An overview of hydro-sedimentological characteristics of intermittent rivers in Kabul region of Kabul river basin

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ABSTRACT: The objective of this study is to give an introduction into the intermittent rivers in Kabul region of Kabul river basin and to outline the major flow and sediment transport characteristics of these special river systems. Intermittent rivers are defined as rivers with a high seasonal variability in water and sediment transport. As dominant hydrological characteristics of intermittent rivers, river discharges with the groundwater levels are compared in lowland as well as in upland rivers, to understand the interaction between groundwater and surface water. Suspended sediment and river bed sediments are studied to understand the sedimentological behavior of these rivers. From the investigated data, it can be seen that monthly measured groundwater levels in the vicinity wells reflect the flow fluctuations in the rivers. Suspended sediment transport mainly occurs during spring (March-May), when the highest discharge rates are measured. The measurements show in addition an order of magnitude higher suspended sediment transport rates in lowland intermittent rivers compared to the upland rivers. Sieve and granulometric analysis of river bed sediment shows a coarser grain size composition for upland rivers compared to lowland rivers.

1 INTRODUCTION

1.1 *Intermittent rivers*

Intermittent rivers are classified as rivers with a high seasonal variability of flow and sediment. Such rivers may partially dry up during the year (usually from weeks to a few months), resulting in water as well as habitat discontinuity. Rough estimations indicate that intermittent rivers contribute to more than 30% of the total length and discharge of the global river network (Raymond et al., 2013). The numbers of intermittent rivers are increasing as result of climate change, land use and water abstraction (Datry et al., 2014). Most of once perennial rivers of arid and semiarid regions are now intermittent (Gleick, 2003).

However, in Afghanistan this number would be much higher, since these estimates do not include low order streams, like the headwater streams, which drain most of Afghanistan’s catchments. Intermittent rivers are generally subject to a flow volume decrease further downstream due to seepage loss or groundwater recharge (Tooth, 2000; Shanafield & Cook, 2014). With the increase of population, the stress on water resources will increase specially in areas where water availability has a high seasonality. Therefore, there is an increasing interest in studying this kind of water resources in order to find sustainable solutions for water management in these regions. Hence, in this study an attempt is made to present a general overview of intermittent rivers in Kabul region of Kabul river basin and their interaction with groundwater as main source for water supply for Kabul residents. Additionally, suspended sediment transport and river bed sediments are analyzed and presented for a preliminary understanding of sediment transport in this river system.

1.2 *Hydro-sedimentological characteristics of intermittent rivers in Kabul region basin*

The main water source for most of Kabul regions’ intermittent rivers is snowmelt and rain, because most precipitation occurs during the winter months and in early spring. Long term precipitation measurements for Kabul region show that more than 80% of annual precipitation occurs from December to April (CLIMWAT Database, 2006). When the temperature rises, the flow in the rivers increases and peak discharges occur between March and May. During summer and autumn the intermittent rivers remain fully or partially dry throughout its length or at parts of its length for several months. When the wet season begins, the river starts to have water again in the river bed, and hence the recharge processes reinitiates. The extended period of low flow velocities causes the intermittent rivers bed to reduce the permeability, due to accumulation of fine sediments on the bed surface (external colmation/clogging) (Schälchli,1992, Beyer and Banscher, 1975). This phenomenon can be seen from the grain size analysis of the river bed surface layer, which contains a considerable amount of fine sediments. As a result of river bed colmation, the hydraulic conductivity of the river bed is reduced. This causes also a reduction in the groundwater recharge from the surface water, until deposited sediments are remobilized by the next flow events.

Intermittent rivers show a close interaction with groundwater levels. Groundwater studies by Broshears et al. (2005), show that in Kabul region basin, the groundwater flow path follows the surface water flow direction.

Most of the suspended sediment transport happens during high flow in the spring months. The transport of suspended sediments is reduced during winter months, as most of the catchment area is covered by snowpack, which reduces wash load from mountain ranges. In addition to flow, surface vegetation and snow cover, the suspended sediment transport is strongly influenced by the type of geology making up the catchment area.

Unfortunately for this region there is no data of bedload transport available yet. However there is currently a research project ongoing, where the bedload transport in mountainous intermittent rivers located in Kabul region basin is monitored.

2 METHOD

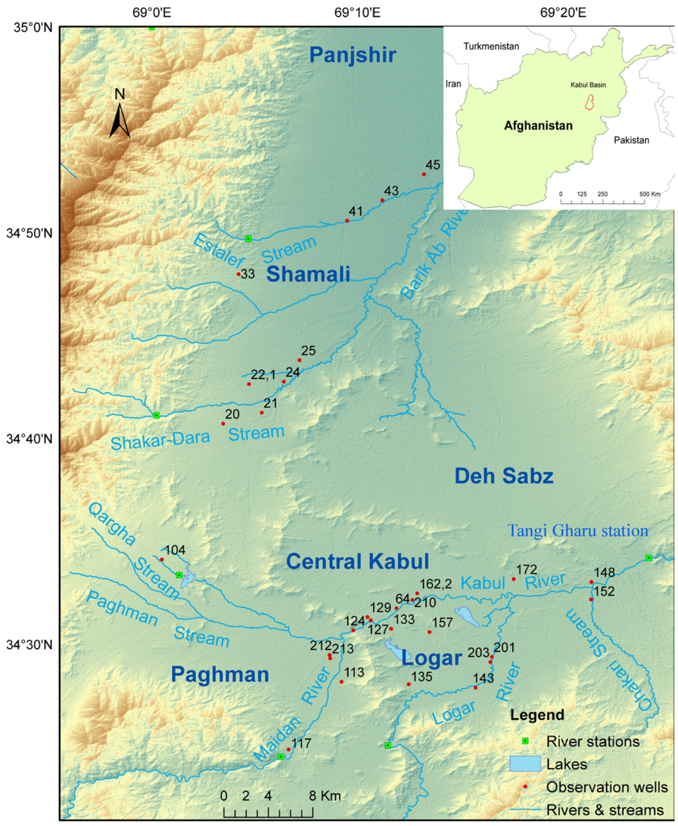
2.1 *Study area*

Six rivers in the Kabul region of Kabul river basin namely Kabul, Logar, Maidan, Shakar-Dara, Estalef and Qargha rivers with catchment areas of 12,850 km^2, 9,735 km^2, 1,625 km^2, 93 km^2, 83 km^2 and 70 km^2, respectively, are chosen for this study (Figure 1). Except Maidan and Qargha rivers that run dry for four to seven months a year, the rest of the rivers maintain fully or partially a minimum flow discharge during the dry months as well.

The three lowland rivers (Kabul, Logar and Maidan) have altitudes of 1,775 m, 1,813 m, and 1,870 m and the three upland rivers (Shakar-Dara, Estalef and Qargha) have altitudes of 2,168 m, 1,821 m and 2,007 m at their gauging stations respectively.

Kabul groundwater basin is divided into six subbasins as result of faulting surrounded by mountains. The six subbasins are the Central Kabul, Deh Sabz, Logar, Paghman and Upper Kabul, Shomali, and Panjsher. The subbasins are filled with quaternary and tertiary sediments and rocks. Quaternary sediments are typically less than 80 m thick in the valleys. The underlying tertiary sediments have been estimated to be as much as 800 m thick in the city of Kabul and may be more than 1,000 m thick in some areas of the valley (Mack et al., 2010).

A network of wells to measure and monitor groundwater levels to assess seasonal, areal and potentially climatic variations in groundwater characteristics in the Kabul basin are established by a joint cooperation of Afghanistan geological survey and U.S. geological survey. Groundwater levels are monitored in 71 wells in the Kabul basin since July 2004 (Taher et al., 2014). To understand the groundwater and surface water relation, some selected observation wells located in the vicinity of rivers are considered for this study. The wells are numbered according to Afghanistan geological survey database (Taher et al., 2014). The wells are completed in tertiary or quaternary sediments in depths of 4.9 m to 160 m (Akbari et al., 2007).



Based on U.S. Geological Survey Shuttle Radar Topography Mission data, 30-meter resolution

Figure 1. Location of the Kabul region basin study area in Afghanistan

2.2 *Groundwater levels and river discharge comparisons*

For comparison of groundwater levels fluctuations and river discharge rates, groundwater level measurements from 2004 to 2013 are used together with data from the corresponding river discharge. In most of the wells groundwater levels are measured once a month, except well number 64, where more frequent measurements are conducted (Taher et al., 2014).

For Kabul river in the central Kabul basin, as shown in figure 1, daily discharge measurements from 2005 to 2013 at Tangi-Gharu station are used to compare the groundwater levels measured in the wells number 64, 124, 127, 129, 133, 148, 152, 157, 162.2, 172 and 210.

In the Logar subbasin, Logar river discharge measurements from 2006 to 2013 at Sangi-Naveshta station are compared with the groundwater levels recorded in wells number 135, 143, 201 and 203. Maidan river discharge measurements from 2007 to 2013 at Tangi-Sayedan station are used to compare with groundwater levels measured at wells number 113, 117, 212 and 213.

In the Shamali subbasin, two rivers, namely Shakar-Dara river and Estalef are selected. Discharge measurements from 2009 to 2013 at Shakar-Dara and Estalef stations are compared with groundwater levels at wells number 20, 21, 22.1, 24, 25, 33, 41, 43 and 45. Finally, discharge measurements from 2007 to 2013 at the inflow of Qargha reservoir are compared with groundwater levels measured at well number 104.

2.3 *Suspended sediment transport data analysis*

Two data sets of suspended sediment transport measurements, conducted during years 1965 to 1980 and 2012 to 2015, are used in this study. Historic data exists for Kabul, Logar and Maidan rivers.

The data for Kabul river is divided into four seasons namely spring, summer, fall and winter to understand the effect of the snow cover, vegetation cover and availability of sediments for mobilization. Additionally, temporal changes in suspended sediment transport are analyzed to understand the type of hysteresis effect.

For Maidan and Logar rivers, historic and recent suspended sediment transport measurements as function of the river discharge are compared. The aim of this comparison is to show whether a systematic increase or decrease in the suspended sediment transport rate, due to modifications of catchment area as result of urbanization can be observed.

The measured suspended sediment transport is in addition compared between rivers with fully or partially dry period (Maidan), and that with minimum discharge during the dry period (Shakar-Dara) to understand the effect of dry period on the suspended sediment transport.

Finally, to understand the effect of catchment area's geology and land cover on suspended sediment yield, suspended sediment for the three upland rivers are compared with the three lowland rivers. In all cases, the suspended sediment transport rate is computed from the measured mean suspended sediment concentration multiplied by the flow discharge.

2.4 *River bed sediments analysis*

The aim of a river bed sediment analysis is to know the grain size distribution, stratification, armoring and possible colmation of river bed. Maidan river and Shakar-Dara river are selected for a bed sediment analysis in this study, since these two rivers are of interest for further hydro-sedimentological studies and have already available sediment data.

Eight river bed sediment samples from the surface, subsurface and as mixture of both layers are sieved and analyzed. The surface layer samples are taken from a depth of one grain size to approximately 15 cm, mix samples are taken from a depth of 15 cm to 25 cm and subsurface layer samples are taken from a depth of 25 cm or deeper. The samples locations are given in table 1, shown as distance from the respective river gauging station, both upstream and downstream. Additionally, photographs from river bed surface are taken and analyzed granulometrically to compare them with the results of the sieve analysis. Some photographs were manually improved by drawing boundaries to individual grains for a better detection by Basegrain photogranulometric analysis tool (Detert and Weitbrecht, 2013).

Table 1. River bed sediment samples taken from Maidan and Shakar-Dara rivers

Sample location	Sample weight	Layer
[Distance from station]	[kg]	[1st, 2nd or mixed]
197 m upstream*	19.50	first layer
197 m upstream*	9.20	second layer
2,220 m downstream *	21.50	mixed
3,289 m downstream *	19.60	mixed
783 m upstream**	22.80	mixed
river station**	10.80	first layer
1,284 m downstream**	27.60	first layer
1,284 m downstream**	16.00	second layer

*samples from Maidan and ** samples from Shakar-Dara river

3 RESULTS

3.1 *River discharge-groundwater level comparison*

Groundwater levels and associated river discharges are plotted in figure 2(a-f). The groundwater levels are shown from the ground surface on the right axis (dotted lines) and river discharges are shown on the left axis by red lines.

For central Kabul basin figure 2(a), the groundwater level fluctuations observed in all wells in the vicinity of Kabul river follow the discharge fluctuations in Kabul river. The groundwater level is some days offset to the river discharge peak, due to the fact that water moves slower in the soil than on the surface. Some sharp reductions in the groundwater level curves are due to pumping effects.

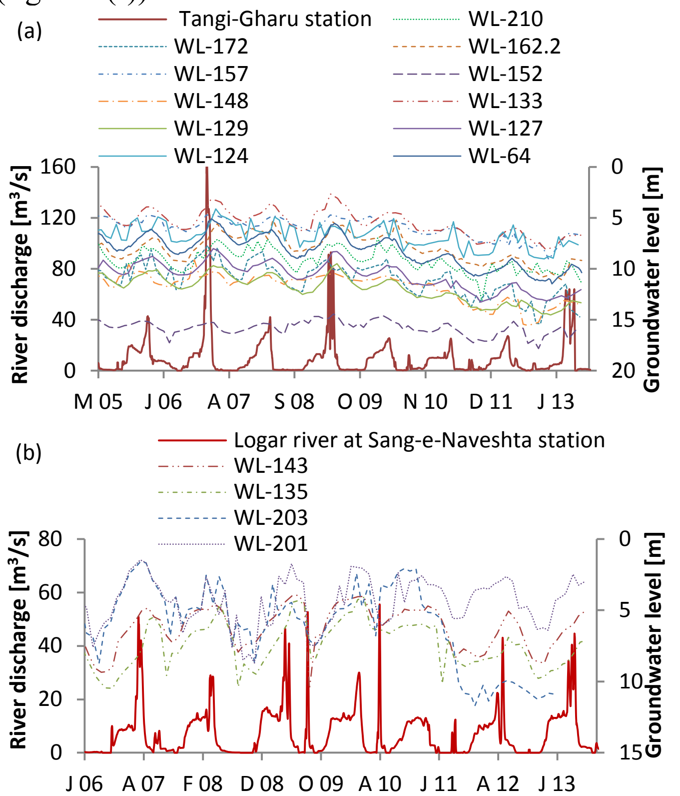
A similar trend is observed for Logar river shown in figure 2 (b). In Logar river, very short period flood peaks, for example in July 2009 and 2010, do not influence the groundwater level. This means that the short period high discharges do not significantly contribute to groundwater recharge and the water leaves the basin very quickly to downstream area. The longer the dry period lasts, the lower the groundwater levels would be.

The long dry period in the year 2011 to 2012 for Maidan river causes a decrease in the groundwater level much more than other dry periods as shown in figure 2(c).

In Shakar-Dara river, low peaks in the groundwater level are shown in figure 2(d). These peaks are not referable to natural processes, but are due to pumping before groundwater level measurement in well number 20 in July 2012 and in well number 22.1 in July 2010 and August 2012.

In Estalef river (figure 2(e)), in general the groundwater level peaks follow the river discharge peaks. However, in April 2010 the peak in groundwater level occurs about a month earlier than the river discharge peak (May 2010). This unexpected behavior could be due to measurement error.

For Qargha river typical correlations between groundwater and surface water level can be observed (figure 2(f)).



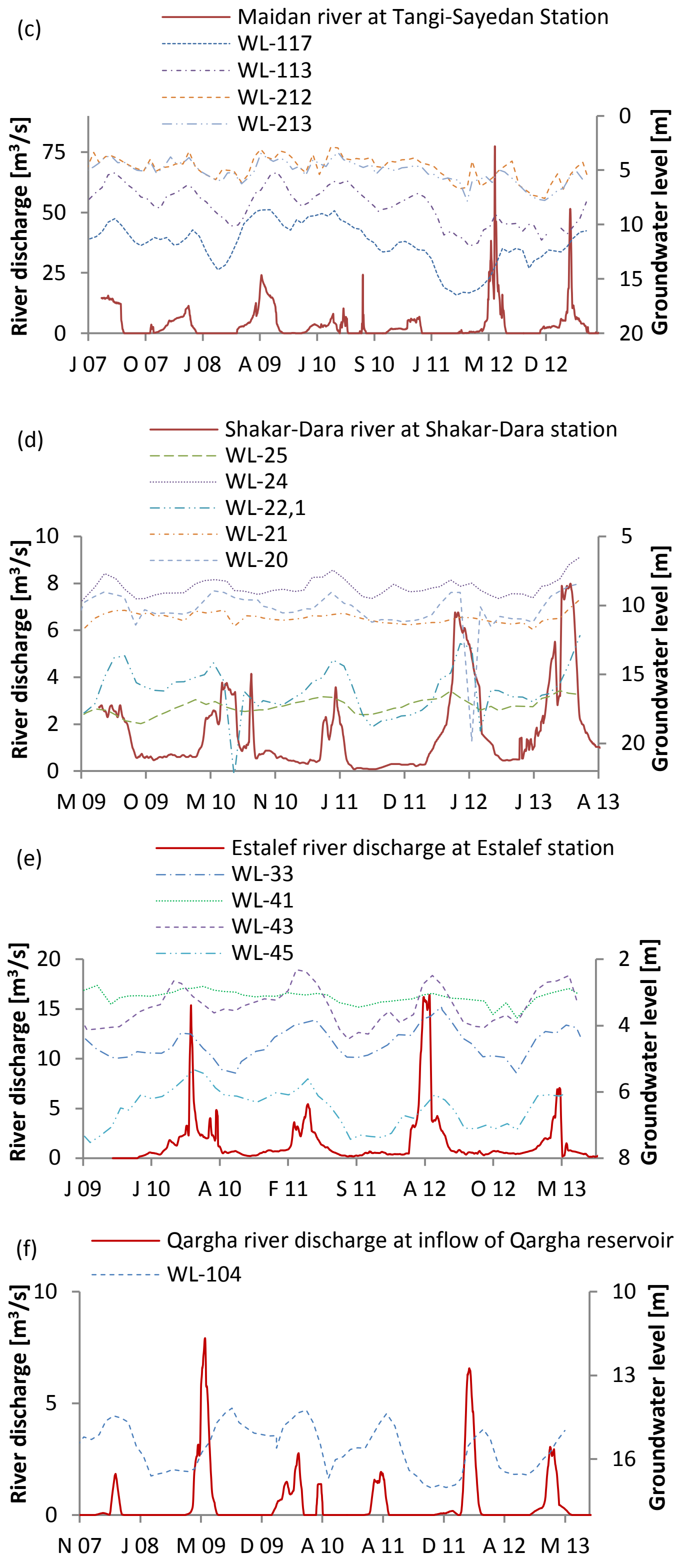


Figure 2. River flow discharges and groundwater levels at vicinity wells for (a) Kabul (b) Logar (c) Maidan (d) Shakar-Dara (e) Estalef and (f) Qargha rivers

3.2 *Suspended sediment transport*

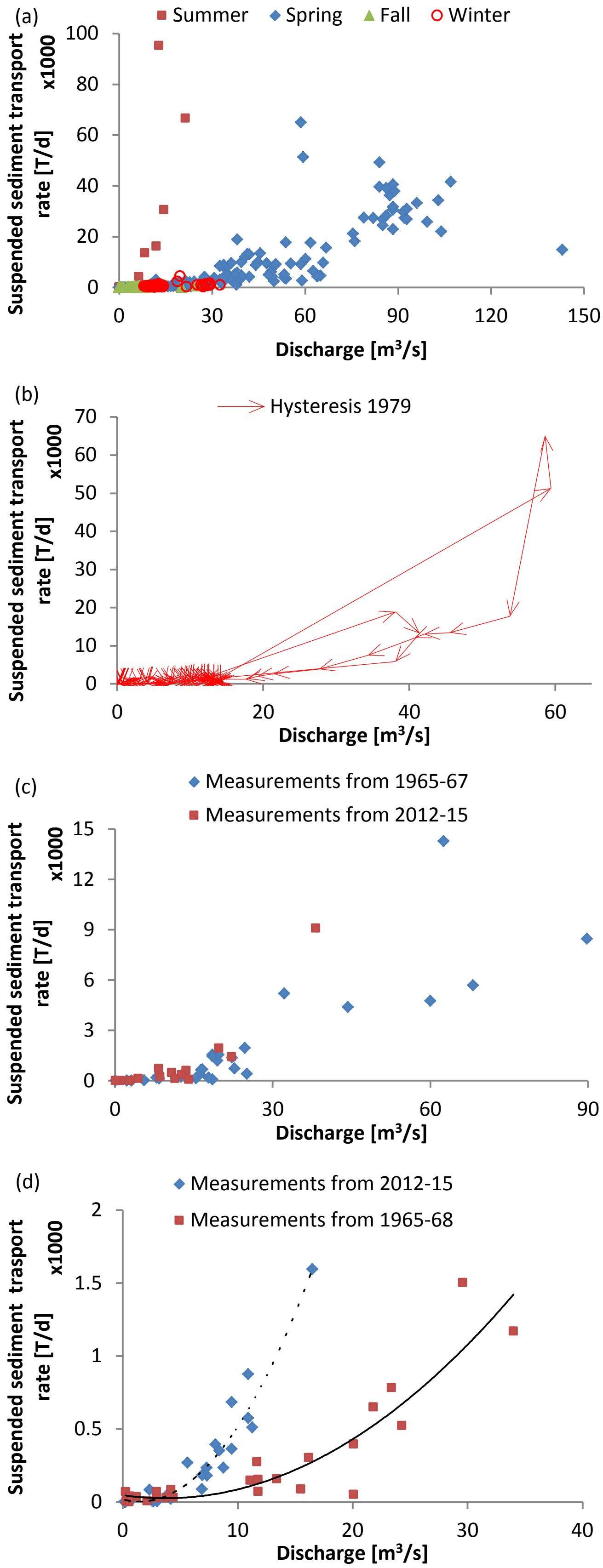
The suspended sediment transport rates (in tons per day) are calculated from average measured suspended sediment concentrations for all rivers and are shown as function of the flow discharge in figure 3(a-f). For Kabul river (figure 3(a)), suspended sediment transport occurs mainly during peak flows as result of snowmelt and rain in spring (March-June).

In August 1979 a single rain storm event caused extreme high suspended sediment transport rates compared to usual spring events. Unlike spring months, the snow cover does not exist in August and the occurring precipitation directly erodes soil from the catchment area and entrains a huge amount of wash load into the stream, resulting in a high suspended sediment concentration. In fall and winter, least amount of suspended sediment transport occurs, since the river either runs partially dry or has very low flow. Temporal analysis of continuous suspended sediment transport during two successive floods with peak discharges of 60 m^3/s and 41 m^3/s occurred in April and May 1979, show a clockwise hysteresis effect in Kabul river (figure 3(b)).

Historic and recent suspended sediment transport measurement comparison is made for Logar and Maidan rivers and shown in figures 3(c-d). No significant difference between historic data and recent suspended sediment transport is observed (figure 3(c)). However, For Maidan river, figure 3(d), the measurements of suspended sediment transport rate show a considerable difference between historic and recent data. A clear increase in suspended sediment transport rate in recent measurements (trend is shown in dotted line) appears. However, more frequent measurements are required to ensure that this shift is not due to any systematic error in the measurements. But in general excessive harvesting of vegetation cover from the catchment area, urbanization and climate change could be some possible reasons for this intensified suspended sediment transport rate.

For the three upland rivers, shown collectively in figure 3(e), relatively lower suspended sediment transport rate is measured. For instance, at a common discharge of 10 m^3/s, mean suspended sediment transport rate of 100 tons/day and 1,000 tons/day are measured for upland and lowland rivers respectively. Unlike lowland rivers that flow mostly in alluvium and unconsolidated materials, upland rivers flow through a rocky geology with limited supply of fine sediment. Additionally, the average barren land coverage exposed to erosion, reaches approximately 1% for the three upland rivers whereas 10% of lowland rivers' catchment area are barren land (Afghanistan land cover atlas, 2012). These seem to be the main reasons for lower suspended sediment transport in the lowland rivers. However, more measurements, specially during higher discharge rates are required to further validate this conclusion.

The impact of dry period on suspended sediment transport is shown in the figure 3(f) on the example of Maidan river with several months dry period (trend is shown in solid line) and Shakar-Dara river with no dry period (trend is shown in dotted line). Maidan river has an order of magnitude higher transport rate than Shakar-Dara river. The higher suspended sediment transport rate is not only due to the drying of river bed but because of a combined effect of catchment area's geology, land cover and availability of fine sediments.



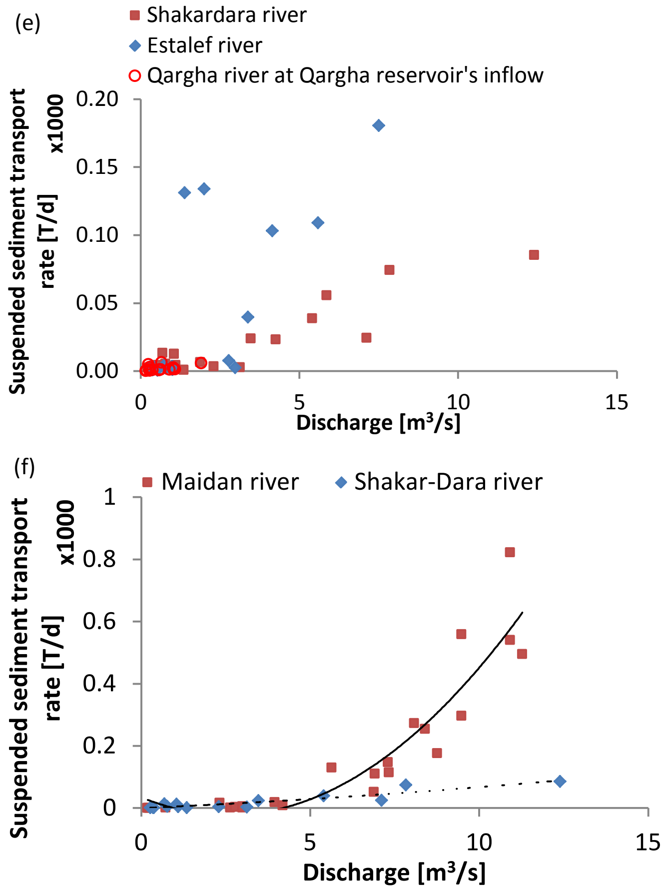


Figure 3. (a) Measured suspended sediment transport rate for Kabul river (b) hysteresis effect in suspended sediment transport during two successive floods in Kabul river (c) historic and recent suspended sediment transport for Logar river (d) and Maidan river (e) suspended sediment transport as function of discharge for three upland rivers (f) and comparison of suspended sediment transport in river with dry periods (Maidan) and without dry period (Shakar-Dara)

3.3 *River bed sediment characteristics*

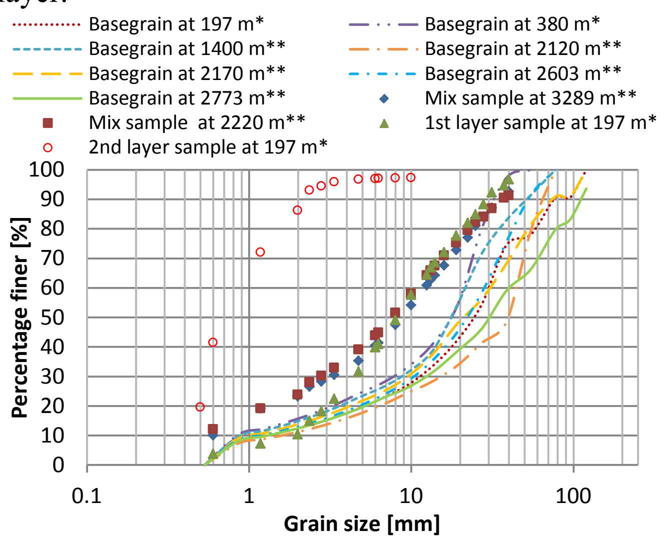
The results of the grain size distribution from sieve and the granulometric analysis by Basegrain tool are presented in figure 4(a) and (b) for Maidan and Shakar-Dara rivers respectively. The results of the sieve analysis are shown as points of circular, triangular, square and diamond shape and Basegrain analysis results are shown by series of lines and dotted lines. The results of the sieve analysis for Maidan river show a significant difference between the first layer (surface layer) and second layer (subsurface) grain sizes distribution. The surface layer is containing about 3.8 % of fine sediments (<0.5 mm) within the coarse river bed sediments with mean grain diameter ($d_{m=}$11 mm), which indicates that the river bed is colmated. This phenomenon is also seen in the photographs taken from the river bed surface shown in figure 5. The fine sediments accumulation in the surface layer deposits because extended low flow period that causes the deposition of suspended fine sediments. The existence of fine sediments in the surface layer also supports the clockwise hysteresis in suspended sediment transport (see section 3.2) which contributes to high suspended sediment concentration by resuspension from the bed surface during the rising limb of the flood.

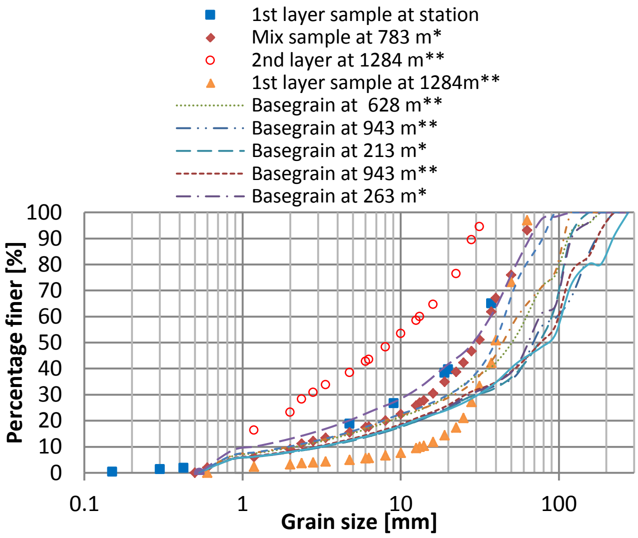
Granulometric analyses by the software tool Basegrain were conducted by using the photographs taken from the bed surface at different locations. The granulometric analysis shows a rather coarse grain size distribution with mean diameter ranging from d_m= 19 mm to 42 mm for the river bed surface layer, since only surface grains excluding very fine grains can be detected by Basegrain. The grain size distribution analysis results vary within a certain range from one location to another and also within a single location due to inhomogeneous nature of sediment distribution in the river bed's surface layer.

For Shaker-Dara river (figure 4(b)), the bed is composed of sediments size from medium sand to boulders. No colmation or clogging of the river bed is observed, rather an armored surface layer is observed. The average mean diameter ranges from d_m= 20 mm to 103 mm. The subsurface layer is composed of medium sand to coarse gravel with a mean diameter of d_m= 10 mm.

Unlike Maidan river, Shakar-Dara river has a distinct surface layer with almost no fine sediment fraction. This can also be seen from the results of sieve and Basegrain analysis. The difference in the results of both methods is smaller for Shakar-Dara river, because almost all grains in the surface layer can be fully detected by Basegrain. The slight percentage of fine sediments originates from the surface layer sample that may include some materials from a finer subsurface layer.

The surface layer samples and mixed samples show a similar grain size composition in both rivers, due to the fact that mixed samples contain very small portions of subsurface layer sediments. Therefore, the mixed samples can also be considered to represent the grain size composition of the surface layer.





*Photographs and samples from upstream of river station
**Photographs and samples from downstream of river station

Figure 4. River bed sediments grain size distribution for (a) Maidan river (b) Shakar-Dara river

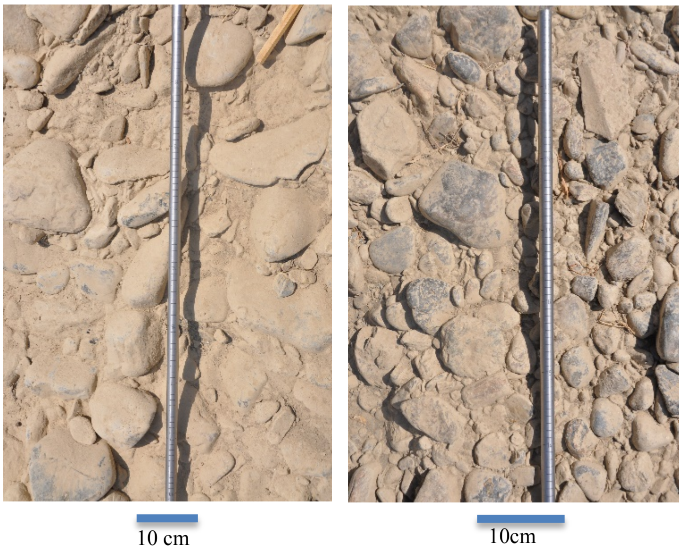


Figure 5. External colmation/clogging of river bed at Maidan river

4 CONCLUSIONS

In this work, hydro-sedimentological characteristics of selected intermittent lowland (Kabul, Logar, Maidan) and upland (Shakar-Dara, Estalef and Qargha) rivers in Kabul region of Kabul of river basin are studied. The first two rivers are perennial at most of its flow length, whereas the last four rivers are intermittent rivers which are partially or fully drying up from one to several months per year. The main water source for all of the tested rivers are mainly snow and rain in winter and spring months.

As dominant hydrological characteristics of intermittent rivers, groundwater and surface water relationship is studied by comparing groundwater levels at vicinity wells to river discharges. The groundwater level fluctuations show a close interaction with river discharges flowing nearby the observation wells. In all rivers, the seepage loss through the river bed is seen to be a function of the river discharge magnitude and its duration.

Historic and recent suspended sediment measurements show that suspended sediment transport mainly occurs during the spring season (March-May), when the rivers show the highest discharge rates. The suspended sediment transport rate show a similar trend for the lowland rivers, while in the three mountainous upland rivers, an order of magnitude lower transport rates are observed. An explanation could be that lowland rivers flow in the study length through alluvium and unconsolidated sediments whereas the three upland rivers flow through coarse and consolidated materials. Secondly, the barren land coverage, exposed to erosion, is 10% in lowland rivers and 1% in upland rivers. A clockwise hysteresis effect was observed in continuous suspended sediment transport behavior of Kabul river. A comparison of historic suspended sediment measurements (1965-68) and recent measurements (2012-15) show an intensified suspended sediment transport rate in Maidan river, which can be due to anthropogenic impacts on the catchment area as result of urbanization, excessive harvesting of vegetation cover and/or climate change.

The river bed sediment analysis for Maidan and Shakar-dara rivers is made by sieve and photogranulometric analysis of river bed sediments. The analysis shows a finer surface and subsurface sediment grain size composition for Maidan river compared to Shakar-Dara river. From the analysis, it can be seen that a considerable amount of fine sediments has clogged the coarse river bed in Maidan river. The comparison of sieve and granulometric analysis of river bed surface layer's sediments show a coarser granulometric distribution by using the software tool (Basegrain), due to presence of fine sediments in the surface layer that cannot be detected in granulometric analysis. Unlike Maidan river, Shakar-Dara river has a coarse sediment surface layer followed by a second medium to coarse sand subsurface layer. The granulometric as well as the sieve analysis of river bed surface layer sediments show good agreement for Shakar-Dara river, because there are no fine sediments in the surface layer and all grains can be detected in granulometric analysis.

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