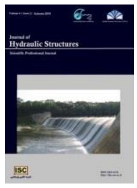
Journal of Hydraulic Structures
J. Hydraul. Struct., 2024; 10(1): 72-81
DOI: 10.22055/jhs.2024.19074



OPEN ACCESS

# Investigating sediment changes during dry and wet periods at both upstream and downstream stations of the Karkheh Dam

Somayeh Rezaeimanesh [1]
Sara Parvizi [1]
Ali Talebi [*1]

## Abstract

Estimating sediment yield accurately in watershed areas is always a concern for planners. A noteworthy aspect in this regard is the variation in river behavior within watershed areas during dry and wet periods. The objective of this study is to investigate sediment variations during dry and wet periods at both upstream and downstream stations of the Karkheh Dam. To achieve this, flow and sediment statistics from the Afrineh-Kashkan station upstream of the dam and the Pay-Pol station downstream, spanning a 38-year period (1350-1398), were utilized. For this purpose, dry and wet periods were initially identified, and for each, sediment rating curve was plotted. To enhance the sediment rating curve relationship, corrective factors including FAO, QMLE and Smearing were employed. Performance evaluation of each was conducted using indicators such as RMSE, ME and P. The results of the sediment analysis at each station during dry and wet periods indicate that the specific sediment yield has decreased during dry periods and experienced a significant increase during wet periods. Moreover, the specific sediment yield at the downstream station (Pay-Pol) of the Karkheh Dam has also shown a considerable reduction, indicating the dam's impact on sediment regulation downstream.

**Keywords:** Dry, Wetness, Sediment Rating Curve, Flow Discharge, Sediment Load.

Received: 09 November 2023; Accepted: 16 April 2024

## 1. Introduction

Information on the precise mechanisms of erosion, sediment transport, and sedimentation processes in the country is significantly less than the existing needs, and in many cases, substantial discrepancies are observed between measurements and conducted estimates. Rivers are constantly confronted with erosion and sediment transport phenomena. Therefore, estimating sedimentation amounts is of paramount importance in soil conservation projects, watershed management, and the utilization of water resources [1]. Suspended sediment load is an indicator of total watershed sedimentation, and assessments of sediment production in watershed areas often rely on scattered,

[1] Department of Rangeland and Watershed Management, Faculty of Natural Resources , Yazd University, Yazd, Iran.
[*] Email: talebisf@yazd.ac.ir **(Corresponding Author)**



CC BY

limited, and irregular sampling of riverbed suspended sediments [2]. In the absence of actual sediment measurements, hydrologists use sediment rating curves to determine suspended sediment concentration, and the most common method for estimating sediment load involves using data on suspended sediment concentration and flow rate data [3]. Determining the effects of dry or wet periods in a region is a fundamental requirement for environmental and economic planning, especially in resource management, particularly water resources. Sediment load in watersheds is influenced by various factors such as precipitation, topography, geology, vegetation cover, land use and soil erodibility characteristics. Therefore, all these factors must be taken into account for calculating sediment load [4].

The majority of sediment transported by most rivers constitutes suspended load. Accurate recognition of its quantity, especially during periods of dry and wet, is crucial. Ghaffari and colleagues investigated the impact of dry and wet periods on the specific sediment yield in the Karkheh watershed. The results indicated a notable decrease in sediment load during dry periods and a significant increase during wet periods at all study stations [5]. In a study, Nazari Samani and colleagues [6] investigated the general impact of land use changes and precipitation variations on sediment production in the Taleghan watershed. The results indicated a significant increase in suspended sediment load during wet periods and a meaningful decrease during dry periods [6]. Garbrecht examined the impact of climate change on erosion and sedimentation, finding that increased precipitation led to an elevation in suspended sediment load, while decreased precipitation resulted in a reduction in suspended sediment load in the watershed area in western Oklahoma [7].The United States Soil Conservation Service also concluded, through a study on the relationship between climate change and soil erosion, that soil erosion is expected to increase in the future due to the rise in runoff [8].

Talebi et. al [9] focused on determining the optimal sediment rating curve equation and its correlation with physical characteristics in the semi-arid regions of the Pol-Doab watershed. They concluded that the MVUE correction factor in the sediment rating curve at the intermediate range can be utilized for annual-scale sediment yield prediction. Additionally, the FAO correction factor provides a more accurate estimation of sediment yield at monthly, weekly, and daily scales [9]. Talebi et al [10] undertook the examination of the most suitable sediment rating curve equation for dry climates (southwest Iran) and humid climates (north Iran). The research results demonstrated the appropriateness of the intermediate range method for stations in dry and semi-arid regions, as well as stations in humid and semi-humid areas. Moreover, the best correction factor for both dry and semi-arid, and humid and semi-humid stations was found to be MVUE [10].

Finally, the purpose of this research is to investigate sediment changes during dry and wet periods at upstream and downstream stations of the Karkheh dam over a 38-year period. This is done to determine the dam's impact on the concentration of riverine sediments.

## 2. Materials and methods

### 2.1. Study area

The Karkheh Watershed, covering an area of approximately 50.768 square kilometers, is situated between 46 degrees 57 minutes to 49 degrees 10 minutes east longitude and 31 degrees 48 minutes to 34 degrees 58 minutes north latitude. This watershed consists of five sub-basins: Gamasiab, Qarasu, Symareh, Kashkan and Karkheh down. The average annual precipitation in the watershed is 492 millimeters. From a climatic perspective, the Karkheh Watershed belongs to the Mediterranean climate [5]. For conducting this study, hydro-meteorological stations within the watershed were considered, and stations located upstream of the Karkheh Dam (Afrineh-Kashkan) and downstream of the dam (Pay-Pol) were chosen as the study stations. Their specifications are provided in Table 1, and Figure 1 depicts the geographical locations of the Karkheh watershed and the selected stations.

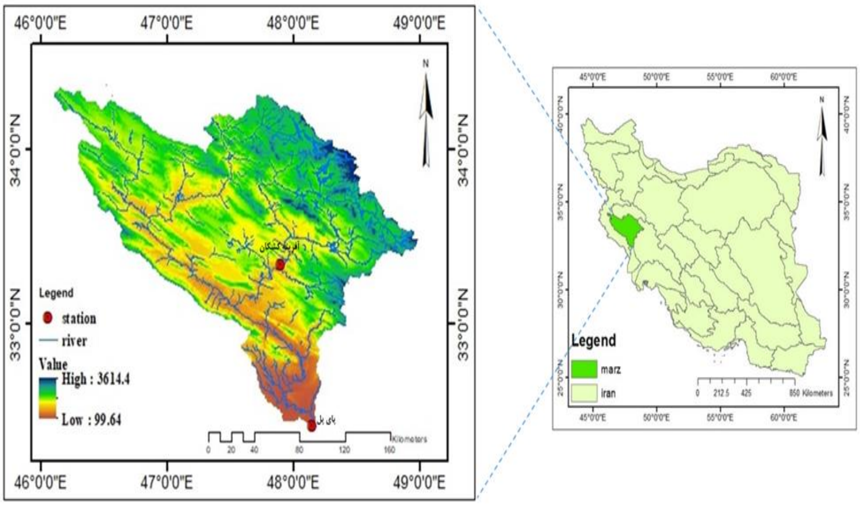



**Figure 1. Geographical location of the study area**

**Table 1. Geographical characteristics of the studied stations**

| Station name | The area of the field) (Km$^2$ | Geographical attributes | | |
|---|---|---|---|---|
| | | Longitude | latitude | Height (m) |
| Afrineh-Kashkan (upstream of the dam) | 3670 | 47-53 | 33-20 | 820 |
| Pay-Pol (downstream of the dam) | 42620 | 48-09 | 32-25 | 90 |

## 2.2. Methodology

In this research, a 38-year statistical period (1350-1398) was utilized. Initially, using Dubai's existing statistics, dry and wet years were identified separately. Subsequently, based on Dubai's data and suspended sediment obtained from the upstream station (Afrineh-Kashkan station) and the downstream station (Pay-Pol station) in the Karkheh watershed, sediment rating curves were plotted for each period of dry and wetness on a logarithmic scale. Finally, an examination of sediment changes during dry and wet periods at the upstream and downstream stations of the Karkheh Dam was conducted.

## 2.3. Determining dryness and wetness

In the present study, Dubai's statistics and sediment data from Afrineh-Kashkan and Pai-Pal stations in the Karkheh River were utilized over a 38-year statistical period (1350-1398). Equation (1) was employed to identify wet and dry periods.

$$\frac{Qi - Qm}{S} \qquad (1)$$

In equation (1), Qi represents the average discharge in each year, Qm is the mean discharge, and S is the standard deviation of the total annual discharge. Years with an index value greater than 0.5 are considered wet years, and those with values less than 0.5 are considered dry years [11].

## 2.4. Sediment Rating curve

In many cases, experts use sediment rating curve models for predicting and estimating suspended sediment concentration in the absence of actual sediment data [12]. To construct the sediment rating curve, the approach of the U.S. Bureau of Reclamation (USBR) is employed. In this method, by simultaneously plotting flow discharge and the corresponding concentration of suspended sediment on a logarithmic coordinate graph and fitting the best line through the data, the exponential equation of the curve is obtained as follows.

$$Q_S = a\, Q_W^{\,b} \tag{2}$$

In equation (2), Qs represents sediment concentration in milligrams per liter, Qw is the discharge in cubic meters per second, and a and b are the constant coefficients of the equation.

In this regard, due to skewness, it has often failed to accurately represent sediment concentration at different flow rates [13]. Skewness has led to the residuals (the difference between observed and calculated values) not following a normal distribution, and its value becoming greater than zero [14]. The skewness of the sediment rating curve arises from two factors. The first factor is due to the transformation of the equation from a logarithmic to a natural form in the linear regression model, essentially related to the nature of the rating curve. The second factor results from extrapolation for estimating sediment in high flow discharges [13], which is associated with the quantity and quality of the data, leading to a significant error in sediment estimation. Various methods have been proposed to reduce skewness and increase accuracy in extrapolating the sediment rating curve.

In order to achieve unbiased estimates with minimum error, various researchers have proposed several statistical correction factors (FAO, Smearing, QMLE and β) that affect the sediment rating curve equation [2]. These factors are calculated as follows.

$$a = \frac{\overline{Q_s}}{\overline{Q}_w^{\,b}} \tag{3}$$

In equation (3), $\bar{Q}$s represents the observed average sediment concentration in milligrams per liter or ton per day, $\bar{Q}$w is the observed average flow discharge in cubic meters per second, a is the FAO correction factor, and b is the same coefficient as in the USBR equation [9].

$$CF_{Smearing} \frac{1}{n} \sum_{i=1}^{n} 10^{\varepsilon i} \tag{4}$$

$$\varepsilon_i = \log(C_o) - \log(C_e) \tag{5}$$

In equation (4), n represents the number of observational samples, ε^i is the residual of the least squares regression model, CO is the observed sediment concentration in milligrams per liter or ton per day, and Ce is the estimated sediment concentration in milligrams per liter or ton per day [9].

$$CF_{QMLE} = e^{(2{,}561 S^2)} \quad (6)$$

$$S^2 = \frac{\sum_{i=1}^{n}(\log C_o - \log C_e)}{(n-2)} \quad (7)$$

In equations (6) and (7), (e) is the exponential function equal to 2.718, \($S^2$) is the standard error, (n) is the number of observational samples, (ε^i) is the residual of the least squares regression model, (CO) is the observed sediment concentration in milligrams per liter or ton per day, and (Ce) is the estimated sediment concentration in milligrams per liter or ton per day [9].

$$CF_\beta = 1 + \beta \quad (8)$$

$$\beta = \frac{\sum_{i=1}^{n}(\varepsilon_i)}{\sum_{i=1}^{n} \alpha {Q_w}^b} \quad (9)$$

In equations (8) and (9), ε^i represents the residual of the least squares regression model. (b) and (a) are the coefficients of the USBR equation, and (Qw) denotes the mean flow rate of observed samples in cubic meters per second [9].

After obtaining the sediment index equations using the provided correction factors, performance evaluation and determination of the optimal equation are carried out in this study using indicators such as Root Mean Square Error (RMSE), Maximum Error (ME), and Accuracy Index [15]. These indices are calculated as follows:

$$RMSE = \left[\frac{\sum_{i=1}^{n}(SSC_o - SSC_e)^2}{N}\right]^{1,2} \quad (10)$$

In equation (10), (SSCo) represents the observed sediment concentration in milligrams per liter or ton per day, (SSCe) is the estimated sediment concentration in milligrams per liter or ton per day, and (N) is the number of observed samples. A smaller value for this coefficient indicates less difference between observed and estimated data, resulting in higher predictive accuracy of the relationship [9].

$$ME = 1 - \left[\frac{\sum_{i=1}^{n}(SSC_o - SSC_e)^2}{\sum_{i=1}^{n}(SSC_o - SSC_m)^2}\right] \quad (11)$$

In equation (11), (SSCo) represents the observed sediment concentration in milligrams per liter or ton per day, (SSCe) is the estimated sediment concentration in milligrams per liter or ton per day, (SSCm) is the average observed sediment concentration in milligrams per liter or ton per day, and (ME) ranges from negative infinity to one, with higher values indicating greater accuracy in estimation [9].

$$P = \left[\sum_{i=1}^{n} \frac{SSCe}{SSCo}\right] \Big/ N \quad (12)$$

In equation (12), (SSCo) represents the observed sediment concentration in milligrams per liter or ton per day, (SSCe) is the estimated sediment concentration in milligrams per liter or ton per day, (SSCm) is the average observed sediment concentration in milligrams per liter or ton per day, and ( ME ) ranges from negative infinity to one, with higher values indicating greater accuracy in estimation [9].


CC BY

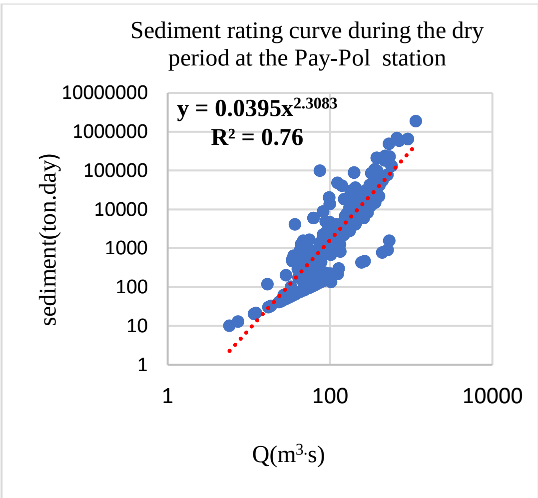
## 3. Results and Discussion

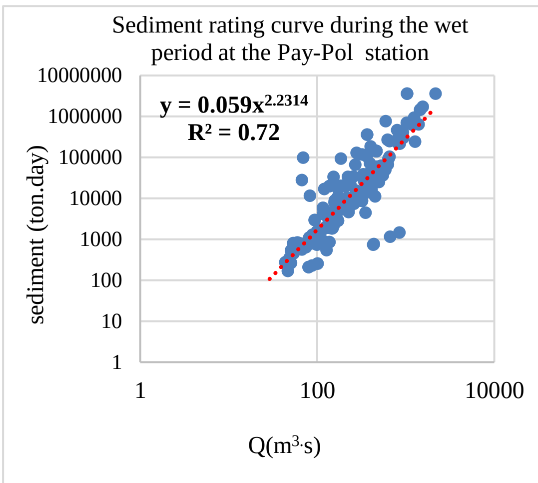
Based on the discharge data of the 38-year period of dry years, wet periods were determined separately. In the next step, based on the discharge and suspended sediment data collected at the upstream station (Afrineh-Kashkan) and the downstream station (Pay-Pol) located in the Karkheh watershed, for each of the statistical periods of dry and wet periods, separate the sediment Rating curve of the basin in a plane with coordinates Alogarithm was drawn. The equation of the initial sediment measurement of each station in the period of dry and dry can be seen in Table (2). Figure 2 shows the graphs of sediment Rating curves in the studied stations of Karkheh basin in dry and wet periods.

**Table 2. Equations of primary sediment Rating of each station in dry and wet periods**

| Station name | dry periods | | wet periods | |
|---|---|---|---|---|
| | Rating equation | $R^2$ | Rating equation | $R^2$ |
| Afrineh-Kashkan (upstream of the dam) | $Q_S=0.4201Q_W^{2.1015}$ | 0.76 | $Q_S=0.202Q_W^{2.2886}$ | 0.78 |
| Pay-Pol (downstream of the dam) | $Q_S=0.0395Q_W^{2.3083}$ | 0.76 | $Q_S=0.059Q_W^{2.2314}$ | 0.72 |

After plotting the sediment rating curve for each station, factors such as FAO, QMLE, and Smearing were employed to enhance the curve's relationship. For evaluating the performance and determining optimal equations in both wet and dry periods, metrics including root mean square error (RMSE), maximum error (ME), and accuracy index (P) were utilized. The closer the value of P and ME is to 1 and the value of RMSE is to zero, the more accurate the model is [9]. To select the optimal equation for each station, the ranking of the evaluation index values has been used. In this way, the closest value of P and ME index to 1 and the closest value of RMSE index to zero at the station in question, which represents the smallest difference between estimated and observed sediment values, was assigned the rank of 1. The next values of the indicators in the desired station were also ranked accordingly. Then, the ranked values of the columns were compared and the optimal equation was selected based on the column with the lowest ranked values. Tables 3 and 4 show the results of the values of the evaluation indices of each of these equations and the results related to the ranking of the values of the evaluation indices.



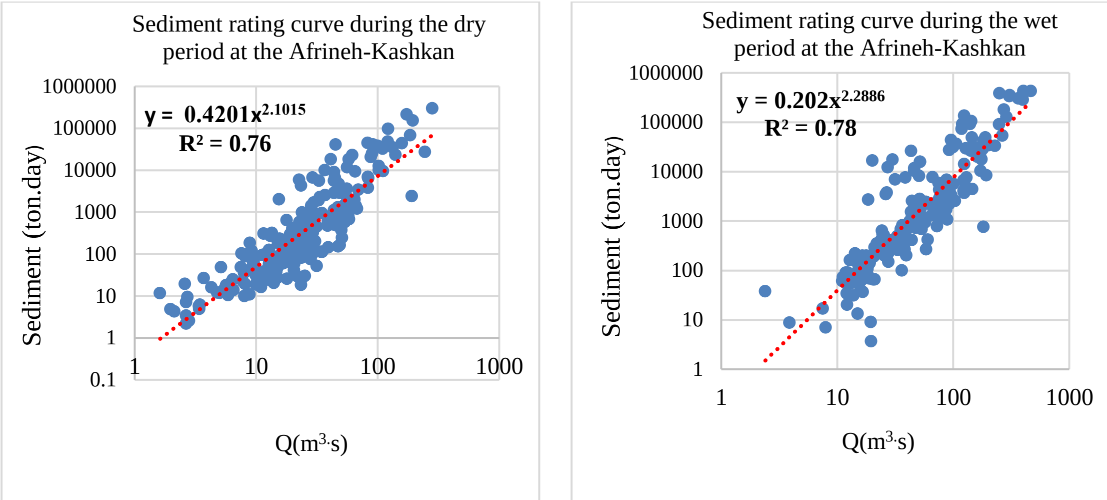



**Figure 2. Graphs of sediment rating curves in the studied stations of Karkheh watershed in dry and wet periods.**

**Table 3. Evaluation indicators of the accuracy of the sediment Rating curve using the correction factors of Afrineh-Kashkan station**

| Index evaiution | | No coefficients | FAO | QMLE | Smearing |
|---|---|---|---|---|---|
| dry periods | RMSE | 13135.396 | 10835.02 | 12571.33 | 10756.64 |
| | ME | 0.07725 | 0.4825 | 0.154 | 0.260 |
| | P | 1.665 | 23.74 | 3.15 | 5.46 |
| | Total rating | 9 | 7 | 8 | 6 |
| wet periods | RMSE | 122378.8 | 634355.78 | 81757.55 | 88257.85 |
| | ME | 0.410 | -14.83 | 0.737 | 0.693 |
| | P | 2.10 | 36.52 | 4.32 | 3.93 |
| | Total rating | 7 | 12 | 5 | 6 |

**Table 4. Evaluation indicators of the accuracy of the sediment Rating curve using the correction factors of Pay-Pol station**

| Index evaiution | | No coefficients | FAO | QMLE | Smearing |
|---|---|---|---|---|---|
| dry periods | RMSE | 47311.86 | 69018.902 | 33931.26 | 40027.67 |
| | ME | 0.3611 | -0.36 | 0.671 | 0.542 |
| | P | 2.56 | 23.22 | 5.529 | 4.134 |
| | Total rating | 7 | 12 | 5 | 6 |
| wet periods | RMSE | 887615.56 | 3695396.61 | 711471.84 | 766246.94 |
| | ME | 0.295 | -11.212 | 0.547 | 0.4749 |
| | P | 2.5895 | 61.196 | 5.0913 | 4.3012 |
| | Total rating | 7 | 12 | 5 | 6 |

Given the results of Tables 3 and 4 during the dry period, the optimal equations for the Afrineh-Kashkan and Pay-Pol stations, respectively, are obtained using the smearing correction factor (Equation 13) and the QMLE correction factor (Equation 14). During the wet period, the equation obtained using the QMLE correction factor (Equations 15 and 16) was selected as the optimal equation for the Afrineh-Kashkan and Pay-Pol stations

$$Q_S=1.38Q_W^{2.1015} \quad (13)$$
$$Q_S=0.085Q_W^{2.3083} \quad (14)$$
$$Q_S=0.4141Q_W^{2.2886} \quad (15)$$
$$Q_S=0.116Q_W^{2.2314} \quad (16)$$

Continuing with the utilization of the obtained equations and substituting the daily discharge, the total sediment yield for each station is determined in tons per day. By dividing the average sediment load per unit area of the study basin for each station, the specific sediment yield is obtained in tons per year per square kilometer. The examination of the specific sediment yield at Afrineh-Kashkan station (upstream) and Pay-Pol station (downstream) during dry and wet periods indicates that the specific sediment yield has decreased in dry periods and experienced a significant increase in wet periods. Figure 3 illustrates the trends of sediment changes during both dry and wet periods for both Afrineh-Kashkan and Pay-Pol stations. As can be seen, in dry periods the rate of sediment is subtractive while in wet period, sediment is additive.

Additionally, the specific sediment yield at the downstream of the dam station (Pay-Pol station) has also shown a considerable decrease in both dry and wet periods. Figure 4 depicts the trends of sediment changes at Afrineh-Kashkan and Pay-Pol stations. Table 5 presents the average sediment load and specific sediment yield values for each station during dry periods.

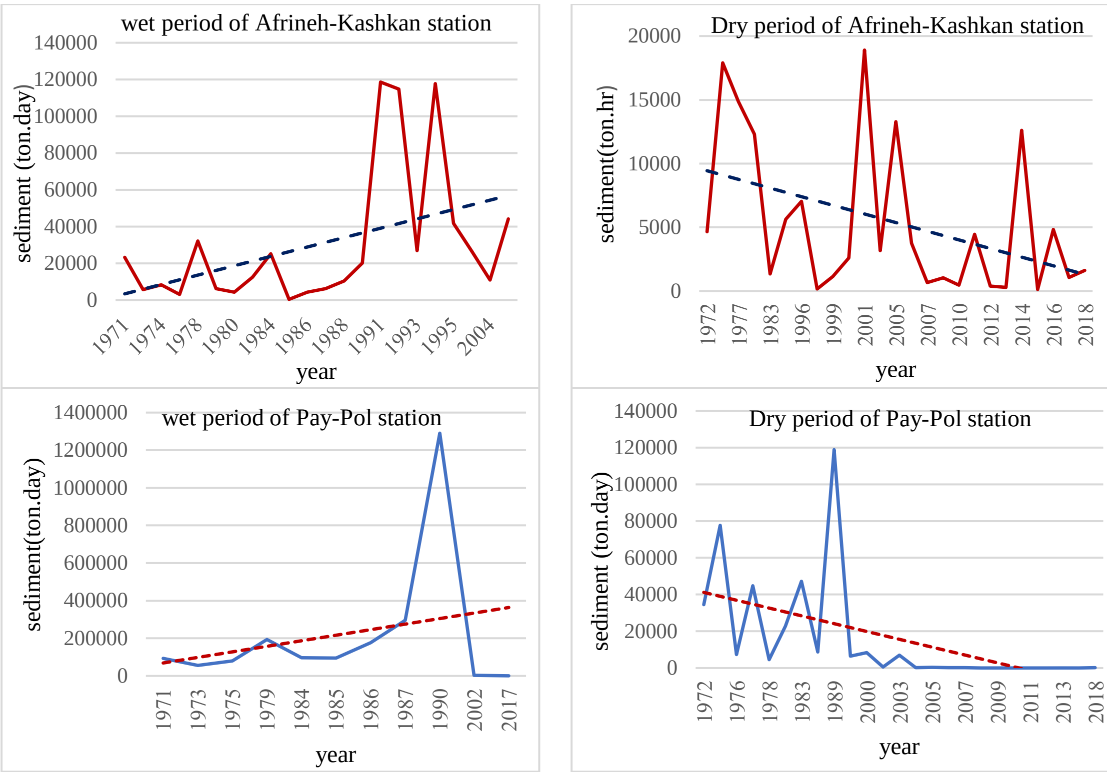



**Figure 3. The trend of sediment changes during dry and wet periods at the Afrineh-Kashkan and Pay-Pol stations**

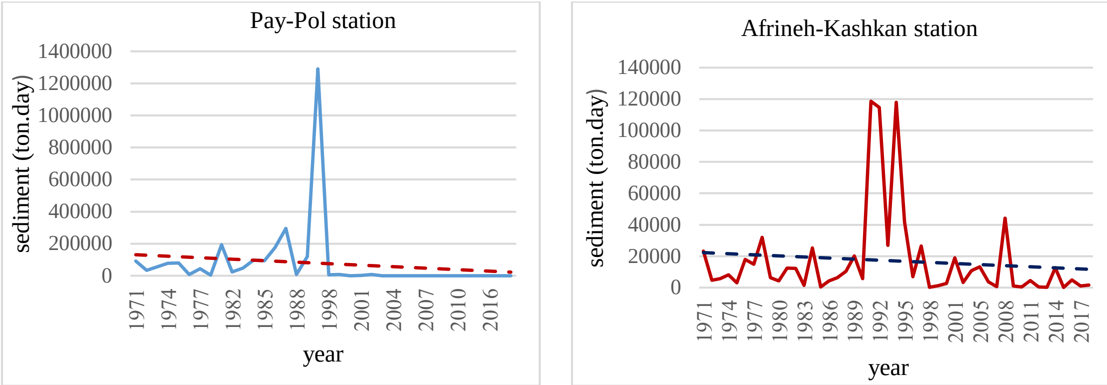



**Figure 4. The trend of sediment changes at the Afrineh-Kashkan station (upstream) and the Pay-Pol station (downstream)**

**Table 5. Average Sediment Load and Specific Sediment Yield for Each Station During Dry and Wet Periods**

| Station name | Area ($Km^2$) | dry periods: Average sediment load (ton.y) | dry periods: Special sediment ($ton.y.km^2$) | wet periods: Average sediment load(ton.y) | wet periods: Special sediment ($ton.y.km^2$) |
|---|---|---|---|---|---|
| Afrineh-Kashkan (upstream of the dam) | 3670 | 4838.169 | 1.31 | 24124.24 | 6.57 |
| Pay-Pol (downstream of the dam) | 42620 | 20382.01 | 0.47 | 11850.5 | 2.78 |

As can be seen in Table 5, the presence of a dam in both wet and dry periods, leads to the regulation and reduction of sedimentation.

## 4. Conclusion

The current study focuses on investigating sediment changes during dry and wet periods at the upstream and downstream stations of the Karkheh Dam, utilizing sediment rating curves. Using discharge and sediment data and employing the mentioned methods, optimal sediment rating curve equations were determined for dry and wet periods at both the upstream and downstream stations of the Karkheh Dam. The results indicate that during the dry period, the Afrineh-Kashkan station exhibited a Smearing correction factor, while the Pay-Pol station showed a QMLE correction factor. In the wet period, both the Afrineh-Kashkan and Pay-Pol stations displayed a QMLE correction factor, demonstrating greater accuracy compared to other coefficients.

The notable increase in specific sediment yield during the wet period can be attributed to the rise in precipitation during wetter periods and the subsequent increase in runoff. Additionally, the intensification of destructive floods enhances the capacity for erosion and sediment transport. The volume of sediment transported into rivers is higher during wet periods compared to dry periods. These results coincide with the results of Ghafari et al. [5], Garbrecht [7], American Soil Conservation Service [8], Nazari Samani et al. [6] in relation to the increase in the amount of sediment load, it corresponds to the increase in the amount of precipitation. Furthermore, the


CC BY

results indicate a significant decrease in specific sediment yield at the downstream of the dam station (Pay-Pol station) during both dry and wet periods. This highlights the role of the dam in mitigating sediment transport.

## References


1. Sadeghi, S.H.R., Mizuyama, T., Miyata, S., Gomi, T., Kosugi, K., Fukushima, T., Mizugaki, S. & Onda, Y. (2008). Development, evaluation and interpretation of sediment rating curves for a Japanese small mountainous reforested watershed. Geoderma, 198-211**.**
2. Kao, Sh., Lee. T., & Milliman, J.D.(2005). Calculating highly fluctuated suspended sediment fluxes from mountainous rivers in Taiwan. Terrestrial Atmospheric and Oceanic Sciences, (16) 3, 653-675.
3. Horowitz, A. J. (2003). An evaluation of sediment rating curves for estimating suspended sediment concentrations for subsequent flux calculations. Hydrological Processes. 17(17), 3387–3409.
4. Thampson, S, A. (1999). Hydrology for water management, Balkema, Rotterdam.
5. Ghafari, G., & Mahdavi, M. (2013). The effect of periods of dry and dry on the amount of specific sediment (case study: Karkheh watershed). Iranian Journal of Watershed Management Science and Engineering, 8(27), 49. (In Persian)
6. Nazari Samani, A., Hervey, H., Panahi, M., & Jafari Shalmazari, M. (2012). The effect of land use change and precipitation on the sediments of Taleghan basin. Rangeland and watershed management journal. 165-157. (In Persian)
7. Garbrecht, J. (2010). Climate variations, soil conservation, and reservoir sedimentation, Federal Interagency Conference, In 2nd Joint Federal Interagency Conference, Las Vegas.
8. Benjamin, H. (2008). Draft National Water Program Strategy: Response to Climate Change Request for Comments, United States environmental protection agency, Washington, D. C.20460.
9. Talebi, A., Bahrami, A., Mardian, M., & Mahjoobi, J. (2015). Determination of optimized sediment rating equation and its relationship with physical characteristics of watershed in semi-arid regions. Desert, 20(2): 135-144.
10. Talebi, A., & Pourmohammadi, S. (2015). Investigating the most appropriate sediment measurement equation in dry (southwestern Iran) and humid (northern Iran) climates. Geographical Research, 31 (1) :118-128 (In Persian)
11. Mahmoudian Shushtari, M., & Ranginkaman, M. (2009). Investigation and comparison of different methods of preparation of sediment Rating curve based on water regime in Dez River (Tale Zang station), 8$^{th}$ International Seminar on River Engineering. Ahvaz, Iran. (In Persian)
12. Masfaei, J., Pourjam, A., & Tabatabai, M. (2016). Comparing the efficiency of sediment Rating model and neural network in river bed load estimation. Geography and Sustainability of Environment, 33-44. (In Persian)
13. Verwani, J., Najafinejad, A., & Mirmoini Kohrorudi, A. (2008). Modification of sediment Rating curve using minimum variance method, Journal of Agricultural Sciences and Natural Resources.


© 2024 by the authors. Licensee SCU, Ahvaz, Iran. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution 4.0 International (CC BY 4.0 license) (http://creativecommons.org/licenses/by/4.0/).