mining and other activities solid disposals is also depriving some dams in Jordan of flood and base water flows. The very obvious examples here are Al-Tannur, Wheidi, and Al-Mujib dams.

[2]JVA Jordan Valley Authority Open Files.

Figure 5. Al-Wehdah Dam at the border between Jordan and Syria.

Direct use of dam lakes' water is found almost in all dams in Jordan, but the extracted amounts, usually small in quantities, are used in irrigation. Continuous extraction of Al-Wala Dam's water for groundwater recharge via recharge wells is affecting the stored water quantity in the dam, but that was one of the purposes of the dam construction. Depending on the flood water amounts reaching the dam, several million cubic meters of water find their way into the groundwater naturally and through recharge wells.

Dams considerably affected by reduced inflows are:

- Due to climate changes: All dams in general and southern dams in particular;
- Due to erosion and siltation: All dams in Jordan;
- Due to leakages and recharge: Al-Wala, Al-Tannur and Al-Kafrain dams;
- Water diversions and drainage blockings: Al-Wehdah, Al-Tannur and Al-Mujib dams.

3. Factors Affecting the Dam's Water Quality

Dams' waters in Jordan are exposed to a variety of manmade pollution sources caused by urbanization, agricultural and industrial activities. In addition, accidents, involving the transportation of dangerous substances may lead these substances to reach dams' lakes. Also sabotage in the turbulent Middle East area can hit dams' water quality, especially those dams used as sources of drinking water.

Most catchment areas of dams in Jordan are heavily urbanized, industrialized to a certain extent, and are used in agricultural production [14] [15]. Merely this fact indicates that such dams are exposed to pollution sources. For example, the catchment area of King Talal Dam, which, practically receives the highest quantity of incoming water to a dam in Jordan is around 30% urbanized, accommodating around 50% of Jordan industrial activities with some agricultural activities. Other dams are: Wadi Al-Arab, Kufranja, Shueib, Al-Kafrain, Al-Karak, Zarqa Ma'in, and partly Al-Wala. Because of their use as drinking water sources, dams of Al-Wehdah, Wadi Al-Arab, Zarqa Ma'in, and Al-Wala deserve special attention and rigorous monitoring and protection programs against pollution.

Other dams, such as King Talal, Kufranja, Shueib, Al-Kafrain, Al-Karak, receive, in addition to flood and base flow water, treated wastewater and hence their water quality is impaired (**Figure 6**). They are strongly affected by eutrophication processes and these processes have consequences on the sediments deposited at their bottoms, causing anoxic conditions.

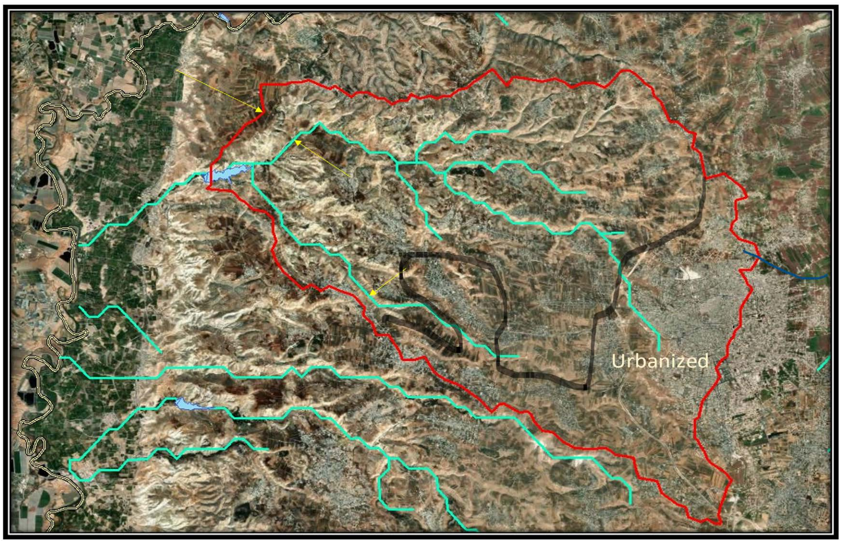
3.1. Urbanization and Industry

Urbanization is becoming a major factor affecting the capacity and integrity of dams in many locations in Jordan. The rapid and unplanned urbanization increases the flood events, adding new and emerging pollutants, such as pharmaceutical residues and biocides, to the catchment, and leading to overloaded wastewater treatment plants, resulting in low quality effluents reaching the dams (**Figure 7**). Catchment areas of dams such as Wadi Al-Arab, Al-Kafrain, Shueib, and King Talal dams are heavily urbanized (**Figures 7(a)-(d)**), compared with Wadi Al-Mujib Dam **Figure 7(e)**.

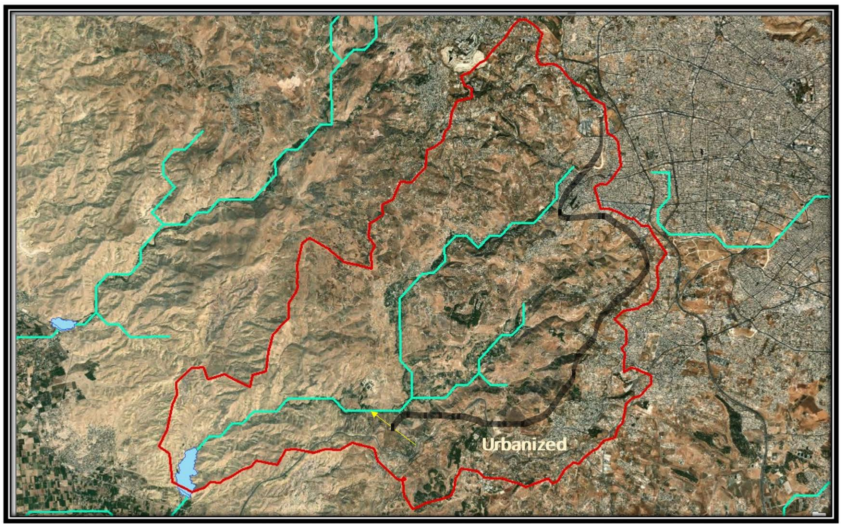
Industrial plants in Jordan are obliged by laws to treat their effluents adequately before releasing them to wadi courses. Violations and unintended discharges of untreated wastewater into water courses are causing some troubles to dams' water quality.

Many dams in Jordan are exposed to accidents, especially the transportation of dangerous chemicals. Dams are used as drinking water sources, such as Al-Wehdah, Al-Arab, Ziglab, Zarqa Ma'in, Al-Wala and Al-Mujib are threatened by such accidents, which consequences can be severe. A previous study showed that heavy metals in sediments of the Al-Mujib reservoir have different anthropogenic incrimination inputs. Manasrah [16], showed that the sediments are polluted with Cd, moderately contaminated with Ni and Zn and uncontaminated with respect to Mn, Pb and Cu.

Figure 6. Zarqa river water affected by Khirbet Al-Samara treated wastewater effluents.



(a)



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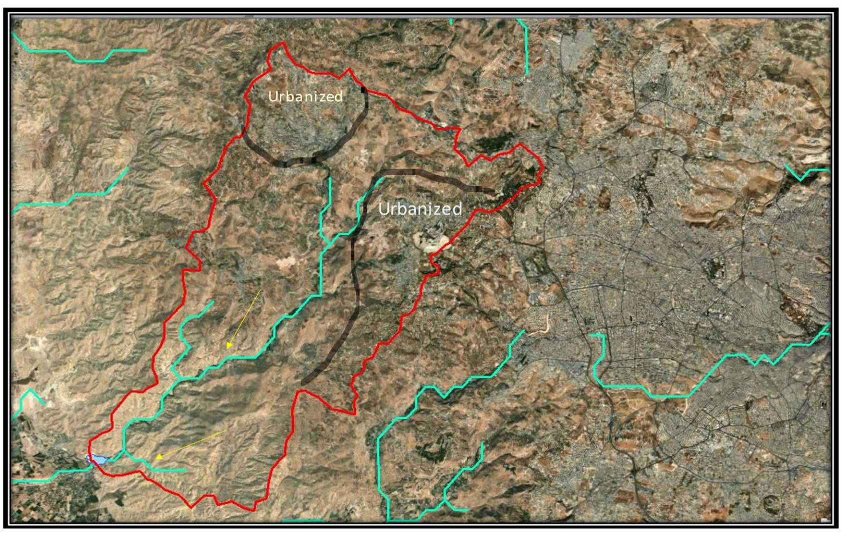

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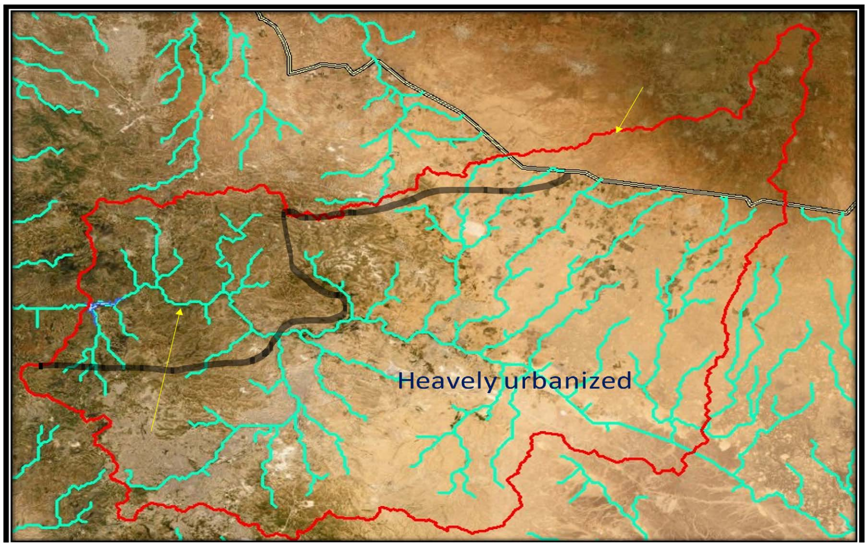

(d)

(e)

Figure 7. (a): Densely urbanized eastern area of Wadi Al-Arab Dam catchment, (the area between the red and the black lines); (b): Densely urbanized eastern area of Al-Kafrain Dam catchment, (the area between the red and the black lines); (c): Densely urbanized eastern area of Shueib Dam catchment, (the area between the red and the black lines); (d): Densely urbanized area of King Talal Dam catchment, (the area between the red and the black lines); (e): Almost non-urbanized area of Al-Mujib Dam catchment.

The territory of Jordan is dominated by surface or near-surface phosphate and oil shale deposits, which erode by rain and flood water that accumulates in dams. Together with other factors such as sunlight, nitrates, and oxidation of organic matter impair the natural water quality in dams, *e.g.* Al-Tannur dam, with huge phosphate deposits within its catchment and Al-Mujib dam with huge oil shale and phosphate deposits covering its catchment area. In addition, excavations or mining processes of such minerals will be reflected in the water quality of the respective dams.

3.2. Water Quality

Dams considerably affected in their quality:

- Liquid wastes: Al-Wehdah, Wadi Al-Arab, Ziglab, Kufranja, King Talal, Al-Kafrain, Shueib, Zarqa Ma'in, Al-Wala, and Al-Mujib dams;
- Mining industry: Al-Tannur (phosphate and gypsum) and to a lesser extent Al-Mujib (phosphate gypsum and oil shale) and Al-Karak (Gypsum), King Talal Dam leachates from old phosphate mining by-products.

4. Factors Affecting Dam Stability

4.1. Overflow (Over Flooding)

All dams in Jordan have been provided with spillways to discharge the highest probable floods of, at least 50 years frequency. When properly managed, none of the dams in Jordan is threatened by overflows, because of the provision of suitable spillways.

Mismanagement and blocking the discharge of floodwater along Wadis and its sudden release due to the collapse of barrages may, according to the blocked floodwater quantities, lead to spillway damages such as what happened in the case of Wheidi dam in the winter of 2022/2023 (**Figure 8**). Otherwise, spillways of dams were designed and constructed to accommodate potential flooding events.

4.2. Ground Collapses (Underground Erosion) Activation of Faults or Karst Development

The main dams in Jordan are constructed on wadis eroded in solid rocks, but wadis in general represent weak zones in the geology of the respective areas. The weakness of the wadis course can be the result of a fault, a flexure, a synclinal bending, a depression, or easier erodible rocks than the surroundings. All these weaknesses along wadis may still be active and hence dams are exposed to the

Figure 8. Wheidi Dam spillway in Ma'an governorate early 2023.

results of their activities. Such activities are slow processes and some types of dams possess enough flexibility to accommodate slight movements in their foundations and abutments during their lifetime. Other types such as concrete dams may react by fracturing or total collapse. Most dams in Jordan are equipped with sensors for the measurements of differential movements of dam body parts and for some of them early warning systems are provided and evacuation plans prepared. Dams in Jordan have been constructed after adequate geo-engineering studies, design and construction, but extreme and rare events may affect any dam structure and cause its damage.

4.3. Earthquakes

Due to its geologic position and geologic setting, Jordan is exposed to earthquakes, especially along the Jordan Rift Valley and its Eastern Mountains' surroundings [17]. Small earthquakes, of less than 3 M on the Richter scale, are very common and happen very frequently. Large damaging earthquakes of more than 6 M can hit at any time, but they were calculated to occur once in a century [17]. Concerning water infrastructures, earthquakes can affect dams and result in dam destructions, interrupted water supply and loss of water storage. But, dams in Jordan are generally built to stand earthquakes of 6.5 - 7.0 M.

The last major earthquake which hit the northern area of Jordan in 1927 was 6.1 or 6.2 M on the Richter scale, affecting Palestine more than Jordan. A stronger earthquake hit the area south of Aqaba in 1995 with a 6.8 M and caused some damage to old buildings and killing one person.

The faults, along which earthquakes may take place are with the exception of the Jordan Rift Valley fault relatively short in their extent and of, generally, extensional type. Also, the Jordan Rift Valley fault is a pull-apart structure, with limited parts of it exposed to compressional stresses due to the S-shaped fault line and its strike-slip nature forming sag-ponds and ridges along its course [18].

Stronger protection measures against earthquakes than those taken into consideration in the design and construction of dams in Jordan do not seem necessary, although some danger of bigger earthquakes still exists.

4.4. Volcanic Eruptions

Volcanic rocks cover around 12% of Jordan's territory and are distributed all over the country, especially in north Jordan, Harrat Ash Sham basalts, and along the high mountains east of the Jordan Rift Valley. The last known volcanic eruptions were active in Harrat Ash Sham area 4.500 years ago [19]. The great number of active volcanoes during the Neogene and Pleistocene, and some during the Holocene of less than about 12.000 years ago may indicate that volcanic eruptions or re-eruptions in Jordan, especially in the Yarmouk and Azraq catchment areas are quite possible. The dams that may be affected by such eruption is Al-Wehdah dam at the Yarmouk River, and Zarqa Ma'in dam south of Madaba City, but the probability of volcanic eruption remains low.

4.5. Construction Failure

Al-Wala dam was constructed in the upper reaches of Wadi Al-Wala; the northern branch of Wadi Al-Mujib to collect flood water for use in drinking and irrigation purposes. Part of the dams' water is pumped for an artificial recharge scheme via recharge wells. The lake area of the dam proved to be leaky and much of the collected water infiltrates down to reach the groundwater body in the area. The initial dam was constructed as earth fill dam provided with a clay core. Recently the dam was raised by adding concrete blocks built on the clay core of the old dam, which a new technique is not used before. The investigators, designers and constructors of the dam assured that the dam will be stable and no danger of collapse exists when filling the dam gradually and afterward. But, due to this unique unfamiliar type of dam construction, doubts arose about the stability of the dam and rigorous warning systems were prepared for the case of its collapse. Fears related to the stability of the dam are justified, because of the unique, not yet proven technology used in the raising of the dam and because the failure of that dam will not only be a catastrophe for human and animal life and the environment but also to the water supply system of the water-scarce country trying to make use of each drop of water within its territory.

5. Factors Affecting Dam Security

All dams in Jordan are threatened by sabotage actions, which threaten the stability of dams and the amounts of stored water in addition to the chemical and biological quality of the stored water, especially in dams used for drinking purposes such as Al-Wehdah, Wadi Al-Arab, Al-Wala, and Al-Mujib dams (**Table 2**) [20].

Safety Plan

Dam safety requires continuous monitoring and installation of Early Warning System (EWS) at most threatened dams, at which they can serve as risk-reduction measures and thus provide cost savings to dam owners. Specifically, EWS are very important as they provide: 1) A near real-time and continuous data recording with more frequent and event-driven data recording under heavy loading conditions; 2) Ability to analyze data remotely through web-based applications with rapid processing and plotting of data, allowing easier and quick evaluation and interpretation; 3) Initiating an automatically alarms notification for staff at real time bases; 4) Rapidly changing phenomena can be measured; 5) They provides continuous data even under harsh weather conditions (e.g. flooding, snow, storms, *etc.*); and 6) Increased accuracy, reliability, and consistency through remote diagnostics and reduced human error from manual data inputs. 7) Besides, better informed resources to support critical decision-making process. However, based on the severity of the threat, technical and environmental priorities for actions will be defined and worked out. For implementation of actions and action plans economic, social and political consensus has to be properly considered (**Table 3**).

Table 2. Threats categorization for the main dams in Jordan (X = moderate threat, XX = strong threat and XXX = extreme threat).

Dam/threat	Design & construction problems	Climate change	Urbanization	Siltation	Lack of water supply	Increasing water demand	Pollution/ treated wastewater	Natural events	Security & sabotage
Al-Wehdah		XX	X	X	XX	XX	XX	X	XX
Al-Wadi Arab	X	XX	XX	X	X	XXX	XX		X
Ziglab		XX	X	X			X		
Kufranjah	X	XX	X	X		XX	XX		
KTD	X	XX	XXX	XXX		XXX	XXX	X	
Al-Karamah	XXX				XX			XX	
Wadi Shueib		X	XX	XX		XXX	XX		
Al-Kafrain	X	X	XX	XX		XX	XX	X	
Zarqa Ma'in	X	XX	X	XX		XX	XXX	X	X
Al-Wala	XX	XXX	XX	XXX		XXX	XX	XX	X
Al-Mujib	XX	XXX		XXX	XXX	XXX	X	X	X
Al-Tannur	XX	XXX		XXX	XXX	XXX		X	
Al-Lajjoun		XXX	X	XX	X		X		
Al-Karak		XX			XX	X	XX		

Table 3. Problems affecting dams in Jordan and the responsible agencies for correction and mitigation measures.

Factors affecting dam storage	Responsibility	Factors affecting dam water quality	Responsibility	Factors affecting dam stability	Responsibility	Factors affecting infrastructure Security	Responsibility
Climate changes	Mainly industrial countries	Solid wastes along wadis	Muni., MoE	Overflow	MWI,	Sabotage	DoIS, MWI, MoI
Siltation (erosion)	Muni., MoPW	Solid waste disposal sites	Muni., MoE	Ground collapses	MWI, MoPW		
Leakages	MWI and MoPW	Liquid wastes	MWI, Muni., MoE	Volcanic eruptions	MoENR		
Water diversions by other countries	MoF	Pharma residues	MoH, MoJ	Piping and leakages	MWI		
Conveyance and on farm efficiency	MWI (JVA), MoA	Mining industry	MoENR, MoE, MoJ				

MWI: Ministry of Water and Irrigation, MoH: Ministry of Health, MoF: Ministry of Foreign Affairs, MoE: Ministry of Environment, MoENR: Ministry of Energy and NR, MoJ: Ministry of Justice, MoPW: Ministry of Public Works, Muni: Minicipalities, MWI: Ministry of Agriculture, MoI: Ministry of Interior, DoIS: Department of Infrastructure Security.

6. Conclusions

In Table 2 the threats facing the main dams in Jordan are categorized and the following conclusions are derived from that table and from the discussion of the individual threats facing the dams.

1) Common among all dams are the impacts of climate change, which requires recording and monitoring of:

- Precipitation prediction and high-resolution recording of each precipitation event;
- Floods water measurements along dam feeding Wadis;
- Analyses of the hydrological effects of human activities (urbanization, industrialization and agriculture) on inflows into dams.

2) Dams of Al-Wehdah, Al Arab, Ziglab, and Al-Wala (Table 2), which are used in the drinking water supply, are gradually threatened by inflows of treated and untreated wastewater in addition to solid waste disposal in their catchment areas.

3) All dams in Jordan have siltation problems, caused by natural erosional processes and by manmade activities of urbanization, tailing and mining.

4) Dams of Al-Tannur, Al-Wala, Zarqa Ma'in, and Al-Kafrain deserve close monitoring of their geotechnical stability of leakages and settlement.

5) It is worth mentioning here that pharma residues may in the future, represent a new threat to the water quality, especially as a result of agricultural and household water uses and releases into the environment.

7. Recommendations

1) Programs aiming at improving the understanding of the above issues require provision and installation of advanced equipment such as:

- Representative rainfall recording station, at least one per 100 km^2 of the catchment area of a dam;
- Upstream gauging station of inflowing water for the main wadis;
- Groundwater observation wells (a few tens of meters): A. In the upstream area of dams' lakes. B. At a few hundred meters downstream of dams. These wells should be provided with loggers for water levels, salinity, temperature and EC values;
- Water hydrographs for the dams' lake water level.

All the above equipment should be of a telemetric type and provided with the necessary receiving stations within the dam premises and in the Ministry of Water and Irrigation.

2) Mapping of the sources of pollution; mainly solid and liquid disposal sites, their types and quantities has become an urgent necessity in order to set preventative measures to minimize their negative impacts.

3) Surveying and mapping the sources of siltation have become very necessary in order to implement action plans to minimize their impacts. This is urgent in the case of Al-Tannur, Al-Mujib, Wadi Al-Arab, Wheidi, and King Talal dams,

but also necessary for all others.

4) Al-Tannur, Al-Wala, Zarqa Ma'in, and Al-Kafrain Dams deserve close monitoring of their geotechnical stability due to leakages and settlement by providing them with monitoring equipment for differential movements and leakages and transmission of information by telemetry.

5) Quick installation of Early Warning System EWS is very much needed at dams of high risk such as Al-Wala, Wadi Al-Mujib, King Talal, and Zarqa Ma'in dams.

6) On the management part; until now dams in Jordan, even those constructed more than 50 years ago are still managed by the government. Such management was suitable at that time, but owners, beneficiaries, stakeholders, and other actors related to such dams, all over the world [21] have since then changed. Therefore, the change of governmental management of dams to also include other actors has become imperative to guarantee maximizing the benefits of dams and their smooth management. Dam committees composed of governmental officials, dam operators, beneficiaries, stakeholders, emergency agencies, and affected groups (downstream settlements, livestock owners, environmentalists) have become a necessity in Jordan for the proper functions of dams and for magnifying their benefits to achieve dam's societal services. Change from dams' governmental management to societal governance has become a necessity in Jordan and that will certainly reflect positively on accommodating dams in the local societies.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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