

Chapter 15

Integrated Study of Flash Floods in Wadi Basins Considering Sedimentation and Climate Change: An International Collaboration Project



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Abstract Recently, Wadi flash floods (WFFs) have happened frequently in arid environments, resulting in great damage the society and the environment. In Oman, severe WFFs have occurred repeatedly within the last 10 years causing a huge impact on human lives and properties. This paper aims at introducing the framework of an international collaboration project between Japan and Oman for WFF management considering sediment dynamics and climate changes. Four research groups were established: climate change (G1), rainfall-runoff modeling (G2), sediment yield and transport (G3), and sedimentation and infiltration processes (G4). Several field investigations were conducted since 2017 until now. The detailed field survey to assess the deposited sediment in a dry reservoir by using sediment bars, and infiltration test, as well as drone survey were addressed. Some of the prelim-

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inary results and findings from the field investigation is discussed. The results show there is an adverse impact of sedimentation clogging on the infiltration process at the reservoirs. Based on the historical rainfall data analysis, there is a systematic increasing trend of the annual average precipitation with remarkable cycles over the MENA region and Oman. The knowledge obtained from this project is expected to be valuable to understanding sediment dynamics at Wadi basins.

Keywords Collaboration project • Wadi flash floods • Sedimentation • Climate change • Arid regions

15.1 Introduction

Information about hydrological processes in arid regions is scarce—although the associated problems are severe, particularly the management of water resources and soil erosion (Reid and Frostick 1987). Sediment yield data from a humid and a semiarid region was compared (Wolman and Miller 1960), and the conclusion of the study was the greatest part of the sediment removed from both drainage basins was carried by small to moderate flows with a recurrence interval of fewer than five years. This shows a large proportion of sediment yield and the erosion caused by an extremely short-lasting storm is a substantive property of rivers in arid and semiarid regions (Walling and Kleo 1979). Yet there has been surprisingly little attention paid to sedimentation assessments and impacts associated with flash floods in arid regions, especially in the Arab regions with hyperaridic conditions. Several studies have highlighted the importance of sediment monitoring during flash floods to operate and take countermeasures in recharge dams, but the sediment observations have not been recorded and documented adequately (Reid and Frostick 1987). Monitoring the sediments coming from upstream reaches in Wadi basins during the flash floods is extremely difficult in arid regions for two main reasons, the difficulty to access Wadi stream during the floods, and the missing of monitoring tools for sediment transport in most Wadi systems. A large quantity of sediments usually comes with the flash floods and is controlled by several factors such as geological and topographical features of the basins, the land uses and soil type variability, and the intensity and frequency of extreme rainfall, as well as the human impact. Therefore, to assess the sedimentation for any river basin regardless of the climatic conditions, such factors should be investigated to understand the interrelation with sediment yield.

Most of the arid and semiarid regions suffer from several challenges including (a) limited hydrological models due to the lack of monitoring networks, (b) a shortage of water resources—the available surface water is limited due to the paucity and high variability of rainfall events, and subsurface water is very important but suffers from quality problems and depletion due to mismanagement, and (c) the disaster of Wadi flash floods (WFFs) or drought conditions (Saber and Habib 2016). These problems are accompanied by practical difficulties involving

water resources management, planning, and development in arid areas. Several studies and efforts have been performed in WFF modeling to understand behaviors and characteristics (Saber 2010; Saber et al. 2013; Abdel-Fattah et al. 2017), mitigation strategies and water management (Sumi et al. 2013; Abdel-Fattah et al. 2015), and evaluation and bias corrections of satellite-based rainfall for flash flood simulations (Saber and Yilmaz 2018), but the assessments of sedimentation impacts associated with extreme events under climate change impacts are still negligible in Wadi basins.

Recently, WFFs have happened frequently and are becoming more devastating in arid regions, especially when considering climate change and sedimentation impacts. Oman has experienced severe flash floods such as (Cyclone Guno, June 2007 and Cyclone Phet, June 2010). Figure 15.1a shows rainfall totals around the Gulf of Oman between May 31 and June 7, 2007 (Cyclone Guno). For instance, the Cyclone Guno ($Q = 900 \text{ m}^3/\text{s}$) caused 50 fatalities and \$3.9 billion worth of economic losses (Al Barwani 2015). Great damage to infrastructures (Fig. 15.1b), housing, and agricultural lands was recorded from Cyclone Guno. The red areas show where rainfall exceeded 200 mm (8 inches). The most recent cyclone that happened from May 25 to May 26, 2018 was named Cyclone Mekunu. It was much more powerful than previously recorded events in Southern Oman, and it extended to the neighboring countries as well. It reached category 3 as reported by the Ministry of Regional Municipalities and Water Resources (MRMWR). The cyclone endured from May 23 to May 27, 2018, with a total rainfall of about 617 mm. The maximum rainfall was of about 505 mm in just two days (May 25 and 26, 2018) as recorded by the rain gauges.

Wadi systems in arid regions (Fig. 15.2a) are not only characterized by extreme disasters (e.g., flash floods, drought) but also a lack of monitoring networks and integrated management strategies for water as well as sediments. Flash floods have become more frequent, especially in connection with extreme events like cyclones (Fig. 15.2b). In Oman, mitigation structures for flood control and groundwater

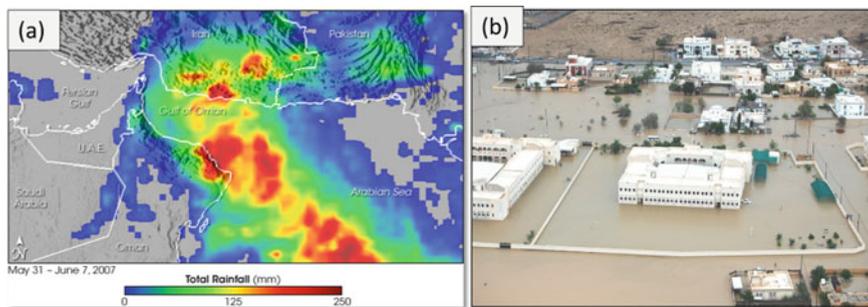


Fig. 15.1 **a** Total rainfall of Cyclone Guno in Oman between May 31 and June 7, 2007 (http://earthobservatory.nasa.gov/NaturalHazards/natural_hazards_v2.php3?img_id=14295). **b** An example of the resulting damage in Muscat City (Al Barwani 2015). *Source* Reprinted from Saber et al. (2018) Copy right 2018

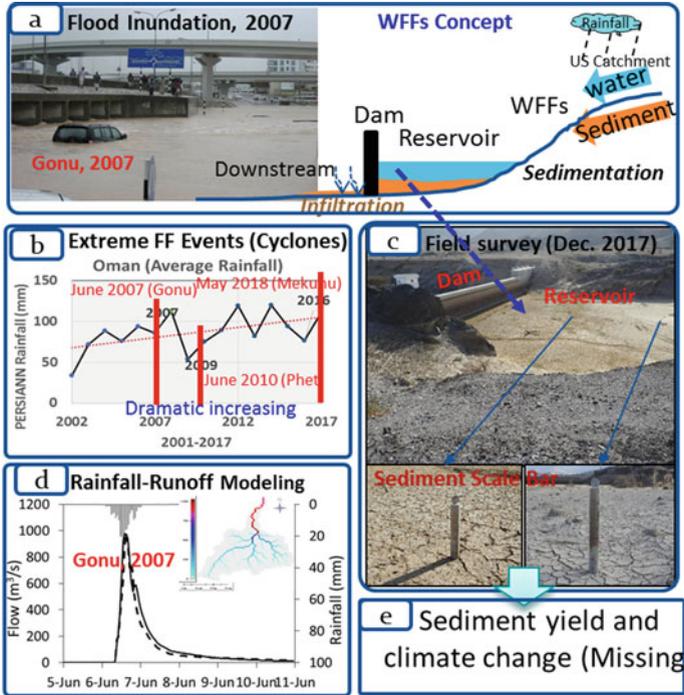


Fig. 15.2 Wadi flash flood concept (a), problematics (b), achievements (c and d), and gaps (e)

recharge have been installed. However, issues of sedimentation were underestimated, leading to environmental problems due to reservoir sedimentation (Fig. 15.2c). This was examined in field investigations in December 2017 and September 2018. Oman is one of the countries that could experience critical sedimentation volumes (Fig. 15.3a) by the year 2050 (ICOLD 2009). The current conditions of sedimentation exhibit real problems at many reservoirs (Fig. 15.3b). In this paper, we present the concept and framework for an international collaborative research project between Japan and Oman. In addition, we refer to efforts done in preparation for the project to prove the feasibility of the implementation and applicability of transferring the technology to developing countries.

Sedimentation is the most serious technical problem in reservoir management, especially in arid regions with increasing extreme flash floods. There are several reasons why sedimentation is so important in Wadi basins:

- The lack of previous studies, especially regarding the impacts on reservoir and infiltration.
- The deterioration of dams’ ability to store water and the influence on their function for flood protection.

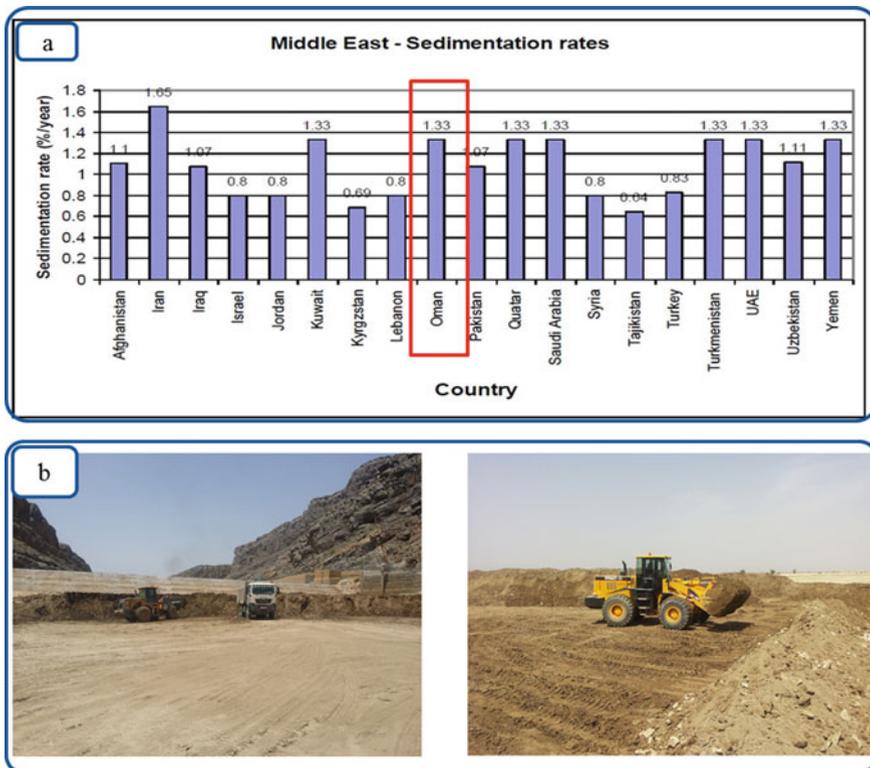


Fig. 15.3 a Actual and predicted sedimentation in the Middle East. *Source* Reprinted from (ICOLD 2009). **b** Reservoir sedimentation at Wadi Tanuf, Nizwa (right photo) and Wadi Al Kabir, Ibri (left photo), Oman

- The decrease of infiltration at the recharge zone at the downstream, consequently affecting the groundwater recharge.
- The increase of probability of the disaster impacts of WFFs.

In dry environments such as Wadi basins, the aforementioned problems are expected to be more serious and destructive than for perennial rivers, particularly with respect to climate change. Therefore, the assessment of the adverse impacts of sedimentation at Wadi basins is desperately crucial to bring forth a secure integrated water and sediment management strategy. The project’s key scientific questions were

- What is the impact of climate change on extreme rainfall events?
- How can sediment yield be predicted based on understanding flash floods’ spatiotemporal variability and sediment dynamics?
- What are the impacts of sedimentation on the infiltration processes?

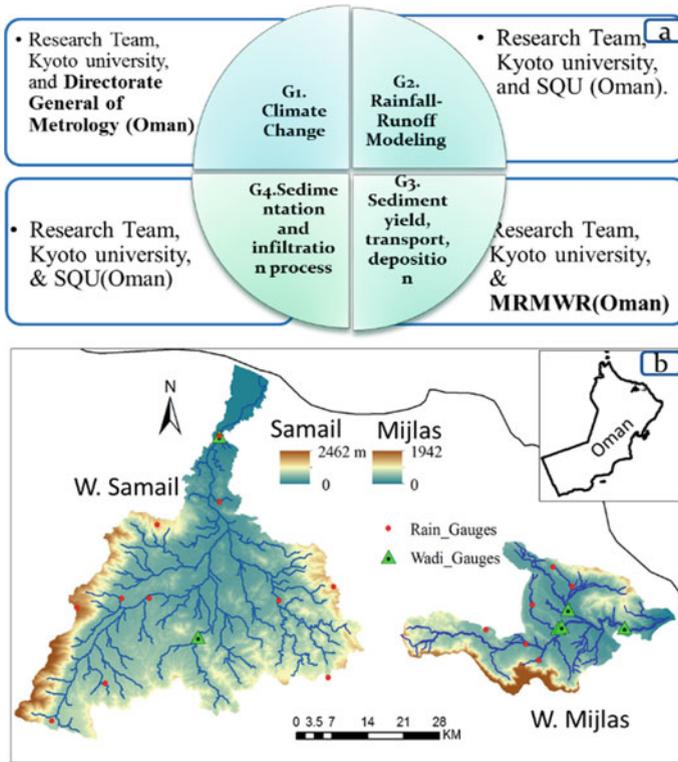


Fig. 15.4 a Research groups and roles in Japan and Oman. **b** Study areas of Wadis Samail and Mijlas in Oman

To address the raised questions and overcome the related problems of WFFs in arid regions, a project was initiated based on the international collaboration between Japan and Oman. The project consisted of four research groups (Fig. 15.4a): climate change (G1), rainfall-runoff modeling (G2), sediment yield and transport (G3), and sedimentation and infiltration processes (G4).

The target Wadi basins for the implementation of the project were Wadi Samail and Mijlas (Fig. 15.4b). The selection criteria included the possibility of monitoring data and the availability of facilities for the field surveys and the conduct of field investigations. Other aspects were (a) the knowledge that Oman is a Middle East leading country in the implementation of a unique flash flood management strategy, (b) the long history of collaboration with Kyoto University, Japan, since 2015, and (c) the expertise of Kyoto University concerning approaches for WFF simulation and sedimentation issues.

The main objectives of this project were to.

- Analyze the extreme rainfall events from historical records and assess the impacts of climate change (G1)

- Combine the developed sediment transport model with the developed hydrological models to simulate water discharge and sediment transport (G2 & G3)
- Assess sedimentation impacts on infiltration process by detailed field surveys (G4)
- Utilize the high-resolution satellite data (Interferometric Synthetic Aperture Radar [InSAR], ALOS Phased Array type L-band Synthetic Aperture Radar [PALSAR], etc.) to assess the sediment deposition, erosion, and sediment yield, and then validate by field investigation (G3 & G4)

15.2 Project Approach: Feasibility, Design, and Implementation

15.2.1 Research Approach and Implementation

The project aimed to develop an integrated concept of combined rainfall-runoff modeling with satellite-based data (InSAR, GSMaP) and field investigations to assess the sediment yield associated with WFF water. There was a special focus on understanding climate change impacts as well as sediment dynamics and its impacts on infiltration. The merit of this research project is unique since it assessed WFFs and sediment dynamics under climate change based on extensive field investigations. We started our collaborative network with Sultan Qaboos University (SQU), the Directorate General of Metrology (DGM), and MRMWR in Oman in 2015 and performed field investigations in 2016, 2017, and 2018 for several Wadis. A detailed presentation of each research group is given below.

15.2.1.1 Climate Change (G1)

The frequency of WFFs has dramatically increased within the last ten years (Saber et al. 2018); this might be as a result of climate change or human impacts. Understanding climate change is desperately needed and should be addressed in WFF studies. We started a rainfall analysis for the extreme events in arid regions (Fig. 15.5a), and the details will be addressed in Sect. 15.4. Analysis of the historical extreme events as well as future events will be conducted to understand the occurrence, rainfall variability, and climate change impacts on both intensity and magnitudes of WFFs. Downscaling and bias corrections of global circulation model outputs using the regional climate model to create different scenarios of climate change will be conducted. This will guide us to answer the question of how and why WFFs are recently becoming more frequent and devastating.

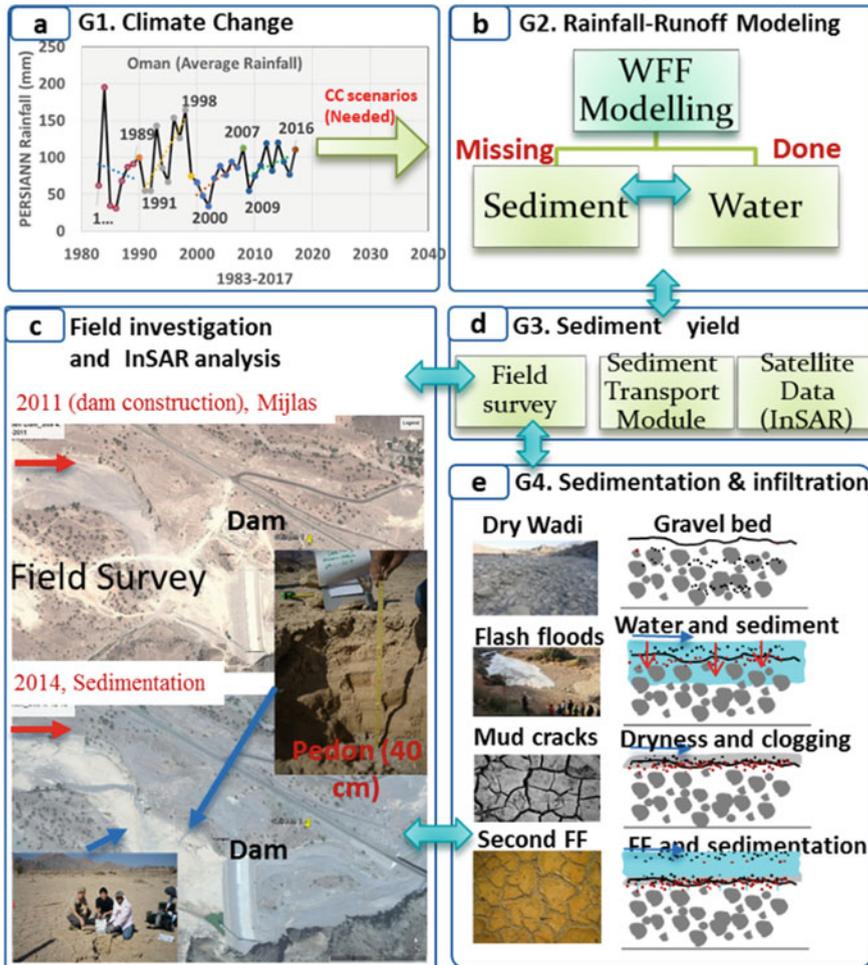


Fig. 15.5 Research plan and methodology

15.2.1.2 Rainfall-Runoff Modeling (G2)

We developed and set up several hydrological and hydrodynamic models for WFFs in different Wadi basins in Oman for instance the Hydrological River Basin Environmental Assessment Model for Wadi systems (Hydro-BEAM-WaS) (Kojiri et al. 2008; Saber et al. 2010a, b, 2013; Sato et al. 2013), a rainfall-runoff model (Sayama et al. 2012; Abdel-Fattah et al. 2018), and TELEMAC-2D (Riadh et al. 2014; Ogiso et al. 2017). The models have not yet been combined with a sediment transport module in arid regions (Fig. 15.5b). A sediment transport model will be

developed (G3) (Fig. 15.5d) and coupled with the hydrological model to simultaneously simulate both sediment and water (G2). Field investigations were conducted by G3 and G4 for validation (Fig. 15.5c–e).

15.2.1.3 Sediment Yield and Transport (G3)

Globally, sedimentation is the most serious technical problem in reservoir management, but in arid regions, the challenge becomes much more serious with increasing extreme flash floods. Two approaches will be used to estimate sediment yields and numerical simulations. The sediment transport module will be implemented to predict the sediment volumes associated with WFFs (linked with G2). The satellite data (InSAR, PALSAR-2) will be utilized to quantify sediment volume and determine the morphological changes along Wadi channels and then validated by field investigations (G3 & G4) (Fig. 15.5d, e). The researchers in SQU and MRMWR have already conducted several studies for sedimentation and pedon analysis (Al-Maktoumi et al. 2014, 2015).

15.2.1.4 Sedimentation and Infiltration Processes (G4)

We will assess the influence of sedimentation on infiltration processes in the selected Wadi basins (sediment clogging in Fig. 15.5e). This group will focus on conducting field surveys to investigate the sedimentation at Wadi basins (Fig. 15.5c). A disk infiltrometer will be used to measure the impacts of sedimentation clogging on the infiltration rates at the reservoirs. This will help in understanding the adverse impacts on groundwater recharge and trapping efficiency of dams.

15.2.2 Project Potentiality and Feasibility

Oman is a Middle East leading country in the implementation of a unique flash flood management strategy. Japan is also a world leader in the field of sediment management techniques on the river basin scale. Therefore, transferring such technologies to developing countries is crucial. The project was initiated based on the long history of activities such as meetings, conferences, and detailed research among the counterparts. There are, however, several factors controlling the applicability of the project and implementation. The Kyoto University team started a collaboration with the Arab countries (e.g., Egypt, Oman) in 2009 with establishing the Japan–Egypt Hydro Network (Sumi et al. 2013). Then, several field surveys were conducted for the target Wadis (Samail & Mijlas) in 2010, 2014, 2016, 2017, 2018 to better understand Wadi characteristics (Saber et al. 2018). The Japanese research group modified, calibrated, and validated hydrological models for WFFs.



Fig. 15.6 a The third international symposium on flash floods (ISFF) symposium, GUTech, Oman, showing the research teams from Oman and Japan. **b** The third ISFF outcomes in the news. *Source of (b):* <http://www.omanobserver.om/guidelines-mooted-managing-flash-floods/>

Moreover, the Kyoto University research team initiated a series of conferences titled the International Symposium on Flash Floods in Wadi Systems (ISFF). The first ISFF was organized in Kyoto University (2015), the second ISFF in Egypt (2016), the third ISFF in Oman in 2017 (Fig. 15.6a) (ISFF 2017), and the fourth ISFF in Casablanca, Morocco (2018) (ISFF 2018). The fifth ISFF is scheduled to take place in Kyoto in 2020.

Through discussions at the third ISFF, the Japanese research team and the international counterparts from Oman, Morocco, and the other countries agreed to continue discussions, cooperate to share experiences, and develop outstanding methodologies for sediment yield and sedimentation throughout such international collaboration. These activities were reported by an Omani newspaper (Fig. 15.6b) (<http://www.omanobserver.om/guidelines-mooted-managing-flash-floods/>) and a TV program (<https://youtu.be/GojsIFCBHYM/>) that is widely recognized locally.

The project is expected to enable undergraduate students and young researchers through the efforts of the international collaboration. Students from both Oman and Japan are involved in the project. For instance, there are three master's students from Oman working under the project topics, as well as Japanese students. Based on these factors, the project is expected to be feasible and applicable mainly for hydrological investigations of WFFs to complete the missing gaps related to sedimentation and climate change.

The significance and the expected outcomes of this project are an increased understanding of WFFs spatiotemporal variability with implications of climate change, upgrading current hydrological models to simulate WFF water and sediment, validating high-resolution satellite products for sediment yield assessments, and clarifying the adverse impacts of sedimentation on infiltration processes. Additionally, learning lessons from the international collaboration project is beneficial for further understanding of climate change and drought/flood cycles. Also, since Japan is a world leader in the field of sediment management techniques on the river basin scale, transferring such technologies to developing countries is important. Mutual benefits from learning lessons from Oman and transferring Japanese advanced technologies will be accomplished.

15.3 Field Survey and Preliminary Results

In the ungauged Wadi systems, field surveys were essential for better understanding the real physical conditions of WFF phenomena and, mainly, the sedimentation issues in arid regions. Therefore, two field surveys were conducted for Wadis Mijlas and Samail in Oman in December 2017 and September 2018, respectively, to study sedimentation issues and their impact on reservoir capacity and identify flash flood marks. Several measures have been implemented such as Wadi channel leveling, the use of sedimentation pedons to study the vertical layers of sedimentation at the reservoirs by collecting sediments samples for further laboratory analysis and detecting flash flood marks. Additionally, drone surveys, infiltration tests, and field questionnaires about flash floods were conducted. The sedimentation volume at the reservoir along Wadi Mijlas was estimated from the sedimentation measure bars installed in the reservoir before the dam construction. Currently, InSAR data is being processed to assess the sedimentation changes. Numerical models were set up to estimate sediment transport. All these outcomes will be compared and validated by the field investigation findings. Details of the field investigations are presented in the following subsections.

15.3.1 Sedimentation Measures

Several sedimentation bars were installed by MRMWR. We measured the level of these bars and estimated how much sediments were deposited from 2011 to 2017 (Fig. 15.7). The sedimentation volume at the reservoir along Wadi Mijlas was estimated from the sedimentation measure bars installed in the reservoir before the dam construction. The sedimentation volume due to four flash flood events over the seven years was estimated to be about 8433 m³ at Asserin Down Dam 1 and about 15,041 m³ at Asserin Up Dam 2.

15.3.2 Pedon Survey

Several sediment pedons were dug at Asserin Up Dam (Fig. 15.8a) along the reservoir to analyze the sediment grain size and organic contents and check the layers of sediments accumulated during the previous flash floods. Samples were collected from each layer for detailed laboratory analyses (grain size analysis, microscopic analysis, ash separation, and organic contents assessment). All layers were analyzed and described in the field to understand the correlation with rainfall data. At Asserin Up Dam, we found six layers as shown in pedons 1, 2, and 3 (Fig. 15.8c). The layers were separated and distinguished by two techniques:



Fig. 15.7 Sedimentation measures at the reservoir of Asserin Up Dam at the upstream of Wadi Mijlas (photographs taken by the Kyoto University team: field survey from Nov. 29 to Dec. 2, 2017). Reprinted from Saber et al. (2018), Copyright 2018

vertical grain size variations and the occurrence of mud cracks at the top of a layer (Fig. 15.8b).

Based on the measure bars and sediment pedons analyzed, the sediment thickness along the central line of the reservoir was estimated for the six layers. This will be very beneficial in calibrating the sediment transport model in the reservoir (Fig. 15.9).

15.3.3 Morphometric Changes

An investigation of the morphometric changes along Wadi channels is required to understand the sediment yield, transport, and erodibility at the basins. We tried to assess and investigate the depositions and erosions along Wadi channels. Wadi channel leveling was conducted in the field to assess the Wadi channel elevations at different flash flood events. Also, we used Google Earth maps to check the Wadi channels' morphometric changes due to the impact of flash floods. For instance, the sedimentation changes at the dams before and after the constructions showing the spatial topographic changes at the reservoir at both dams along Wadi Mijlas

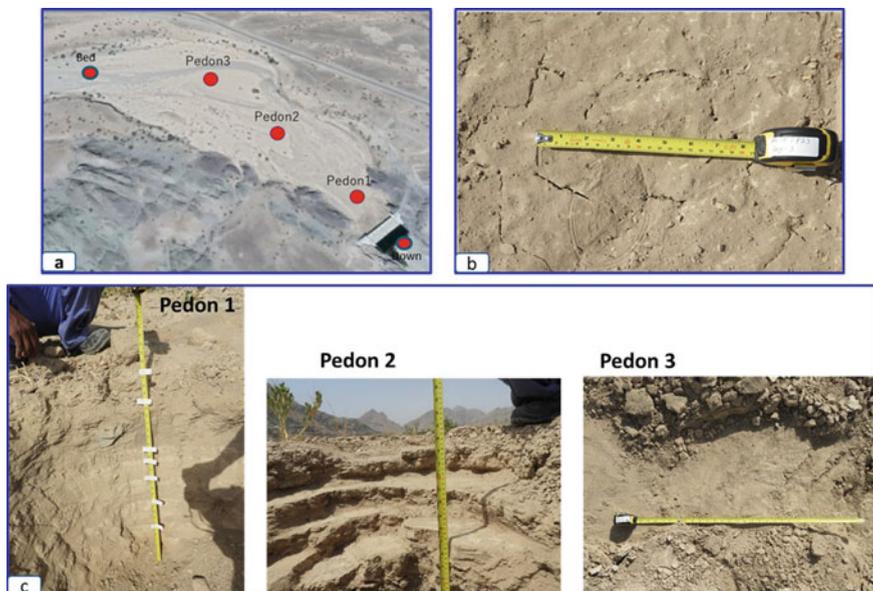


Fig. 15.8 a Pedon sites at Asserin Up Dam, Wadi Mijlas. b Observed mud cracks at the top of layer 3, pedon 2. c Three investigated pedons: pedons 1, 2, and 3

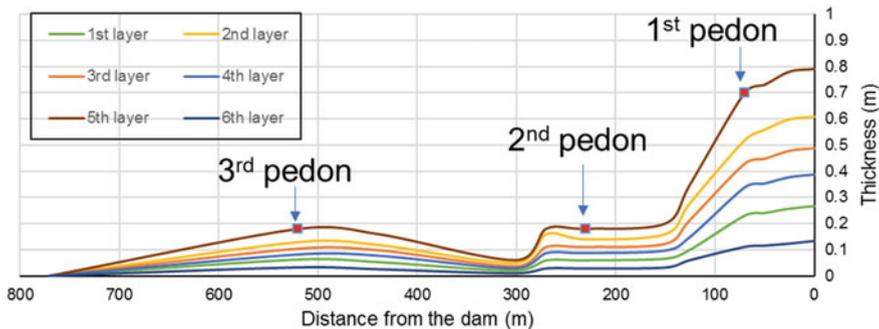


Fig. 15.9 Sediment thickness changes along the central line of the reservoir at Wadi Mijlas (Asserin Up Dam)

(Fig. 15.10). Along the Wadi channels, the impact of Cyclone Guno was observed, examining changes on the channel morphology as shown on Google Earth maps before and after the flash floods (Fig. 15.11). Currently, we are analyzing synthetic-aperture radar images to assess the sediment changes at the catchments after the flash floods.

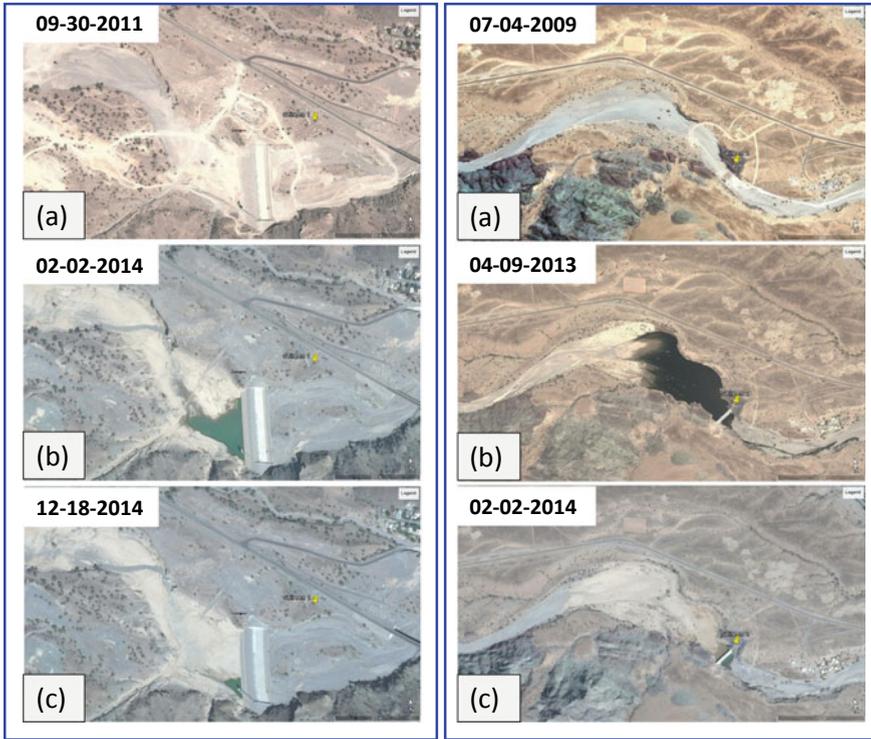


Fig. 15.10 Left Panel: Asserin Dam 1 (downstream) construction and sedimentation impacts. **a** The completion of the dam construction in 2011. **b** The sedimentation impacts on the reservoir in February 2014. **c** The sedimentation impacts on the reservoir in December 2014. Right Panel: Asserin Dam 2 (upstream) construction and sedimentation impacts. **a** Before the dam construction in 2009. **b** After flash floods and sediment deposition on the reservoir in April 2013. **c** Dryness of the reservoir in February 2014. Reprinted from Saber et al. (2018), Copyright 2018



Fig. 15.11 Wadi channel morphology changes after Cyclone Guno in 2007. The sedimentation bars in photograph (a) disappeared after the extreme floods revealed the massive transported sediment and the difference in the soil colors, as observed in photograph (b). Reprinted from Saber et al. (2018), Copyright 2018

15.3.4 Infiltration Tests

During the field investigations, we observed the clogging phenomena of sedimentation at the reservoir (Fig. 15.12), both upstream and downstream of the dams at Wadi Mijlas. Therefore, we conducted several infiltration tests vertically as a unique approach to understand the sediment dynamics as well as impacts on the groundwater recharge.

Using the disk infiltrometer, we conducted several tests at the investigated pedons, considering different layers to understand sedimentation impacts on the infiltration. The objectives of the infiltration tests were to measure the change of infiltration rate by sedimentation and assess the influence of clogging. The saturated hydraulic conductivity (K_s) was determined using tension infiltrometers (Reynolds and Elrick 1991) at the target sites (pedons). About 13 infiltration tests were conducted at several layers as shown in Fig. 15.13. As preliminary results, we found the sedimentation decreases the infiltration. Concerning the infiltration tests, however, further discussion is still in progress. The relationship between pedon sediments and infiltration tests was also investigated.

At pedon 2, the results of the infiltration test and grain size analysis showed the relationship between the soil texture and K_{sat} : K_{sat} decreases at the layers from upstream to downstream with depth (Fig. 15.14). It was also found that K_{sat} declines when the grain size decreases. The findings of the study by (Mazaheri and Mahmoodabadi 2012) agrees with these results indicating the soil particle distribution affects the infiltration rate. Furthermore, the longitudinal change of K_{sat}

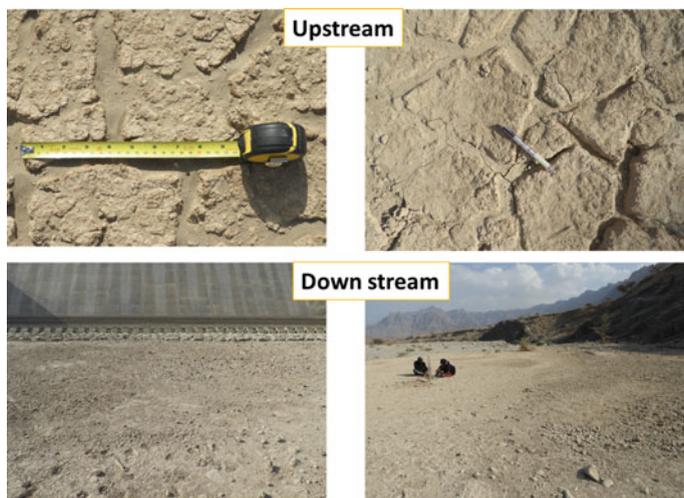


Fig. 15.12 Sediment clogging upstream (the two upper photographs) and downstream (the two lower photographs)

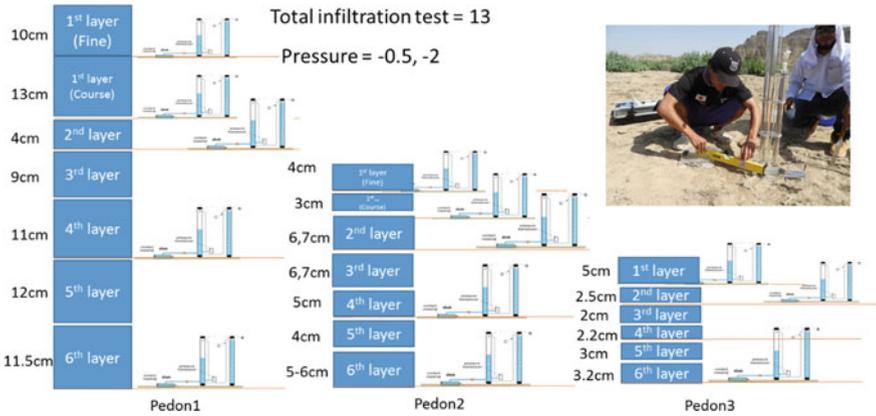


Fig. 15.13 Infiltration tests at several layers of the three pedons, Asserin Up Dam

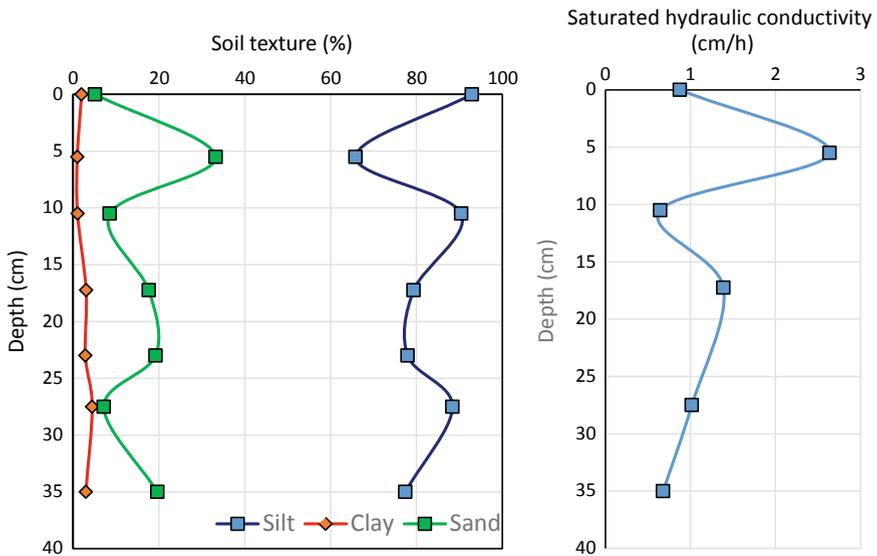


Fig. 15.14 Soil texture and saturated hydraulic conductivity at pedon 2

along the tested sites was observed (Fig. 15.15). This revealed the impact of sedimentation on the infiltration rate. Also, K_{sat} of the surface layer decrease from upstream to downstream, which is also related to the soil texture. Further analysis of all the layers by using the infiltration model to simulate such changes are still running.

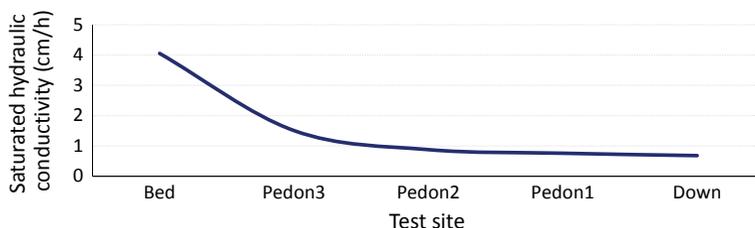


Fig. 15.15 Longitudinal change of saturated hydraulic conductivity at the pedon sites (see Fig. 15.8a)

15.3.5 Drone Surveys

Over two days we conducted drone surveys using Phantom 4 Pro at different locations and sites (Fig. 15.16) including Asserin Up Dam, Asserin Down Dam, Al Sawaqim, the monitoring station, the old monitoring station along Wadi Mijlas, the newly proposed dam, and also at the Wadi gauge station site. The reservoir of Asserin Up Dam was selected to develop the bathymetry DEM (Fig. 15.16). The drone images were analyzed to produce a very high-resolution DEM at the reservoir (Fig. 15.17), with about 0.5 m spatial resolution, that will be very useful to enhance the topographic data inputs for the hydrological models. The drone images were processed using the Photo Scan software. This DEM will be very crucial to enhancing the input topographic maps for the hydrological model and consequently reducing the model uncertainty related to topographic data accuracy. These results will be used for the future modeling of sediment transport models and also for future sediment changes over the target basins by comparing them with future results to assess the extent of the deposited sediments for any future flash flood events.



Fig. 15.16 Satellite image showing the sites for the drone survey of Wadi Mijlas, Oman, on the right and the drone photograph of Asserin Up Dam, Wadi Mijlas, Oman on the left

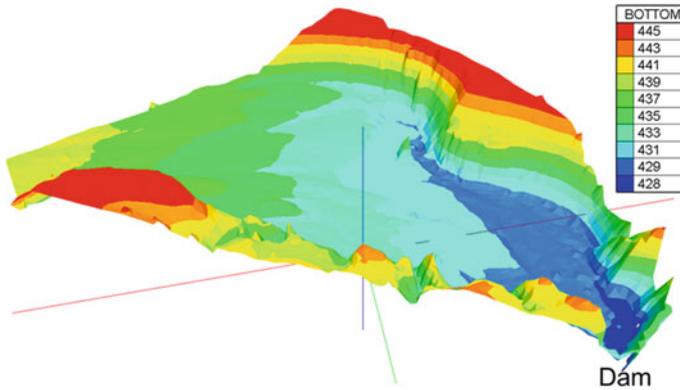


Fig. 15.17 High-resolution digital elevation model generated from unmanned ground vehicles will be used to enhance the input topographic maps for sediment transport modeling

15.4 Climate Change and Extreme Rainfall Events

As a part of this project, the impacts of climate change on WFFs was addressed. We analyzed long-term rainfall data to understand the temporal variability over the Arab region and Oman. The satellite rainfall data of the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) was used (Sorooshian et al. 2000; Ashouri et al. 2015). The results of the analysis of PERSIANN rainfall data from 1983 to 2017 exhibited the whole Arab region had experienced systematic cycles of increasing trends of rainfall about every seven years (Fig. 15.18a) and the same behaviors were recorded for Oman, except the first cycles showed extreme increasing and then decreasing trends in the rainfall data (Fig. 15.18b). To understand the temporal variability for such kinds of systematic cycles of extreme events, additional historical data from the Climate Change Knowledge Portal was freely downloaded and used (WorldBankGroup 2019). The data was derived from observational data, and it provided quality controlled rainfall values from thousands of weather stations worldwide. It was developed by the Climatic Research Unit of the University of East Anglia and reformatted by the International Water Management Institute. The Persian data showed an acceptable agreement between the annual Persian data and historical rainfall data with a correlation coefficient of 0.7693 (Fig. 15.18c). The future climate scenarios will be discussed in a separate research paper to deeply understand the spatial and temporal variability of rainfall over the Arab region and Oman for a long-term period including the past, recent, and future extreme rainfall events.

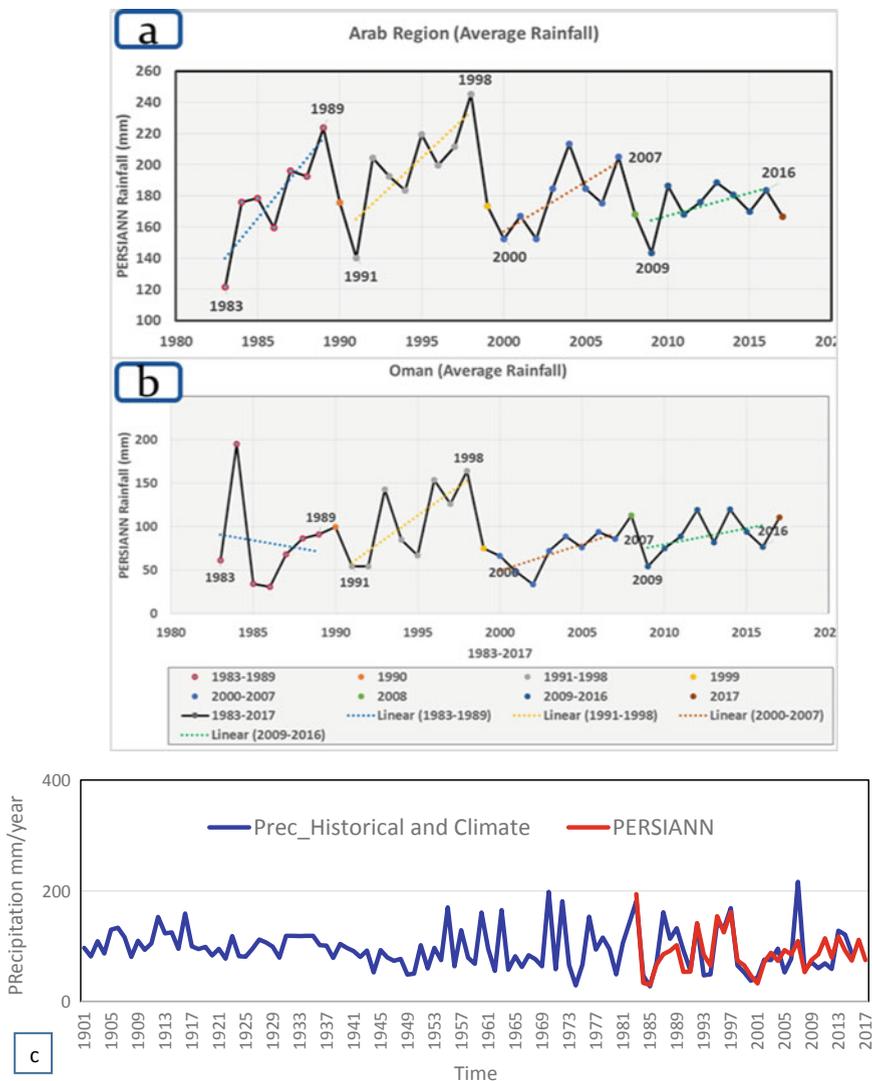


Fig. 15.18 Annual rainfall analysis of precipitation estimation from remotely sensed information using artificial neural networks (PERSIANN) rainfall data from 1983 to 2017 over **a** the Arab region and **b** Oman and **c** the comparison of long-term historical data of Oman with PERSIANN data from 1983 to 2017

15.5 Conclusions and Ongoing Work

In this paper, an international collaboration project is presented and discussed. The collaboration was initiated between the Kyoto University team and the Omani team (in collaboration with SQU, MRMWR, and DGM) to develop an effective hydrological approach for WFFs in arid regions, considering climate change and sedimentation impacts. Four research groups were established to focus on analyzing historical rainfall data to assess extreme events variability and global circulation models for future climate scenarios (G1), developing the hydrological models to simulate water discharge and sediment transport (G2), and assessing sediment yield (G3) by satellite data (e.g., InSAR) and hydrological surveys by conducting investigations for sedimentation impacts on infiltration process (G4). The outcomes will be solutions to overcome challenges related to WFFs and the proposition of a secure long-term sustainable management of water and sediments, as well as the transfer of Japanese technologies. Both the Japanese and the Omani teams are working together to achieve the project tasks, providing approaches and methods to overcome WFF challenges in arid regions.

To therefore understand flash flood phenomena in arid regions in terms of water and sediment management, two field surveys were conducted for Wadis Mijlas and Samail in Oman in December 2017 and September 2018, respectively, to study the sedimentation issues and their impacts on reservoir capacity. Several measures were implemented such as Wadi channel leveling, and the use of sedimentation pedons to study the vertical layers of sedimentation at the reservoir by collecting sediment samples for further laboratory analysis and detecting of flash flood marks. Additionally, drone surveys, infiltration tests, and field questionnaires about flash floods were conducted. The infiltration tests showed the relationship between the sedimentation layers and the Ksat at several vertical sediment layers of three pedons. A high-resolution digital elevation model was generated from the drone images to be used for the sediment transport modeling. Long-term satellite precipitation data and historical data were used to analyze the temporal variability in the whole Arab region and also at Oman, and the results exhibit interesting systematic cycles every seven years. Thus, additional detailed analyses of these data and climate change scenarios are still ongoing. Thus, this study is quite crucial in assessing the sedimentation in the field survey, numerical modeling, and satellite data, as well as in proposing the best sediment management techniques in Wadi basins. Further field surveys will be conducted in the near future to extend the analysis, especially concerning long-term rainfall analysis and climate change impacts.

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