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Suspended Sediment Concentration and Stream Discharge Relationship During Storm Events in Tributaries of Smaquli Stream, Erbil, Iraq

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Abstract:

The primary objective of this study is to monitor and collect data from the main tributaries of Smaquli stream during rainfall storm events, which can be used to establish relationship between suspended sediment concentration and discharge. The Smaquli catchment is divided into two sub-catchments namely Sarwchawa and Krosh with areas of 80.64 and 34.82 km^2 respectively. Jali dam is built at watershed outlet. Rainfall, stream discharge, and suspended sediment concentration are monitored during ten rainfall storms in the water years (2012-2013) and (2013-2014). Analysis of the data from the two sampling sites, shows two different responses of suspended sediment concentrations. The Krosh sub-catchment reacts rapidly to rainfall storms and the same behavior is shown in the suspended sediment that is resulted seven single and three double-peaked graphs. On the other hand, the reaction of Sarwchawa sub-catchment was slower. Moreover, analysis of cumulative flow and suspended sediment showed the Krosh sub-catchment ranks almost equally as one of the flow and sediment contributors to the Smaquli stream, in spite of the area difference between Sarwchawa and Krosh sub-catchments. The peak stream flows are highly correlated with total and peak suspended sediments at Krosh station having correlation coefficients of (R=0.96 and 0.84) respectively. In contrast, at Sarwchawa sub-catchment, the peak stream flow was weakly correlated with peak suspended sediment (R=0.47). To reduce sedimentation, this study suggests changing the land use practices for example types of crops and frequent planting and less grazing of sheep and goats.

Keywords: suspended sediment, water quality, soil erosion, Jalidam, NE Iraq.

علاقة تراكيز الترسبات العالقة و التصريف النهرى خلال حالات مطرية في روافد نهر سماقولي، اربيل، العراق

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الخلاصة:

الهدف الاساسي من هذه الدراسة هو رصد و جمع البيانات فى الروافد الرئيسية لنهر سماقولى اثناء حالات مطرية مختلفة لغرض انشاء علاقة بين تركيز الترسبات العالقة و التصريف النهري. ينقسم حوض سماقولى الى حوضين صغيرين هما سروجاوة و كروش وهما يغطيان مساحات 80.64 و 34.82 كم^2 على التوالي. بني سد جلى فى اسفل حوض سماقولى. فى السنوات المطرية (2012–2013) و (2013–2014) تم مراقبة وقياس المطر، تصريف النهر و الترسبات العالقة لعشرة حالات مطرية. تحليل النواتج لمحطتي

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القياس والنمذجة ودلت على تباين كبير فى تجاوب المنطقة للتساقط. التجاوب فى حوض كروش اسرع و يحمل ترسبات اكثر. قمة تصريف النهر مترابطة جدا مع كل من قمة الترسبات العالقة والحجم الكلى، معامل الارتباط فى حوض كروش هو 0.96 و 0.84 على التوالي. على النقيض من حوض سروجاوة معامل الارتباط بين قمة تصريف و قمة الترسبات العالقة كانت 0.49. لتقليل الترسبات المنقولة هذه الدراسة تقترح تغير فى ممارسات استعمال الاراضي الزراعية على سبيل المثال تغير المحاصيل و تكرار الزرع و تقليل استعمال الاراضي كمراعي للاغنام والمواعز.

1. Introduction

One of the most serious problems that face dam reservoirs is sedimentation [1, 2]. It affects the storage capacity of reservoirs, the productivity of basin agricultural lands, and the other environmental implications. The moving sediments also affect the quality of water in river systems [3]. The muddy water affects many water supply projects along the river systems.The major part of transported sediment into dam reservoirs is suspended sediment which is provided mainly during single storm events [4].

Many factors affect the erodibility of soil: particle size of soil, land slope, vegetation, moisture content of soil, soil compaction, soil properties, rainfall characteristics and human activity [5]. Processes of erosion, transportation and deposition are usually accelerated by human activities [6]. For example plowing and tillage enhance the soil erodibility. Other activities such as overgrazing of grass land, cutting forests, forest fires, construction, mines and quarries are weakening the protective layer of the ground surface [5, 6]. Sediment transport subject has been subjected to many researches in Iraq. [7] have predicted rainfall-runoff erosivity for single storms in northern Iraq. A study in 2013, has applied the Swat Model to estimate the sediment load from the left bank of Mosul dam reservoir [8].

The objective of this study is to monitor and collect suspended sediment transport data at two main sub-catchments of Krosh and Sarwchawain Smaquli catchment for establishing a relationship between sediment concentration and stream discharge. Another aim of this work is to study the suspended sediment distribution and pattern during rain storms to find out the sediment source locations and offering suitable solutions. It is believed that a sound understanding of the sediment transport process provides guidance and direction for future surface water management and planning towards reducing turbid water that directly affect water quality in the Jali dam reservoir, which in turn will be used for many water supply projects in the study area.

2. Study Area

The study area is a 126.674 km^2 headwater catchment, located approximately 50 km east of Erbil city in Kurdistan Region of Iraq (Figure 1). The catchment ranges in elevation from 714 to 1478 m. above sea level. The basin outlet is situated nearly 70 m downward of the new constructed JaliDam.The study area is bordered by four mountain ridges. The southwestern part of catchment lies across an important topographic / structural boundary between the southwestern Low Lands and the northeastern High Folded Zone. The mean channel slope is 0.05256[9].

The Smaquli catchment is divided into two sub-catchments namely Sarwchawa and Krosh with areas of 80.64 and 34.82 km^2 respectively. These two sub-catchments are representing 63.66 and 27.49 % of the total catchment area. The remaining area 8.85% (11.22 km^2), is representing the draining area from the stations to the catchment outlet. The main stream is formed as a result of confluence of tributaries of Krosh and Sarwchawa at a point locally called Du-Rubaran. It trends west-east. The Krosh stream drains the Krosh sub-catchment at the southern and southwestern parts of the study area, while the Sarwchawa stream drains the Sarwchawa sub-catchment at the northern and northeastern parts of the basin Figure-1.

The area is semi-arid and characterized by long dry hot summer and moderately raining cold winter. Average annual precipitation is 582.8 mm for the period of 13 years (2001-2014) reported by the Koya Meteorological Station. The soil groups are variation of lithosols, rendzinas, shallow and deep chestnut, rankers and brown calcareous.

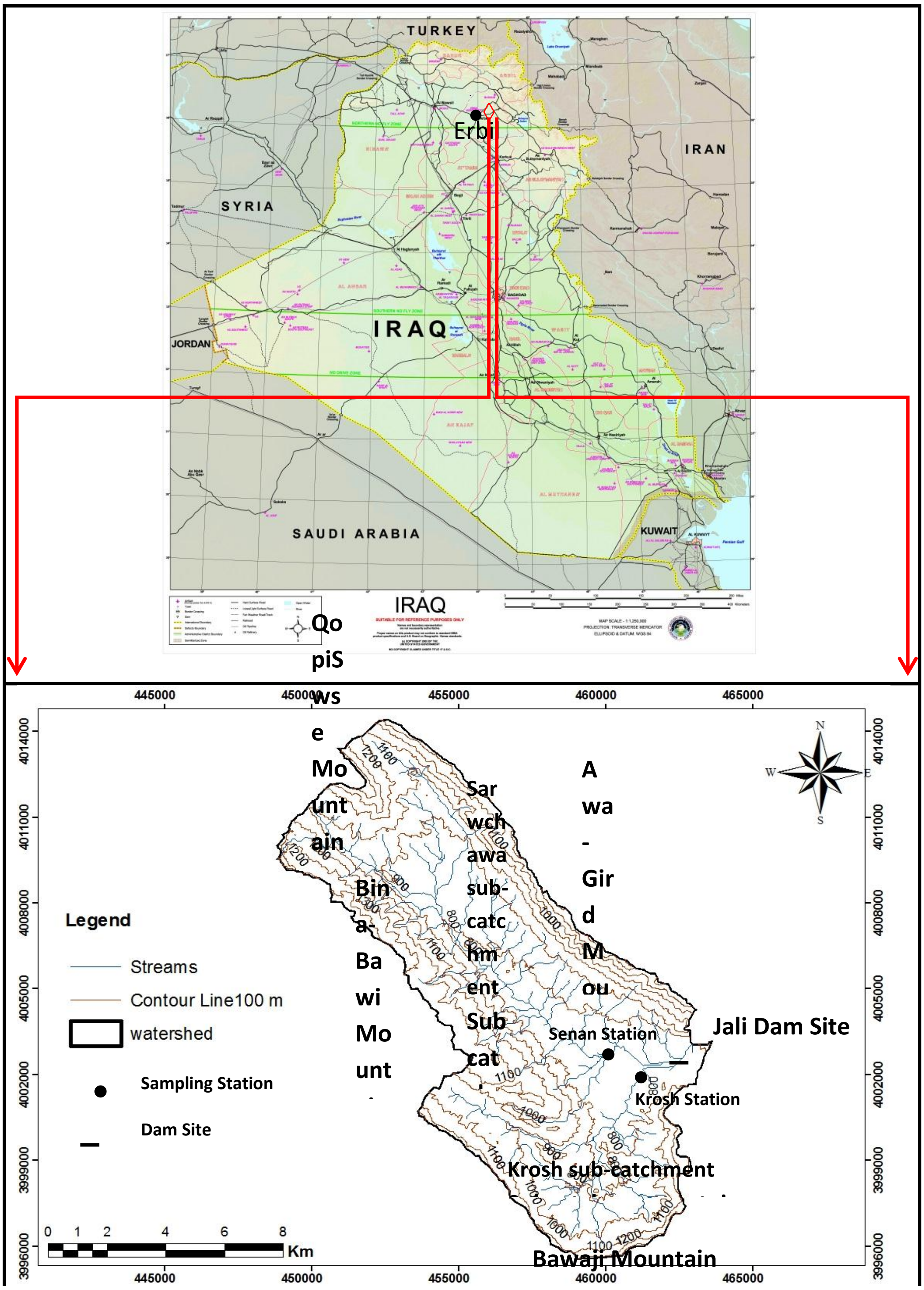


Figure 1- Map of Iraq and the topographical map of the Smaqulicatchment with locations of Senan and Krosh stations.

3. Methodology

Temporal variability investigation of suspended sediment occurs during single storms at a point across streams need catchment rainfall data based on at least hourly basis and stream flow data at the same station for small intervals. Unfortunately these data were not available. Therefore, for ten targeted storms, rainfall is measured using an ordinary rain-gauge which is installed near the Senan station Figure-1.

For stage measurements, staff gages are installed in Senan and Krosh stations Figure-1. They were precisely graduated with reference to a horizontal known datum. Rating curves were established at both stations using float and dilution methods [9]. This was done for water years (2012-2013) and

(2013-2014) apart. Afterwards, water level measurements are converted to discharge using the regression equations obtained from the rating curves.

In this study, the temporal variability of suspended sediment concentration during six rainfall-runoff eventsis examined for Sarwchawa and Krosh sub-catchments at Senan and Krosh stations respectively.Another event is monitored only at Krosh station in addition to other three events which is investigated only at Senan station. Attempts are made to choose targeted rain events in a way represent various durations and intensities. Additionally, factors such as stream flow level and condition, antecedent precipitation index and season of the year are taken into account in selecting those ten storms.The rainfall characteristics for the measured 10 events are given in Table-1.

The sampling procedure is followed by volumetric method. Sampling is started soon after a rise in stream water level. It was done by taking an amount of 2 liters of water for each sample, as close as possible to the mid-channel of the stream to avoid local inhomogeneities. All samples are taken opposite site to the stage measurement point at a depth between 7 and 12 cm. During the sampling collection, care is taken to stand in a stream and to reach the upstream of the current to obtain the sample. Monitoring is involved measurements of water level and collection of water samples at both Senan and Krosh stations.

The water sampling time interval varied from 15 minutes to three hours. In certain cases, it was once in 24 hours. The filtering procedure is done at the field by pouring the water sample on Melitta® 1X4 coffee filter paper (FSC No. C095206). Labeled and weighed empty, dry filter was used by setting it onto a filtering flask. Depending on suspended sediment amount, sometimes up to 5 filters are used per sample.Drying and weighing of filter paper and sediment were conducted at the laboratory of soil mechanics at Faculty of Engineering in Koya University. The TRiSTAR oven was set at 105 *°C* for one hour. Once filters were dried, they weighed using CONTROLS accurate balance with three decimals.

4. Results and Discussion

Stream discharge (Q) and suspended sediment concentration (SSC) are both affected by rainfall characteristics. The latter is originated from soil erosion products flowing into the streams from the surrounding areas and stream bed erosion. It depends on both hydraulic and rainfall characteristics, particularly, rainfall depth and intensity [10]. Therefore, for all storm events, at both Senan and Krosh stations, plots of the relationship between rainfall intensity in time and the resulted runoff and suspended sediment concentration curves are established. Figures 2 and 3 show these plots for storm 10 as an example.

Table 1- Rainfall characteristics for 10 storms measured at Senan station in 2013 and 2014.

Storm No.	Date	Amount (mm)	Duration (hrs)	Maximum Intensity (mm/hr)	Storm Intensity (mm/hr)	Measured Time Interval
Storm 1	12/02/2013	4.03	3.0	1.6	1.3	30 min.
Storm 2	17/03/2013	9.80	7.0	4.0	1.4	30 min.
Storm 3	21/04/2013	6.26	3.5	2.4	1.8	30 min.
Storm 4	22/04/2013	6.80	1.5	6.0	4.5	30 min.
Storm 5	11/05/2013	8.18	1.5	7.6	5.5	30 min.
Storm 6	16/05/2013	4.00	1.0	5.8	4.0	30 min.
Storm 7	04/03/2014	15.61	10.0	2.5	1.6	1 hour
Storm 8	10/03/2014	19.26	5.5	7.2	3.5	1 hour
Storm 9	11/03/2014	47.30	11.0	16.2	4.3	1 hour
Storm 10	30/03/2014	10.00	10.0	8.1	1.7	1 hour

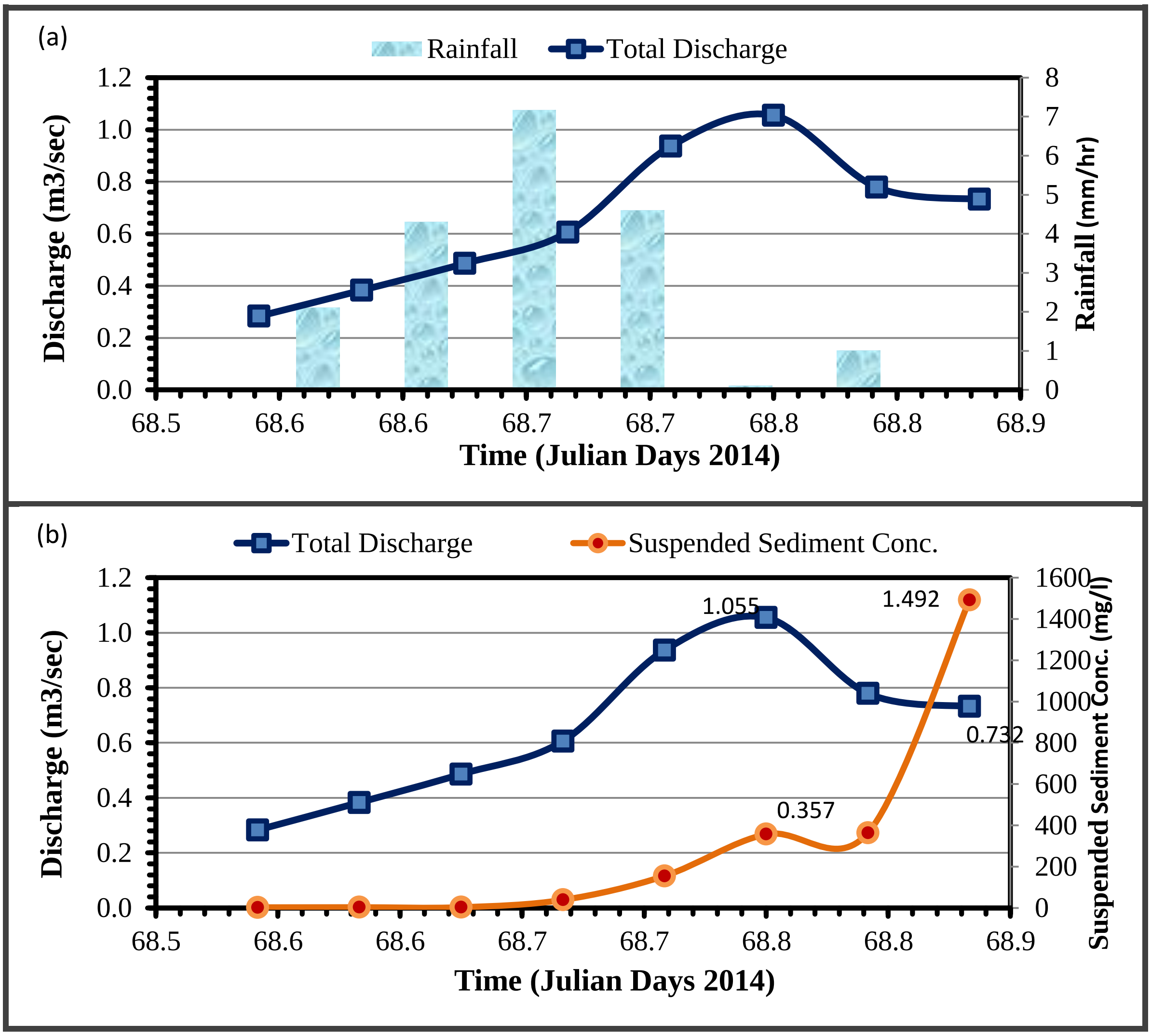
In order to identify runoff and suspended sediment concentration pattern and distribution, cumulative discharge and cumulative SSC plots are established Figures-2 and -3. Further the summary statistics are computed using raw values of runoff and suspended sediment parameters. Afterwards, the regression analysis is performed to represent the dependence (linear or nonlinear) between the measured variables. Individual regression plots at each station and for various storms were developed. At the end, general combined regression plots for all storms at both Senan and Krosh stations are computed and the output data were compared between the two monitoring stations.

As stated before, 9 storms are sampled at Senan station and 7 storms at Krosh station. The peak discharge at Senan station ranges between 0.231 and 11.546 [m^3/sec], while, the suspended sediment concentration ranges between 68.6 and 6246.5 [m*g/l*]. On the other hand, the peak discharge at Krosh station ranges between 0.376 and 2.762 [m^3/sec] and the suspended sediment ranges between 124.2 and 5322.5 [m*g/l*] Tables-2 and -3.

Hydrographs have shown that the Krosh sub-catchment reacts rapidly to rainfall storms and the same behavior shown in the suspended sediment that is resulted a single or sometimes double-peaked graph. On the other hand, the reaction of Sarwchawa sub-catchment was slower. The sediment curves generally differ on the basis of whether the peak concentration occurs before, simultaneously with, or after the discharge peak.

Generally, increasing flow has occurred at Senan station slowly. Similarly suspended sediment needed more time to pass the monitoring station.Conversely, the Krosh sub-catchment had rapid responses associated with fast transport of eroded materials. This may be due to the effect of several factors occurring simultaneously in both areas. These include rainfall characteristics, geology, slopes, vegetation, land use and infiltration capacity.

Analysis of cumulative flow and suspended sediment showed the Krosh sub-catchment ranks almost equally as one of the flow and sediment contributors to the Smaquli main stream, in spite of the area difference between the Sarwchawa and Krosh sub-catchments. Tables-2 and -3 presents the total weight (in kg) of suspended sediment monitored during events for each sub-catchment.



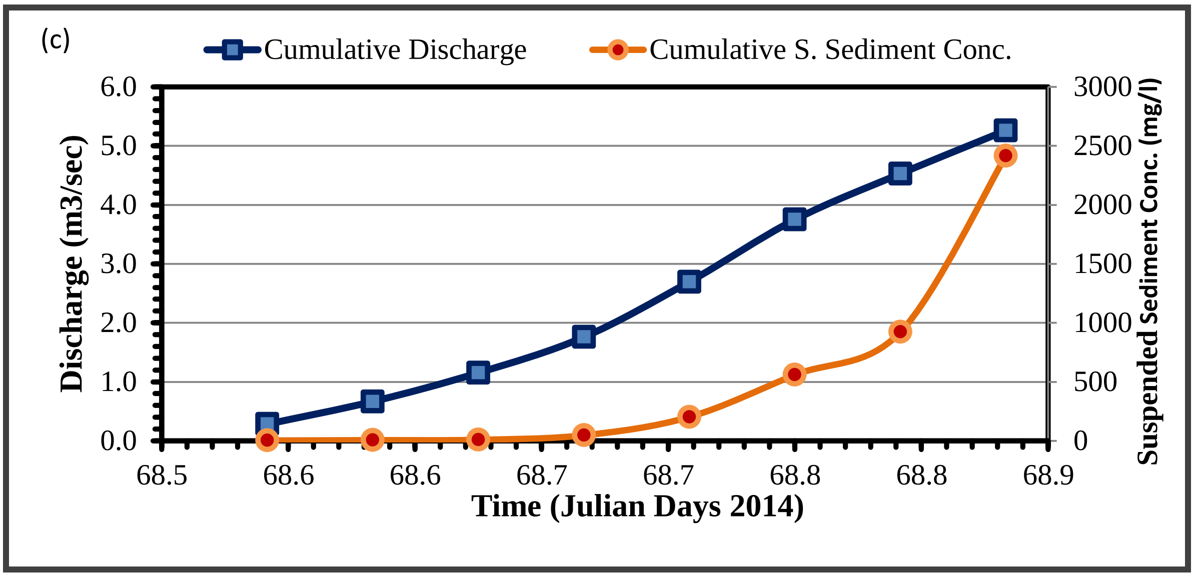
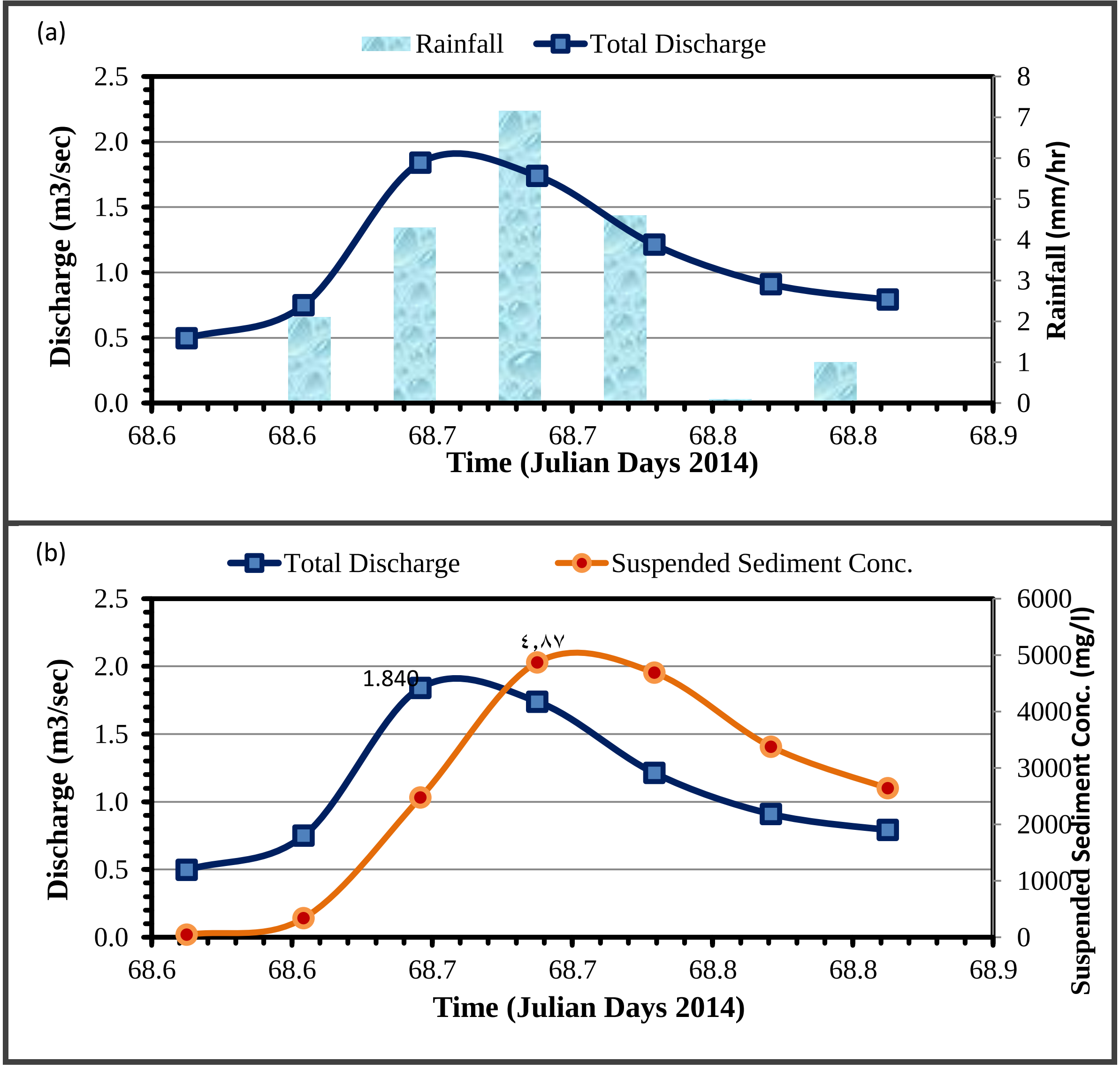


Figure 2- Rainfall – runoff – suspended sediment concentration (SSC) relationships at Senan station for a storm on 10-03-2014 (a) Hyetograph of rainfall intensity and the resulted hydrograph (b) Hydrograph of discharge and SSC(c) Cumulative discharge and cumulative SSC in time.



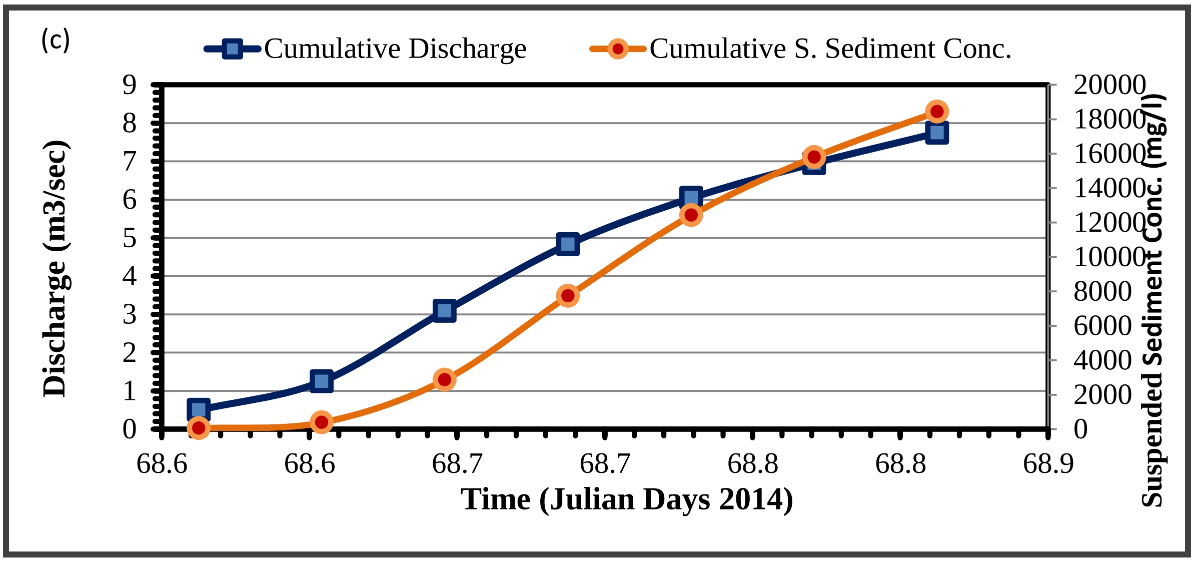


Figure 2- Rainfall – runoff – suspended sediment concentration (SSC) relationships at Krosh station for a storm on 10-03-2014 (a) Hyetograph of rainfall intensity and the resulted hydrograph (b) Hydrograph of discharge and SSC (c) Cumulative discharge and cumulative SSC in time.

Table 2- Runoff and the resulted suspended sediment parameters of 9 events measured at Senan station in 2013 and 2014.

Storm No.	**Date**	**Direct Runoff Volume (m^3)**	**Peak Discharge (m^3/sec)**	**Occurred At**	**Total Suspended Sediment (*kg*)**	**Peak Suspended Sediment (*mg/l*)**	**Occurred At**
Storm 1	12/2/2013	97844	0.983	14:45	30308.1	688	15:45
Storm 2	17/3/2013	1387	0.979	16:30	1521.5	210.5	17:30
Storm 3	21/4/2013	25	0.357	17:00	2355.4	908.5	17:30
Storm 4	22/4/2013	552	0.481	16:30	2290.4	565.9	14:00
Storm 6	16/5/2013	65	0.231	17:00	120.8	68.5	19:30
Storm 7	04/3/2014	9913	0.568	14:30	1768.3	429.8	19:00
Storm 8	10/3/2014	11801	1.055	18:00	6922.3	1490	20:00
Storm 9	11/3/2014	360702	11.546	7:00	681164.0	4783.1	7:00
Storm 10	30/3/2014	200858	3.802	15:35	288800.1	6246.5	17:30

Table 3- Runoff and the resulted suspended sediment parameters of 7 events measured at Krosh station in 2013 and 2014.

Storm No.	**Date**	**Direct Runoff Volume (m^3)**	**Peak Discharge (m^3/sec)**	**Occurred At**	**Total Suspended Sediment (*kg*)**	**Peak Suspended Sediment (mg/l)**	**Occurred At**
Storm 4	22/4/2013	2248	0.735	16:15	20543.1	3919.2	16:15
Storm 5	11/5/2013	322	0.376	19:00	399.6	233.9	16:30
Storm 6	16/5/2013	267	0.439	17:15	260.4	124.9	17:15
Storm 7	04/03/2014	14567	0.918	18:35	25778.5	1588.8	18:35
Storm 8	10/03/2014	15337	1.840	15:30	86909.6	4870.0	15:30
Storm 9	11/03/2014	45638	2.762	7:30	260170.2	5322.5	7:30
Storm 10	30/3/2014	65161	0.855	11:00	16778.1	826.5	12:05

Table 4- Comparison between response behavior of Sarwchawa and Krosh sub-catchments at Senan and Krosh stations using total stream flow volume and total suspended sediment for 6 storms in 2013 and 2014.

Storm No.	**Date**	**Rainfall Amount (*mm*)**	**Max. Intensity (*mm/hr*)**	**Senan Runoff Volume (m^3)**	**Senan Runoff Duration (*hrs*)**	**Krosh Runoff Volume (m^3)**	**Krosh Runoff Duration (*hrs*)**	**SenanTotal S. Sediment (*kg*)**	**KroshTotal S. Sediment (*kg*)**	**SenanTotal S. Sediment (kg/km^2)**	**KroshTotal S. Sediment (kg/km^2)**
Storm 4	22/4/2013	6.80	6.0	8899	6.17	16099	7.5	2290.4	20543.1	28.4	590.0
Storm 6	16/5/2013	4.00	5.8	4097	5	7575	5	120.8	260.4	1.5	7.5
Storm 7	03/04/2014	15.61	2.5	22830	11.5	39489	11.5	1768.3	25778.5	21.9	740.3
Storm 8	03/10/2014	19.26	7.2	19951	8	27861	8	6922.3	86909.6	85.8	2496.0
Storm 9	03/11/2014	47.30	16.2	445029	32	102893	32	681164.0	260170.2	8447.1	7471.9
Storm 10	30/3/2014	10.00	8.1	427466	33.5	149127	34	288800.1	16778.1	3581.4	481.9

The lag-time at Senan stations for measured runoff events varied from 1 to 7.5 hours with an average of 4 hours. That of suspended sediment varied from 1 to 5.5 with an average of 2 hours. In contrast, the lag-time at Krosh station ranged between 0.5 and 7 hours with an average of 2.4 hours. While the suspended sediment peak mostly comes simultaneously with the discharge peak, if after then, it needs an hour in average to reach the station. The small size of the sub-catchment here plays a great role.

Another geomorphological factor that affects the time lag of stream flow and sediment curves of the two sub-catchments is the shape of them. The Sarwchawa sub-catchment has a fern shape, while the Krosh sub-catchment possesses a semi-fan shape. In the former the time of concentration is large. Thus, a droplet of water needs to travel from the most distant point of the sub-catchment which costs more time to reach its outlet. The delay of suspended sediment at Senan station is associated with the delay of stream flow. A part is exclusively related to routing of the discharge from the source areas to the gauging station.

This is a clear indication that during a storm event more water will be infiltrated in Sarwchawa sub-catchment compared to Krosh and in turn which more rain water runs off. Any increase in runoff results in an increase in transport capacity, which also includes a higher bed load fraction [11]. The influence of infiltration capacity on sediment transport in Sarwchawa sub-catchment is consistent with the nature of the limestones and dolomitic limestones of the Bekhme and Qamchuqa Formations, which cover a large part and are highly fractured [12].

Total suspended sediment in kilograms is strongly positive correlated with maximum rainfall intensity during a storm at both stations. The correlation coefficients (R) were 0.90 and 0.86 for Sarwchawa and Krosh streams respectively. The peak suspended sediment was also positively correlated with maximum rainfall intensity at Senan station (R=0.72). Similar positive correlation was found with rainfall amount (R=0.70) at Krosh station. The total suspended sediment and peak suspended sediment are significantly positive correlated with the storm durations at Senan station with R=0.65 and 0.61 respectively. Sediment parameters were not correlated with storm intensity at both sub-catchments.

Furthermore, highly positive correlations of total and peak suspended sediments with peak stream flows at Krozh station with correlation coefficients of (R=0.96 and 0.84) are again evidence on the transportation of the major portion of the sediments through the above mentioned first flush.

In contrast, at Sarwchawa sub-catchment, the peak suspended sediment was weakly correlated with the peak stream flow (R=0.47), while the total sediment was positively correlated with the peak stream flow (R=0.73). Both total and peak suspended sediments were strongly positive correlated with the direct runoff volume with R values of 0.97 and 0.82 respectively.

Figures-4 and -5 illustrate the regression plots between stream flow and suspended sediment concentration at Senan and Krosh stations respectively. All the data sets were used to find out a possible relationship between these two variables.Krosh stream data demonstrated significant relationship between suspended sediment concentration and stream discharge. A regression model for Krozh stream was developed using 50 observed values (Figure 5). The best fit of the data was obtained by polynomial trend type (Order five) in which ($R^2 = 0.68$). Hydrological variables tend to generate non-linear responses at catchment scale [13].The regression equations suggest:

$$SSC = -1764.4Q^5 + 14441Q^4 - 42999Q^3 + 56065Q^2 - 28227Q + 0.6808$$

Where, SSL is suspended sediment concentration in [mg/*l*] and Q is stream discharge in [m^3/sec].The above empirical relationship can be used for predicting suspended sediment load at Krosh station when the stream flow data are available during storm events.

Similar regression model was obtained for Sarwchawa sub-catchment at Senan station using 97 measured pair of stream flow and suspended sediment of 9 storms over the course of two years. The result suggested insignificant polynomial relation with ($R^2 = 0.2844$) Figure-4. Moreover, for several events individually, a strong positive regression exists between these two variables, particularly, by high maximum rainfall intensity values.

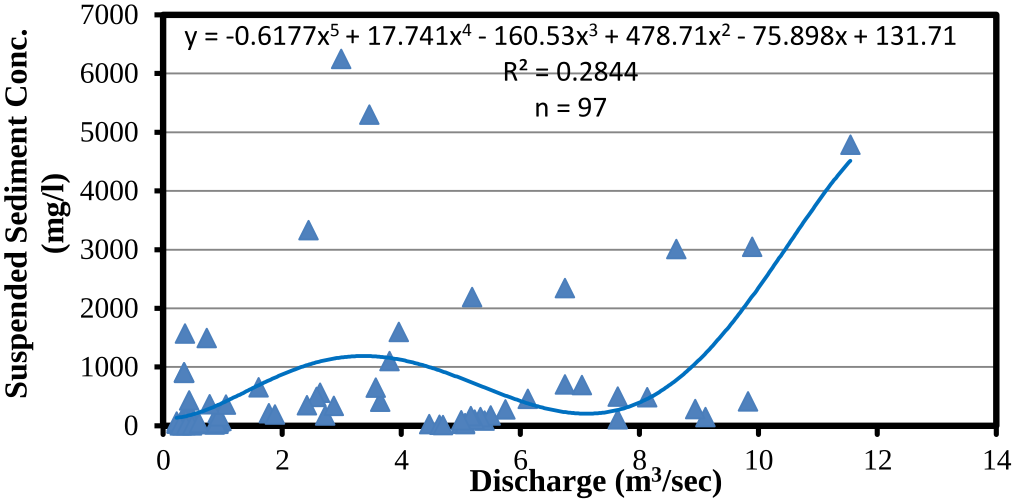


Figure 4- Regression plot between suspended sediment concentration and stream discharge for the Senan station using 97 monitored samples in 2013 and 2014.

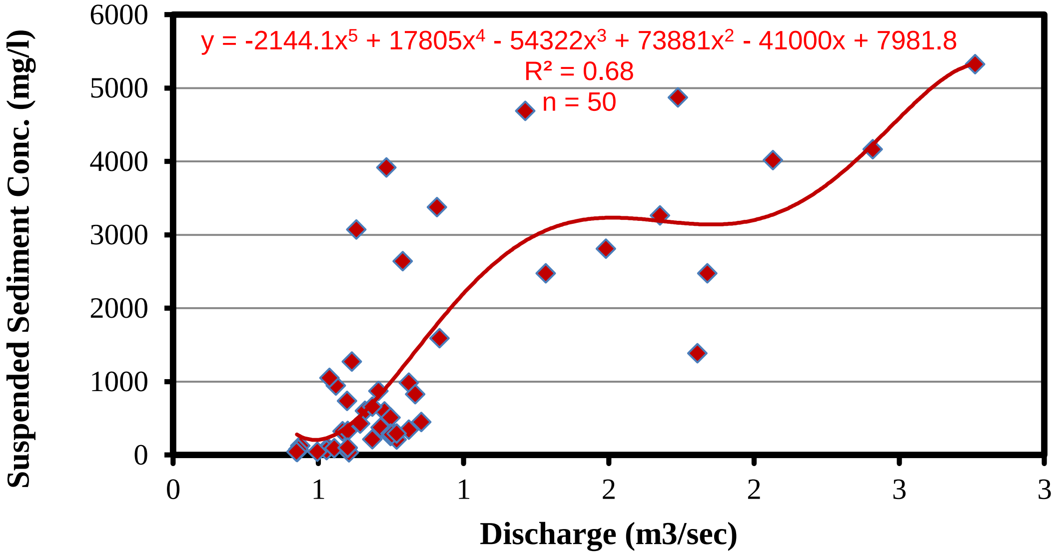


Figure 5-Regression plot between suspended sediment concentration and stream discharge for the Krozh station using 50 monitored samples in 2013 and 2014.

5. Conclusions and Recommendations

A positive relationshipexists between suspended sediment loads and water discharge for the Krosh sub-catchmnet. However, weaker relationships are found for Sarwchawa sub-catchmnet. Observed data at each of the stations showed that rainfall characteristics namely maximum rainfall intensity and amount play an important role in runoff generation process consequently in erosion and sediment transport processes. The results of this study showed a considerable difference in suspended sediment yield and transport from the two sub-catchments. A comparison of measured suspended sediment load values from the two sub-catchments revealed that over the period of sampling, concentration of suspended sediment in the water are 5-33 times greater at Krosh station compared to Senan station.

When the maximum rainfall intensity is less than 8 mm/hr, more suspended sediment will be yielded and transported at Krosh station. In contrast, the Sarwchawa sub-catchment is forming and transporting more suspended sediment when the maximum rainfall intensity is more than 8 mm/hr.

Analysis of the suspended sediment concentrations with stream discharge at both stations reveals that suspended sediment transport is a complex process depending on many factors. These include rainfall amount and intensity, sub-catchment shape, geology, presence of vegetation, infiltration capacity, and land use practices.

Finally, any future water resources planning towards improving water quality namely reducing the turbid water into Jali dam reservoir during single storm events should take the Krosh sub-catchment as a start point. This suggests changing the land use practices for example types of crops and frequent planting, less grazing of sheep and goats (during their movements, they enhance erosion of fine material) and building up small check barriers.

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