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Using GPS and Run-Off Rates Data to Study the Close Monitoring Networks for Dams – Al-Kut Barrages as a Case Study

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ABSTRACT

The dams and barrages are among the most important engineering structures for water supply, flood control, agriculture, and electric power generation. Monitoring the horizontal and vertical deformation of the barrage's body and identifying the risk it's so important to maintain the dam and also to reduce costs. Where in this research the case of the Al-Kut barrage is studied by observing the body of the barrage using surveying devices through (GPS) by taking spatial observations of the two networks of stations, the horizontal and vertical networks. Then compare them with the observations of previous years to determine the magnitude of the deformation through the differences between the observations. By calculating the differences and finding the displacement of surveying observations from 2014 to 2021, It was found that the highest and least displacements in the horizontal stations is 50 and 11 mm, respectively. Also, for the vertical network observations, the highest and lowest differences in elevation were 11and 3 mm, respectively. Where, the results showed a slight deformation within the acceptable limits. In addition, the annual and monthly discharge rates for a number of years were evaluated to observe the extent of the impact of run-off rates on increasing sedimentation at the upstream of Al-Kut barrage. It was found that the accumulation of sediment on the river's left bank affected the gates' efficiency and put pressure on the other gates, which led to some operational issues in the barrage gates.

Keywords: deformation; Al-Kut Barrage; GPS; GIS; sediments; Tigris River.

INTRODUCTION

Monitoring deformations for important engineering facilities is one of the most important applications of geodetic engineering works, which accompany the construction phase and continue during the investment phase, which aims to assess their conditions and safety as well. Determining the displacements of a facility during a certain period based on periodic measurements of the networks of the horizontal and vertical stations. Monitoring stations consist of control points and reference points, where periodic surveying measurements are carried out and the results of the measurements are processed to obtain accurate results. In addition, the presence of multiple vertical and horizontal reference stations for the monitoring network is necessary to improve the accuracy of these surveying measurements. In addition to ensuring the stability of the reference stations from time to time. The stability of the network stations is studied by comparing the results of the differences for the measured elements [Abedalrahman and Mnaty, 2021].

By knowing the difference between previous and recent observations, the impact of the barrage infrastructure over time is known. The main objective of studying the difference between the observations is to detect unexpected horizontal and vertical deformations at an early stage, and thus assess the infrastructure and integrity of the barrage. Where the results of measurements of deformations is important for engineering installations and constitute the basis for evaluating the safety of these facilities [Bayik et al., 2021; Goff et al., 2021], thus addressing the deformations at an early time, before it is too late. The cracks and movements in the elements of the facility may lead to its exit from service or may lead to its collapse, causing major disasters and human disasters, especially in dams and barrages [Goff et al., 2021].

Therefore, the use of modern technologies such as surveying devices associated with the global positioning system (GPS) is one of the most important modern methods and systems in monitoring and evaluating the barrages. Thus identifying potential risks and maintenance requirements to avoid disasters, as well as with the help of GIS programs in the study, analysis, collection of results, and the creation of maps and graphs (Figure 1) [Li et al., 2020].

Al-Kut Barrage is located in Wasit Governorate in the city of Al-Kut on the Tigris River. The barrage is considered one of the longest barrage in Iraq, with a length of 550 m and consisting of 56 gates. Design drainage of barrages is 6000 m^3/sec, where the gates are manually and electrically operated. Al-Kut Barrage was built in 1939. It is considered one of the important barrages in Iraq. The Al-Kut barrage is one of the most important irrigation facilities on the Tigris River, as it controls the water distribution between the governorates of Wasit, Maysan, and Dhi-Qar, and secures irrigation projects on the Garraf River and the Dujaila project. It secures water to irrigate nearly one million and a quarter million acres of arable land (Figure 2) [Abedalrahman and Mnaty, 2021; Hameed, 2018]. This study aims to monitor and calculate the horizontal and vertical changes and deformation of Al-Kut barrage over time using the geodetic data taken from Al-Kut barrage department for different periods to determine the deformation through the differences between the observations. In addition, the study of monthly and annual flow and discharge rates for several years gives us a clear idea of the sedimentation volume above Al-Kut barrage and its impact on the work and efficiency of the barrage gates. Deformation due to corrosion, water holding effect, and water saturation. Therefore, deformation measurements and analysis require high-precision surveying equipment and analysis of the data to identify and avoid hazards. In addition to studying, the sediments collected at upstream of the barrage over time and understanding the effect of sediments on the efficiency of the barrage gates [Abedalrahman and Mnaty, 2021; Hason et al., 2020].

MATERIAL AND METHODS

The horizontal network for monitoring Al-Kut barrage consists of 12 stations distributed over Al-Kut barrage's body, each station (K8, K9, K10, K11, K12, K13, K14, K15, K16, K17, K18, and K19). As for the known reference points, the coordinates of the horizontal network, they are P2 and P3 (Figure 3). The vertical network for

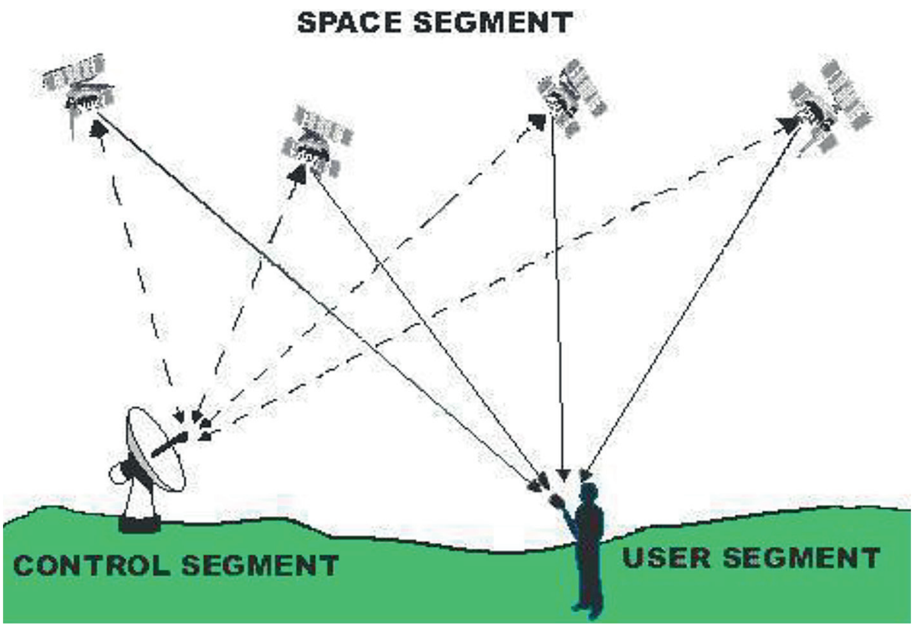

Figure 1. The GPS components

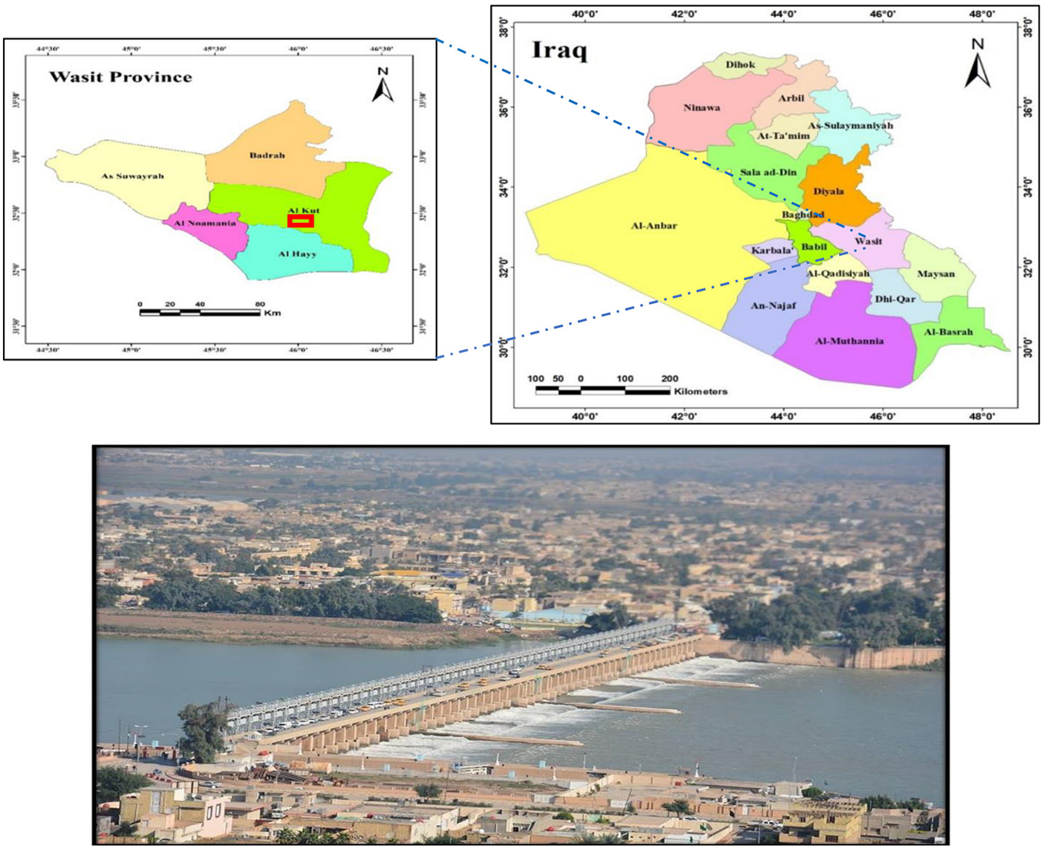

Figure 2. Location map of the study area, Al-Kut barrage

monitoring Al-Kut barrage consists of 15 stations distributed over Al-Kut barrage's body, which are each of the stations (K1, K2, K3, K4, K5, K6, K7, K8, K9, K21, K22, K23, K24, K25, and K26), The known reference point attributed to the vertical network is the point K01 (Figure 4). For surveying measurements, high-precision instruments were provided, the same as those used in the previous measurements, namely: Leica 1200 (RMS) dual frequency (GPS) receiver accuracy with post-processing (constant and fast constant (phase)) with the standard antenna and Leica DNA 03 digital level. Through the available data for surveying observations of Al-Kut barrage for several years (Table 1 and 2), analyzing and comparing the results, and studying the changes that occurred throughout the study period. Where by studying, analyzing, and calculating the differences in the surveying observations of Al-Kut barrage's body of the horizontal and vertical networks. Then, comparing them with the observations of previous years to calculate and determine the size of the deformation through the observations that give us a clear idea of the actual situation of Al-Kut barrage. Where the monitoring network at Al-Kut barrage consists of two horizontal and vertical networks, and both networks consist of a set of stations that are monitored at different times in order to monitor the deformation. In addition, evaluate if it requires intervention to deal with any deviation in the observations taken and determine the extent of its damage, and then assess the safety and integrity of the infrastructure of the barrage body. Also by taking advantage of the data of annual and monthly discharge rates for a number of years. Moreover, analyzing the data to observe the extent to which the flow rates affect the increase in sedimentation the upstream of Al-Kut barrage. Thus, note the extent of its impact

Table 1. The displacement of the horizontal network of Al-Kut barrage for the period (2014 to 2021)

Observation station	DE	DN	Displacement (mm)
K8	0.027	-0.011	0.029
K9	-0.012	-0.029	0.031
K10	0.050	-0.006	0.050
K11	0.004	-0.033	0.033
K12	-0.007	-0.011	0.013
K13	0.000	-0.023	0.023
K14	0.001	-0.022	0.022
K15	0.019	-0.008	0.021
K17	-0.022	0.001	0.022
K18	-0.027	0.006	0.028
K19	-0.011	-0.002	0.011

Table 2. The Elevation difference in the vertical Observed station of Al-Kut barrage for the period 2014 to 2021

Observation station	Elevation reading 2014	Elevation reading 2021	ΔE (mm)
KU01	20.40587	20.40587	0.00000
K1	22.41379	22.42375	0.00995
K2	22.41764	22.42688	0.00924
K3	22.40975	22.41974	0.00999
K4	22.38465	22.39371	0.00906
K5	22.37556	22.38449	0.00893
K6	22.35361	22.36345	0.00984
K7	22.40142	22.41254	0.01112
K8	20.25714	20.26286	0.00572
K9	20.28025	20.28528	0.00503
K20	20.24199	20.24906	0.00707
K21	20.25261	20.25745	0.00484
K22	20.22702	20.23086	0.00384
K23	20.28241	20.29386	0.01145
K24	20.26725	20.27165	0.00440
K25	20.26557	20.26896	0.00339
K26	20.26673	20.27629	0.00956

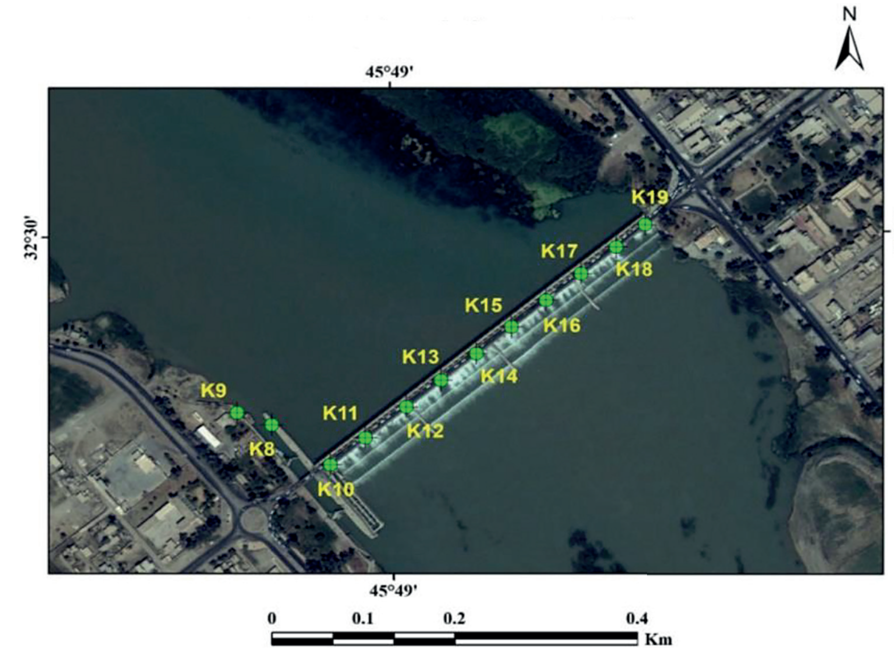

Figure 3. Horizontal network for Al-Kut barrage.

on the efficiency of the barrage. as the higher the flow rates, the less the sedimentation and thus the less pressure on the work of the barrage's gates, and the lower the flow rate, the greater the accumulation Sediments that have a negative impact on the work and efficiency of the gates of Al-Kut barrage [Mnaty and Abedalrahman, 2021].

RESULTS AND DISCUSSION

By calculating the differences and finding the displacement of stations in the horizontal network of areal observations from 2014 to 2021, it was found that the highest displacement in the horizontal network is 50 mm for the station K10. The lowest displacement is 11 mm for the station K19, while the rest of the displacement values range between that as follows 33, 31, 29, 28, 23, 22, 22, 21, and 13 mm (Figure 5). As for the vertical network observations, the highest difference in elevation was 11 mm for the station K7, while the lowest elevation difference was 3 mm for the station K25, and the rest of the differences between them ranged as follows 9, 9, 9, 9, 9, 9, 8, 7, 5, 5, 4 and 4 mm (Figure 6). It was noted through the analysis of the surveying data, as

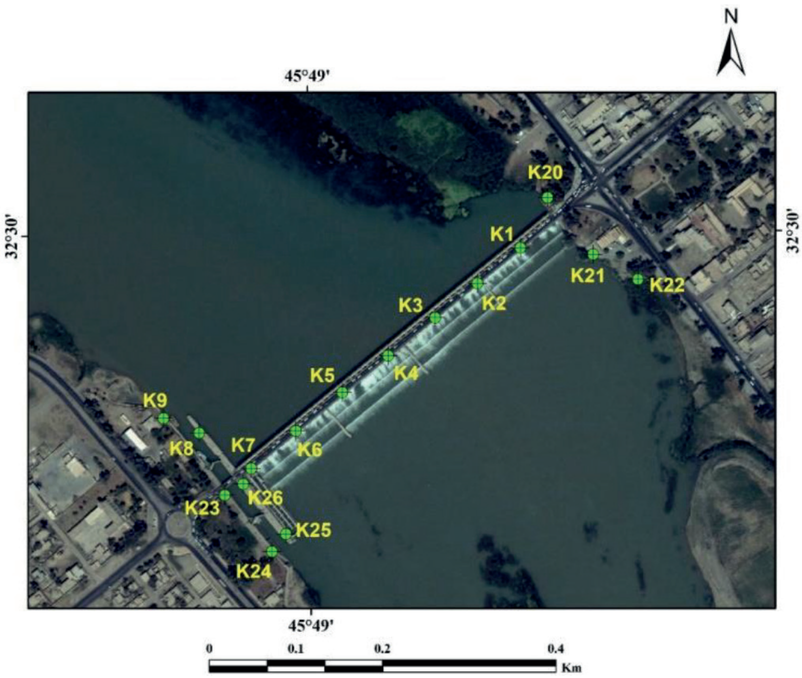

Figure 4. Vertical network for Al-Kut barrage

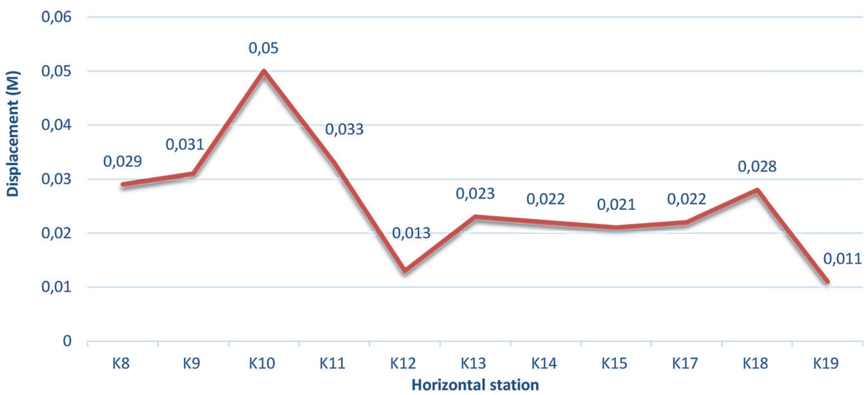

Figure 5. Diagram showing displacements of the horizontal network for Al-Kut barrage from the period 2014 to 2021

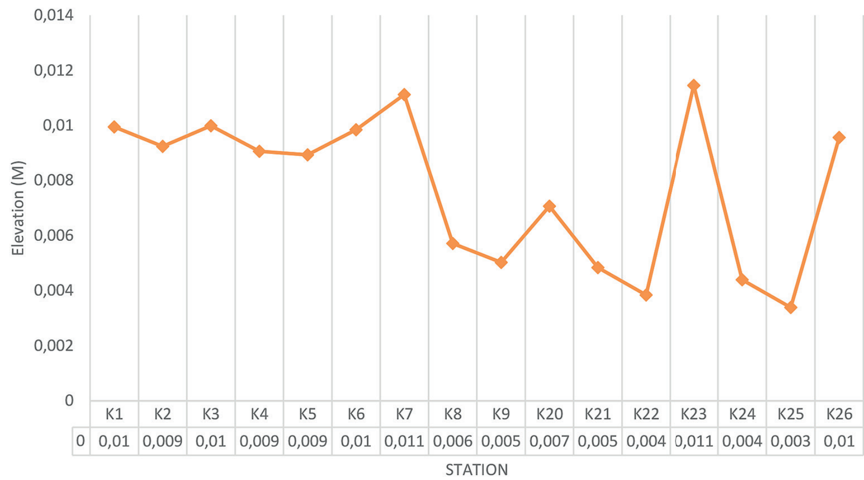

Figure 6. Diagram showing the elevation difference of the vertical network of Al-Kut barrage from the period 2014 to 2021

well as through simple differences, that there is a slight deformation in the structure of the barrage that falls within the permissible limits. The presence of some cracks in the walls of the navigational passage and the fish corridor, and arcs of the barrage body require intervention to treat it and reduce its damage. And by studying the results of the annual and monthly discharge rates for a number of years to observe the extent of the impact of the run-off rates on increasing sedimentation at the upstream of Al-Kut barrage (Table 3 and 4), and consequently noting the extent to which it affects the efficiency of the barrage. It was noticed that the monthly discharge rate increased during the year 2018, as it is considered a humid watery year, in which the total discharge was recorded 4604 m^3/s, and it was the lowest rate recorded in the year 2010, and the total decreased and the discharge reached 3621 m^3/s. As the monthly water revenue rate reached its highest level for the year 2018 during the month of December, at a rate of 12.1 m^3/s. While the annual revenue was also recorded at the highest rate during the wet year 2018, which recorded an average of 12.6 m^3/s. The lowest annual revenue recorded during the year 2010 which amounted to 9.5 m^3/s. Where the sediment accumulated in the studied sections increased during 2019 by 26% compared to the volume of the accumulated sediments in the studied sections during 2018. It was found that the suspended sediment load in the Tigris waters increased during 2019 compared to the sediment load during 2018. Finally, the accumulation of sediment affected the left bank of the river on the movements of some gates and put pressure on the other gates, which led to some operational problems at the origin of the barrage (Table 5).

Table 3. Annual water drainage rate for the period from (2009) to (2018) by (m^3/sec)

Water year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Water drainage	313.5	301.8	315.8	308.9	351.4	323.5	314.9	317.3	309.8	382.5

Table 4. Monthly water drainage rate, the average and the annual total of the water for Al-Kut barrage

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Total
2009	321	315	323	345	311	310	276	222	250	322	389	378	9.88	3762
2010	299	342	321	312	311	311	245	213	222	344	378	323	9.5	3621
2011	298	312	378	322	312	322	287	247	246	321	366	378	9.95	3789
2012	315	311	312	321	314	311	278	237	256	311	354	387	9.74	3707
2013	342	349	345	389	376	387	256	289	296	388	399	401	11.1	4217
2014	398	356	312	344	321	345	287	246	233	321	321	398	10.2	3882
2015	322	345	323	324	333	321	288	234	213	342	345	389	9.9	3779
2016	342	321	322	321	318	311	298	233	256	322	365	399	10	3808
2017	276	328	330	337	315	319	223	240	262	318	380	390	9.76	3718
2018	487	478	487	409	400	398	320	299	298	311	321	398	12.1	4606

Table 5. The quantities of accumulated sediments (m^3) of the upstream of Al-Kut barrage

Section	Distance (m)	Area occupied by sediments (m^2)	Average area occupied by sediments (m^2)	Sediment's volume accumulated (m^3)
0+0	50	1516.34		71453
0+50	50	1341.78	1429.06	70522
0+100	50	1479.1	1410.44	68731.5
0+150	50	1270.15	1374.63	109600
0+230	80	1469.85	1370	101943.8
0+300	70	1442.83	1456.34	132396
0+400	100	1205.08	1323.96	112694
0+500	100	1048.8	1126.94	71453
-				Total = 667340.3

CONCLUSIONS

Dams and barrages are among the most important large facilities in the regulation of water and irrigation. Therefore, monitoring with accurate surveying devices, as well as monitoring sedimentation quantities and rates, also knowing the quantities and samples of sediment, lead to an important and effective role in studying the extent of its impact on the work of the barrage, as well as the efficiency of its gates. The monitoring network in Al-Kut barrage consists of two horizontal and vertical networks. Both networks consist of a set of stations that are monitored at different intervals to monitor the deformation and evaluate the effect of the deformation on the efficiency of Al-Kut barrage if an intervention is needed to maintain any deviation in the observations. It also determines the extent of the damage to the dam body and then conducts an assessment of the integrity of the barrage infrastructure. It was noticed by analyzing the surveying data that there is a slight deformation in the barrage structure with some cracks in the walls of the navigational passage, the fish passage, and in some arcs of the barrage's body, which requires intervention to treat it and reduce its damage in the future, as it was noted through the data of run-off rates, the increase in sedimentation at the upstream of Al-Kut barrage, and consequently noting the extent to which it affects the efficiency of the barrage. It was noticed that the monthly discharge rate increased during the year 2018, as it is considered a humid watery year, in which the total discharge was recorded 4604 m^3/s, and it was the lowest rate recorded in the year 2010, and the total decreased and the discharge reached 3621 m^3/s. Where the sediment accumulated in the studied sections increased during 2019 by 26% compared to the volume of the accumulated sediments in the studied sections during 2018. Finally, the accumulation of sediment affected the left bank of the river on the movements of some gates and put pressure on the other gates, which led to some operational problems at the origin of the barrage.

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