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ARTICLE

Seasonal Variation of Heavy Metals, Uranium, and Thorium Concentration in Jordanian Dams Water

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Abstract: This work investigated the seasonal variation of heavy metal concentrations in the waters of Moujib, Wala, King Talal, Kufranjeh, and Tannour dams in Jordan. Samples were collected from each dam's entrance, dam lake (reservoir), and exit. Samples were collected at the end of the rainfall season, when dams were almost full, and at the end of summer, when the water was at its lowest level. The study investigated the content of As, Cd, Cr, Hg, Mo, Ni, Pb, U, and Th elements. The results revealed that the concentrations of As, Cd, Cr, Hg, Mo, Ni, and Pb were less than the lowest detectable limit during both seasons. The Uranium average concentrations for the wet and dry seasons were 1541 and 1564 ppt, respectively, while the average concentrations of thorium for the wet and dry seasons were 7 and 119 ppt, respectively. These results are below the allowed values according to the Jordanian standard for drinking water and international guidelines. They are comparable with values reported in the literature. This work indicates that Jordanian dam water is free from heavy metals, and the content of U and Th is within accepted levels.

Keywords: Heavy metals, Uranium, Thorium, Dam water, Seasonal variation, Total dissolved solids.

PACS: Dams: 92.40Xx, Environmental Impacts-Surface water quality: *92.40.qc, Environmental Impacts -surface water: *92.40.92.40Qk, Water Quality-surface water: 92.40Qk*92.40qc

Introduction

Dams are a strategic national water resource, as they store water for domestic, industrial, agricultural, and other uses. Maintaining the quality of these resources and preventing pollution is therefore essential. Water stream sources can catch unwanted elements, such as heavy metals, and transfer them to the dam. Geochemical structure, industrial waste, mining activity, and untreated wastewater are potential sources of heavy metal pollution [1-5]. The concentration of heavy metals tends to keep building up in dam water, sediment, and aquatic organisms [6]. The concentration of unwanted elements in the dam water increases in summer due to evaporation [7], which affects water quality at the end of the season.

Consumption of contaminated dam water, or crops irrigated with such water, can transfer harmful elements into the human body. Governments define the maximum concentration limits for harmful elements found in water and

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continuously monitor them. Table 1 summarizes the limits of some elements in drinking water as set by the Jordan Standards and Metrology Organization (JSMO) [8], and by the World Health Organization (WHO) [9]. It could be noticed that limit values set by JSMO are generally comparable to those of WHO. Nevertheless, the WHO didn't set limits for some elements as they were not considered a health hazard, as described in Table 1.

Heavy metals are a particularly harmful group of elements that may originate naturally or from industrial activities [10]. For instance, aluminum salts are widely used in water treatment, which could lead to increased concentrations of aluminum in drinking water [9]. Having a low concentration of natural Al in the dam water is essential to get low levels of Al in treated water. Arsenic is found widely in the Earth's crust, and it can enter surface waters through weathering of exposed rocks. It could also come from coolants used in industry. Lead and cadmium are widely used in car batteries, fertilizers, and pesticides; they could reach the dam through running water [9]. Therefore, monitoring the quality of water in dams is essential to control the probable contamination.

TABLE 1. Upper limit concentrations (mg/L) of selected elements in drinking water as set by JSMO and WHO.

Element	Upper Limit JSMO[5] (mg/L)	Upper Limit WHO [6] (mg/L)	Notes
As	0.01	0.01	
Cd	0.003	0.003	
Cr	0.05	0.05	
Hg	0.006	0.006	
Mo	0.09	NA	Concentrations of Mo, found in drinking water, are generally below health concerns (WHO).
Ni	0.07	0.07	
Pb	0.01	0.01	
U	< 0.5 Bq/l	0.03**	Total Alpha emitters < 0.5 Bq/l (JSMO)
Th	0.5 Bq/l	<1 Bq/l	Total Alpha emitters < 0.5 Bq/l (JSMO) ^{232}Th guidance level <1 Bq/l (WHO)
TDS*	1000	1000	

* TDS: Total Dissolved Solids

** Only hazardous elements were considered

Jordan is one of the most water-scarce regions in the world. Management of water resources is important to meet the increasing demand for water in the country [11, 12]. Protecting water sources and reservoirs against contamination is essential to sustain water resources. Salamah *et al*. [4] identified various threats to Jordan's dams, with industrial wastewater carrying high concentrations of heavy metals being one of the most significant. Drinking water in Jordan is affected by seasonal variations [13]. Therefore, this work aims to highlight the impact of seasonal variation on heavy metal concentrations in dam water across Jordan. Dams store rainwater during the winter season, which is subsequently used for drinking and irrigation during the summer. For this study, major dams were selected. The location, capacity, water resources, and purpose of use for these dams are listed in Table 2 [14].

King Talal Dam catchment lies within the Zarqa River basin, with the Zarqa River and Wadi Rmemeen feeding the dam with water. The Zarqa basin has an arid climate in the southeastern and eastern regions and rainy, humid conditions in the west. Significant industrial activities are located near the Zarqa River, and their wastewater is frequently discharged into the river. In addition, wastewater from Khirbet As-Samra is discharged into the dam through the Zarqa River, and from the Baqa'a treatment plant through Wadi Rmemeen [15].

TABLE 2. Some properties of major dams in Jordan considered in this work (capacity in MCM: Million Cubic Meters).

Dam	Governorate	Total Capacity (MCM)	River/ Wadi	Purpose
Mujib	Al-Karak	31.2	Wadi Mujib	Irrigation, Municipal, and Industrial
Wala	Madaba	9.3*	Wadi Wala	Irrigation, Municipal, and Industrial
King Talal	Jerash	86	Zarqa river	Irrigation and Electricity
Kufranjeh	Ajloun	8	Wadi Kufranjeh	Irrigation and Municipal
Tannour	Tafilah	16.8	Wadi Al-Hassa	Irrigation and Industrial

* Wala Dam is getting an upgrade to increase its capacity up to ~29 MCM.

Mujib Dam catchment has a high slope with Wadi Saeda and Wadi Nukhaila feeding it with water. The dam suffers from frequent flood events, suggesting a significant sediment accumulation [16]. The catchment area includes Wala Dam as well [17]. The catchment has moderate agricultural activity and almost no industry, suggesting minimum or low pollution [18].

Kufranjeh Dam is newly established in Ajloun to solve the water scarcity in the city. The catchment area has a Mediterranean-type climate. Its topography is hilly with slopes toward the west, and the main water resources are from precipitation and spring waters. The dam receives effluents from the Kufranja wastewater treatment plant as well [19]. Al-Tannur Dam is located in Wadi Hasa. Wadi Hasa has a Mediterranean-type climate, characterized by hot, dry summers and cold, wet winters. Most of the catchment area is semi-arid, and the temperature exhibits large seasonal and diurnal variations [20].

Materials and Methodology

This section describes the sample collection, preparation, and measurement.

Sample Collection

The dams for this work were selected according to two criteria: first, they have a large capacity, and second, they are geographically distributed around the country to represent all regions in Jordan. A map showing the locations of the studied dams, marked in red, is provided in Fig. 1.

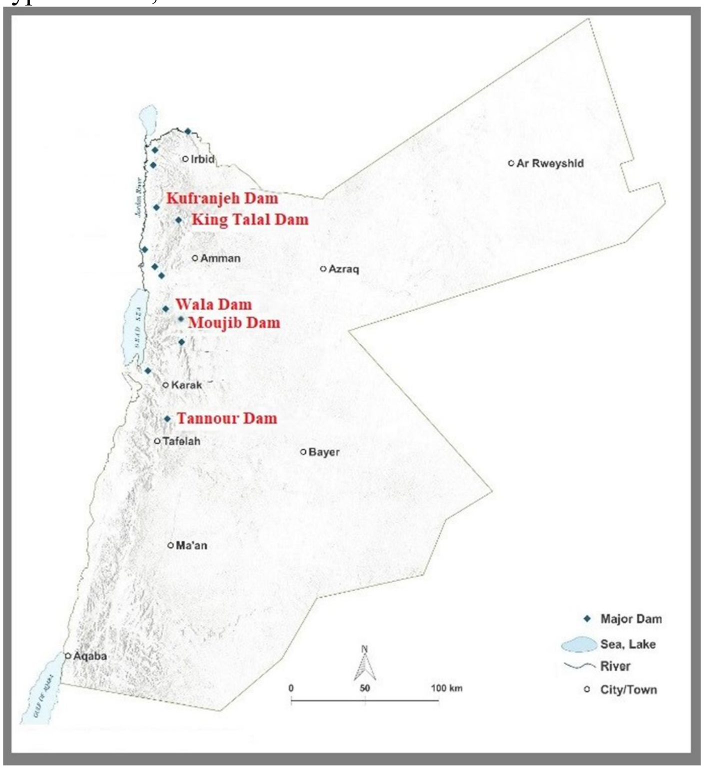

FIG. 1. Map of the dams investigated in this study.

For each dam, three sampling locations were considered: the dam lake, the exit, and close to the entrance of the dam. Samples were collected twice a year during the wet and dry seasons. The entrance samples demonstrate the quality of the water feeding into the dam. The dam lake samples represent the stored content of the dam and were collected at a depth of 1 m below the surface. The sample collection tool is shown in Fig. 2. This tool is equipped with a depth indicator to ensure accurate collection at 1 m below the surface.

FIG. 2. The sample collection tool used to collect samples from the dam lake.

Exit samples were collected directly from the exit pipe in the case of King Talal Dam and Mujib Dam. For all other dams, exit samples were taken from running water right after the exit, collected just below the surface. The geographic coordinates of all sampling points can be found in Table 3. The bottle used for sample collection was first rinsed with some water from the sample location, and then it was filled with the sample. TDS was measured in situ from the bottle directly after sample collection.

TABLE 3. Coordinates of samples collected from dams in this work. Points that were not available are marked as NA.

Dam	Entrance Coordinates		Dam-lake Coordinates		Exit Coordinates	
	N	E	N	E	N	E
Mujib	31°26'36"	35°49'42"	31°26'34"	35°48'58"	31°26'44"	35°49'07"
Wala	NA	NA	31°34'08"	35°48'15"	NA	NA
King Talal	32°11'33"	35°50'16"	32°11'18"	35°48'13"	32°11'25"	35°47'53"
Kufranjeh	32°16'06"	35°38'52"	32°16'07"	35°38'37"	32°16'02"	35°38'26"
Tannour	30°58'05"	35°43'29"	30°58'19"	35°42'47"	30°58'30"	35°42'43"

The first round of sampling took place in 2019, with two collections from the same locations to investigate seasonal variations in heavy metals, U, and Th concentrations due to evaporation during the summer. The last rainfall occurred at the beginning of May 2019. The first set of samples was collected during June and July 2019, representing the wet season, and the second set was collected in November 2019, representing the dry season. Fig. 3 demonstrates the sample collection point from the dam-lake of Mujib Dam for both the wet and dry seasons. During the wet season, the dam was full and the plant in the left corner appeared green and hydrated, whereas in the dry season, the water level had decreased significantly, and the plant was dry.

Another sampling round was conducted in 2021, which was drier than the previous year, with rainfall below the average seasonal precipitation. Many dams were completely empty towards the end of 2021. Samples were collected in October 2021 from the bodies of Mujib, Kufranjeh, and King Talal Dams, as these were the only dams that still contained water. The scarcity of water during this period suggests a corresponding increase in the concentration of the elements of interest.

FIG. 3. These pictures were taken from the same sample location at Mujib dam-lake, showing the difference between the wet and dry seasons. These pictures were captured during sample collection in 2019. The collection point is marked by an X.

Sample Preparation and Measurement

Once a sample was collected, the pH, temperature, and TDS were measured in the field. Samples were filtered to remove solid particles before the measurement was performed. Then HNO_3 acid was added until the pH of the water was less than two. The samples were analyzed at JAEC using an Agilent 7500 Inductively Coupled Plasma Mass Spectrometer ICP-MS with an in-house method accredited to ISO 17025. 10.0 ml of each sample was placed in Teflon vials, and 3.0 ml of HNO_3 and 2.0 ml of H_2O_2 were added. Samples were transferred to the advanced microwave digestion station (Milestone, model Ethos). During digestion, samples were heated in the microwave for 40 minutes to reach 230ºC, which was maintained for 30 minutes, and then the sample was cooled down to room temperature. After this process, samples were transferred to a 50.0 ml polypropylene centrifuge tube and topped up with distilled water until the total volume was 50.0 ml, and then centrifuged at 2000 - 3000 rpm for 10 minutes. The ICP-MS device was calibrated using MISA-06-1, MISA-05-1, U, Th, and As standards. An internal standard of Rh and Bi was used for quality control, with the accepted recovery of 85-115%. The total measurement uncertainty was estimated to be 10% for all the measurements. For comparison purposes, some of the samples were sent to the Water Authority of Jordan (WAJ).

At WAJ, different analytical techniques were applied according to the element: arsenic (As) was measured using atomic absorption hydride generation with an electrically heated cell, while mercury (Hg) was measured using an atomic absorption spectrometer (GTA model AA800, Perkin Elmer) calibrated with As and Hg standard solutions. Samples for this method are measured as is with no extra additives. Uranium (U) and thorium (Th) were analyzed using an ICP-MS (Nexion 300X, Perkin Elmer) equipped with a preconcentration column, which allows achieving detection limits of 0.58 ppt for U and 0.85 ppt for Th. Calibration was performed with U and Th standards, using Re as an internal standard. All other elemental measurements at

WAJ were completed using ICP-OES. Both JAEC and WAJ laboratories have ISO 17025 accreditation and participate in national and international intercomparison tests. The lower limits of detection for both laboratories are shown in Table 4.

Results and Discussion

The results of the TDS measurements for the 2019 wet and dry seasons are shown in Fig. 4. The TDS of the samples during the dry season increased due to evaporation. The TDS for samples collected in the 2021 season rose significantly as evaporation occurred over an extended period. The TDS of the samples collected from King Talal, Kufranjeh, and Mujib dams in the 2021 dry season were 1280, 601, and 2143 mg/L, respectively. Comparing these values with those from 2019, a clear increase in all three dams can be noticed, as shown in Fig. 4. The smallest increase was observed at King Talal Dam, which is continuously fed by the Zarqa River throughout the year. Kufranjeh Dam showed an increase in TDS. Mujib Dam experienced a substantial increase in TDS, likely due to significantly lower precipitation in southern Jordan during 2021, resulting in a very low water level at the time of sampling.

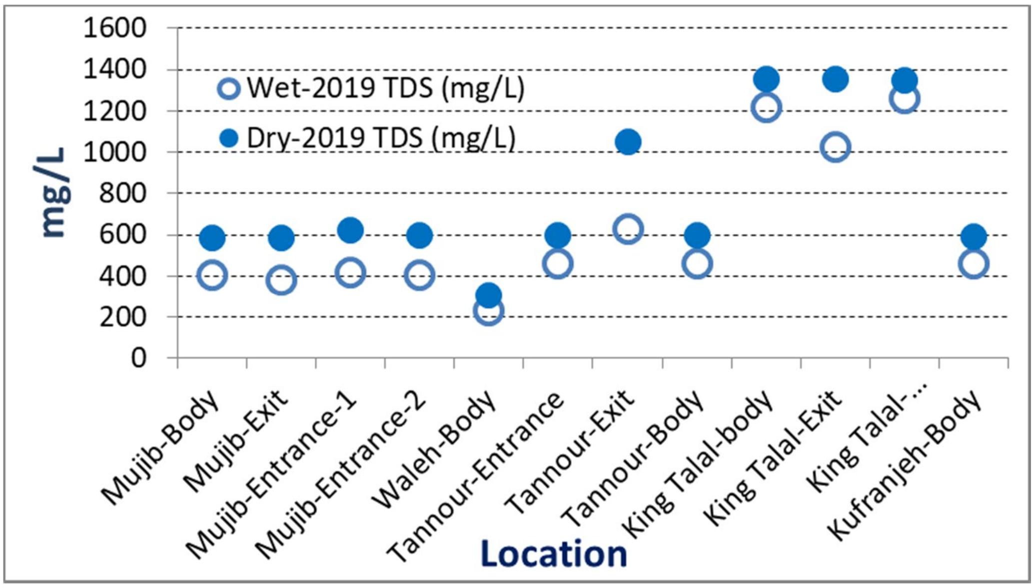

FIG. 4. Comparison between the wet and dry seasons TDS content at each point of the studied dams.

The lower limits of detection for all elements measured at both JAEC and WAJ laboratories are presented in Table 4. For all samples collected, across all points and seasons, including the extremely dry 2021 season, the concentrations of the investigated heavy metals were below these detection limits. Notably, the lower detection limits at both laboratories are equal to or lower than the maximum allowable levels set by JSMO and WHO, as listed in Table 1.

These results indicate that the water in Jordanian dams remains within national and international quality standards, even under dry-season conditions. Therefore, the dam water is safe for various uses, including domestic consumption, irrigation, and industrial applications.

TABLE 4. Lowest limit of detection (mg/L) for the elements investigated in this work at both JAEC and WAJ.

Element	JAEC (mg/L)	WAJ (mg/L)
As	< 0.005	< 0.005
Cd	< 0.005	< 0.003
Cr	< 0.005	< 0.005
Hg	< 0.001	< 0.00015
Mo	< 0.005	< 0.010
Ni	< 0.001	< 0.010
Pb	< 0.001	< 0.005

These results are consistent with the results found in the literature. For example, the Mujib dam water has previously been reported to contain Cd, Cr, Pb, and Ni at concentrations of <0.02, <0.02, <0.01, and <0.02 µg/l, respectively [18]. Another study highlighted the concentration of heavy metals in the Kufranjeh Dam and reported heavy metal concentrations as follows: Cd <0.0025 mg/L, Mo <0.01 mg/L, and Hg <0.001 mg/L [19]. A Small concentration of heavy metals in King Talal Dam were reported in the literature. The reported values were: 0.00557 mg/l of Cd, 0.02701 mg/l of Cr, 0.018205 mg/l of Pb, and 0.040955 mg/l of Ni. These findings align with the results of this study. It is worth noting that the 2019 sampling period coincided with multiple floods in Jordan, including at least four controlled flooding events at King Talal Dam [21]. This indicates that the large amount of freshwater that fed the dam in 2019 diluted the concentrations of these heavy metals, so they were not detected in this work.

Table 5 summarizes the concentrations of heavy metals in dam water from this study, other studies in Jordan, and selected international cases. The results of this work showed that all the element concentrations were below the detection limits. The results in Table 5 showed the absence of Cd and Ni in the water of Al-Wehdah Dam, which is consistent with the results of this work. The work described in [7] shows the presence of traces of Cr and Pb, but this is consistent with the results of this work, as this dam was out of the scope of this work. The next column in Table 5 shows the concentration of heavy metals in the lake of Atatürk Dam in Turkey. These results are consistent with the results of this work, as the heavy metals were below detection limits except for some traces of Ni [22]. For Nairobi Dam in Kenya, the average heavy metal concentrations during the wet and dry seasons showed higher values than those observed in this work, but still within the permissible values of the WHO [1, 9]. Generally, the wet season concentrations are lower than dry season values, mirroring the TDS trend observed in this study [1]. Mercury was reported in Sarawak, Malaysia, in the Dam water with a concentration of 0.000039 mg/l [2].

TABLE 5. Concentration of heavy elements in dam water reported around the world, locally, and in this study.

Element	Concentration (mg/L)				
	This Study	Al-Taani, 2013 [7] (Wehda Dam)	Karadede and Unlu, 2000 (Turkey) [22]	Ndeda and Manohar, 2014 (Kenya) [1] Wet	Dry
As	<LLD	-	-	-	-
Cd	<LLD	<LLD	<LLD	3.76 ± 0.15	5.12 ± 0.18
Cr	<LLD	0.09	-	-	-
Hg	<LLD	-	<LLD	-	-
Mo	<LLD	-	<LLD	-	-
Ni	<LLD	<LLD	0.0132	1.20 ± 0.13	2.11 ± 0.12
Pb	<LLD	0.012	<LLD	11.67 ± 0.21	16.78 ± 0.21

Table 6 presents the uranium concentrations measured in the dams during the wet and dry seasons of 2019. For the wet season, uranium levels ranged from 776 to 2216 ppt, with an average of 1541 ppt, while in the dry season, concentrations ranged from 605 to 2490 ppt, averaging 1564 ppt. Both averages are well below the WHO guideline limit of 30,000 ppt. These results are consistent with literature values; for instance, the average ^{238}U concentration reported for five dams in Morocco was 928 ppt [23], and typical surface water concentrations generally remain below 4000 ppt [24].

Uranium concentrations in Jordanian dam water are particularly important due to the presence of phosphate deposits in southern Jordan. Jiries *et al.* [25] reported high uranium levels in effluent water from phosphate ore processing. From Table 6, it is evident that dams in northern Jordan, such as King Talal and Kufranjeh, have approximately half the uranium concentrations of dams in southern Jordan, including Tannour and Mujib. Tannour Dam exhibits the highest uranium levels, likely due to inflow from the Al-Hisa and Al-Abyad phosphate mining effluents. Establishing these baseline values is essential for future monitoring and management of uranium in Jordanian water resources.

TABLE 6. Uranium concentrations (ppt) in water samples.

Dam	U(ppt) – Wet	U(ppt) – Dry
King Talal	1461	1446
Kufranjeh	1197	1535
Wala	776	605
Mujib	2056	1744
Tannour	2216	2490
Average	1541	1564

The results of thorium concentrations for the wet and dry seasons of 2019 are presented in Table 7. During the wet season, the concentration ranged between 3 and 17 ppt, with an average of 7 ppt. In the dry season, concentrations ranged between 49 and 190 ppt, with an average of 119. The increase in concentration during the dry season is consistent with the increase in TDS values between the two seasons. These average values of thorium are much less than the 1206 ppt value reported in dam water in Morocco [23].

TABLE 7. Thorium concentrations (ppt) in water samples.

Dam	Th (ppt) – Wet	Th (ppt) – Dry
King Talal	3	190
Kufranjeh	8	49
Wala	17	105
Mujib	2	117
Tannour	5	133
Average	7	119

Conclusion

Water samples from large dams in Jordan have been collected during wet and dry seasons. The selected dams cover most regions in the northern and southern parts of Jordan, including Moujib, Wala, King Talal, Kufranjeh, and Tannour. The TDS of the samples was measured on-site, and the results showed that the TDS increased significantly during the dry season due to evaporation. Concentrations of As, Cd, Cr, Hg, Mo, Ni, and Pb were measured in water samples at JAEC and WAJ laboratories. The results showed that their concentration is less than the lower limits of detection for all seasons. U and Th concentrations were measured using ICP-MS at WAJ laboratories. The concentrations of uranium varied from 2 to 17 ppt during the wet season and from 605 to 2490 ppt during the dry season, while the concentrations of thorium varied between 2 and 17 ppt during the wet season and 49 and 190 ppt during the dry season. The results for TDS and the heavy metals in the studied dams did not exceed the allowed national JSMO limits and international WHO limits, even after the end of the dry season. These findings indicate that the dam water in Jordan is of good quality and safe for drinking purposes.

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