JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2021.139939
2022, No. 52 (I–III): 21–26

Importance of river sediments in soil fertility

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RECEIVED 23.03.2020 REVIEWED 19.02.2021 ACCEPTED 26.04.2021

Abstract: Article deals with a fractional and chemical composition of sediments from the sediment reservoir in Ilyash village, Ferghana region, Uzbekistan (Syr Darya river basin) and analyses their feasibility. As a key factor in the study of this process was considered the fractional and agrochemical composition of sediments moving with water in the sediment reservoir, and the change of their share in the water along the length of the reservoir. The main composition of the sediments in reservoir consists of fractions >0.25 and 0.25–0.01 mm, with the average fraction of 69% in the inlet and 60% in the outlet. The river sediments are rich in minerals important for the irrigated cropland. Based on the results we conclude that it is possible to regulate the number of chemical compounds in the water by controlling the exploitation regime of reservoir and the sedimentation process in it.

Keywords: agrochemical composition of sediment, reservoir, sediment, sediment distribution, sediment grain size

INTRODUCTION

Sediments in a reservoir are usually the result of soil erosion process in the landscape. Those soil particles move within the basin by force of water or wind [MIDLER *et al.* 2017] and are transported by water within the river network. The sediment transport in the river network is affected by the several factors (particle size, water velocity, shear stress, stream morphology etc.) on the base of which the sedimentation and transport process are regulated (e.g. KEESSTRA *et al.* [2012], ARIFJANOV *et al.* [2019a]).

Since ancient times basin of Amu Darya, Syr Darya, Zarafshan and other basins within Uzbekistan were modified for the irrigation purpose of cropland located on fertile beds of clay, brought by rivers. These rivers transport large amount of sediments rich in minerals by main and internal canals to agricultural fields. The water flow in the canals is the only source of transporting minerals-rich sediments to cropland [JURIK *et al.* 2019; WALLING 1983]. Therefore, the cropland of Uzbekistan is very fertile [ARIFJANOV *et al.* 2019c; SAMIEV *et al.* 2019; WALLING 1983].

However, in recent years, the management of the Amu Darya and Syr Darya rivers, and the construction of several reservoirs and other hydrotechnical structures, have had a significant impact on the sediment discharge and solid matter. Due to the high demand for water in agriculture and household use, sediments silt up in the water intake structures, reservoirs, main and inland irrigation canals. This, on the one hand, delivers ready mineral fertilizers to agricultural fields, while on the other hand, it has a negative impact on the efficient operation of water structures [ARIFJANOV *et al.* 2018; 2019b; LIU *et al.* 2018; SHAHROKHI *et al.* 2013].

It is necessary to seek a complete solution of the problem by implementing the dynamics of distribution of fractional and chemical composition of river sediments by the system river – canal/reservoir – cropland. It is necessary to take into consideration the canal hydraulic and hydrological parameters and river sediment parameters in the river – canal/reservoir – cropland system during the river management processes. An important aspect of the research is that the fractionation of sediments can be controlled by chemical composition [LIU *et al.* 2018; RAI *et al.* 2017]. It is possible to combine fractional and chemical analysis of sediments on a systematic basis to assess the importance of river sediments, and to effectively use them in the river – canal/reservoir – cropland system [JULIEN 2018; JURIK *et al.* 2019].

The aim of the study is to determine whether sediments can be used as efficient natural resources by achieving separation of sediments into fractions, leaving large sediments aside for later use as building materials. Several researchers (e.g. LATIPOV and ARIFJANOV [1994], ARIFJANOV *et al.* [2019b; 2019c]) stated that the Amu Darya River contributed to the irrigation of fields, improved soil fertility and created good conditions for vegetation growth.

MATERIALS AND METHODS

DESCRIPTION OF THE OBJECT AND RESEARCH AREA

The Sokh feeding canal as a tributary of the Great Fergana Canal is 3.45 km long, 2.25 km of which are made of concrete. Maximum water discharge is 20 $m^3 \cdot s^{-1}$. Sediment reservoir is in Ilyash village of Uzbekistan district of Ferghana region (Fig. 1). The sediment reservoir is 150 m wide and 350 m long The main purpose of the reservoir is to store water for the irrigation of crop land, and therefore it is filled in regular intervals (3 months per year). For the rest of the time it can be cleaned and repaired. An average of 100,000 m^3 of sediments is removed over the year. Analysis of existing methods for calculating the sediment distribution along the length of the canal shows that these methods have been developed mainly for regulated structures with constant cross section, with the average flow rate being constant at the observed length of the riverbed.

DATA COLLECTION

Collection of suspended sediment samples was done by glass bathometer and for bottom sediments sampling Shamov bathometer [SHAMOV 1954] was used. All samples were filtered with filter paper and chemical and mechanical compositions of sediments trapped on the filter paper were analysed in the laboratory.

The mass of sediment samples (in g) used for the laboratory analysis was based on the required for experimental analysis, and the volume (V) of the taken sample during the field sampling of turbidity of river water is given by the following formula:

$$V = \frac{1000 \cdot \alpha}{S} \tag{1}$$

where: α = the required mass (g), S = water turbidity ($g \cdot m^{-3}$).

GRAIN SIZE ANALYSIS

River sediments come in a variety of sizes and shapes, and these features have a major impact on their movement and distribution in streams. In hydraulics and engineering hydrology, river sediments are conventionally divided into bed load and suspended sediments [IMRAN 2008]. Bed load sediments move close to the bottom of the river, and their movement is periodic. As the flow hydraulic parameters change, the bed load sediments can rise to the upper layers of the flow and form a suspended sediment area. Suspended sediments move in a suspended state in all layers of the stream, between the bottom of the stream and the free surface. Their suspended motion is related to the degree of turbulence of the flow and the size of the sediment particles. In the existing literature (e.g. OKEYODE and JIBIRI [2013], MOHTAR *et al.* [2017], ARIFJANOV *et al.* [2019a]) special attention is paid to the grain size in the description of river sediments.

The mass in the range of 0.5–2.0 g of sediments was used in the analysis. If the sample was very small, a mass of 0.25 g was taken. Each sample was mechanically sorted with sieves to fractions of 1–0.5, 0.5–0.2, 0.2–0.1, 0.1–0.05 and <0.05 mm. If the sample contains particles larger than 1 mm, they are roughly sifted through a sieve. For particles smaller than 0.05 mm, the pipette method [University of Iowa 1941] was used. Weights and fractions were measured on an analytical balance. The granulometric curves were created based on these results. Sediment type of clay, silt and sand is identified as sediment with sizes of <0.002, 0.002–0.5 and >2 mm, respectively.

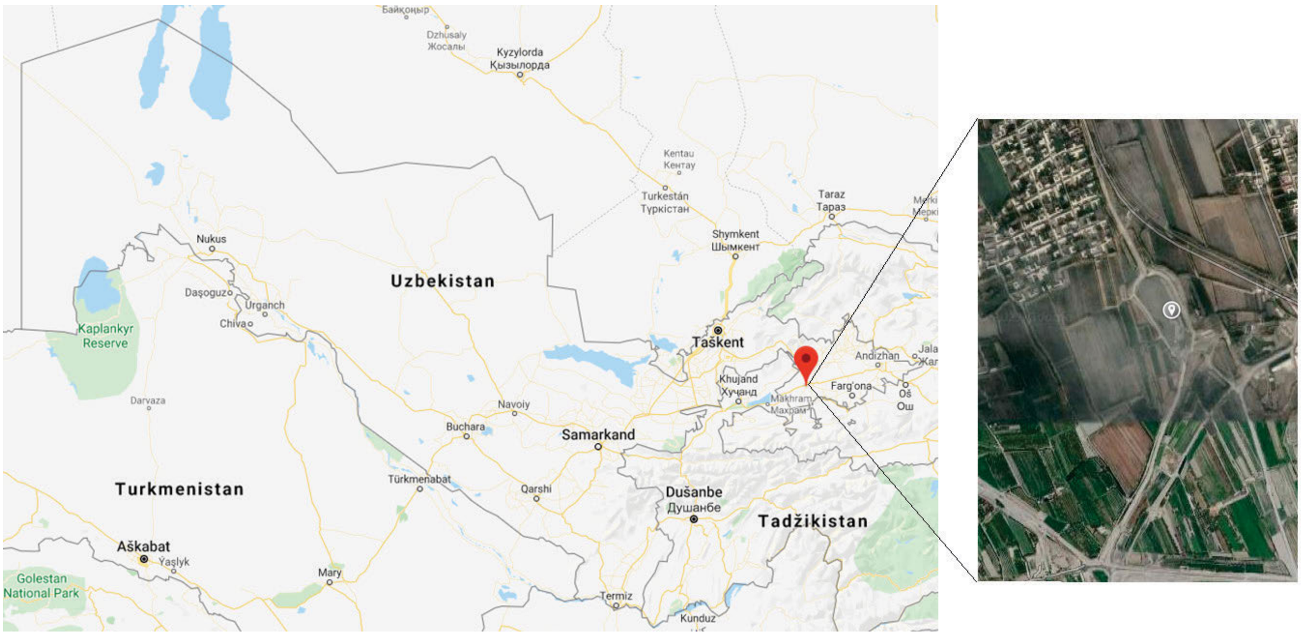

Fig. 1. Location of the area of interest; source: Google [undated a, b], modified

CHEMICAL COMPOSITION ANALYSIS

The Tyurin method, which is easy to perform and does not require much time, was used to determine the amount of humus in the turbid sediment. The total and mobile amounts of nitrogen in sediments were determined by the Kjeldahl method, the determination of the amount of phosphorus by Machigin–Protasov, and the amount of potassium was settled by the method of Protasov. In addition, dry residue, chlorine ions were also detected in various ways [Arinushkina 1979].

RESULTS AND DISCUSSION

According to the analysis of the results, sediments contain high amount of minerals. Irrigation sediment reservoirs play an important role in keeping certain portions of the river water flowing and delivering it to the cultivated areas with irrigation water as the main mineral source. A decrease was found in the amount of suspended sediments in the water from inlet to the outlet of the sediment reservoir (Tab. 1).

Table 1. Mass of the sediments in one litre of water from sediment reservoir

Sampling area	Filter mass	Sediment and filter mass	Net mass of sediment
	g		
Inlet to the sediment reservoir (right bank)	8.834	4.590	4.244
Inlet to the sediment reservoir (left bank)	9.302	5.120	4.182
Central part of the sediment reservoir (right bank)	8.292	4.310	3.982
Central part of the sediment reservoir (left bank)	8.015	4.400	3.615
Outlet of the sediment reservoir (right bank)	7.009	4.510	2.499
Outlet of the sediment reservoir (left bank)	8.281	4.870	3.411

Source: own results.

Suspended solids concentration very well illustrates water quality [Josimov-Dundjerski *et al.* 2015]. Deposit of sediments with grain size exceeding 0.1 mm in diameter in the canal can lead to turbidity. The average turbidity at the inlet was 4.0 and 3.3 $g \cdot dm^{-3}$ at the outlet. The turbidity varied from 2.45 to 3.6 $g \cdot dm^{-3}$. The flow rate of total suspended solids is 19%. The optimal clean-up rate is usually between 45 and 65%. Consequently, the sedimentary insulation of the river is insufficiently controlled [Latipov, Arifjanov 1994; Liu *et al.* 2018; Rai *et al.* 2017; Samiev *et al.* 2019; Walling 1983].

Most of the sediments in inlet to the GFC-Sokh reservoir were 0.1 mm diameter sediment particles (Fig. 2). Similar situation is in the centre part and at the outlet (Fig. 3) from the reservoir, where also most of the sediments were 0.1 mm diameter. However, the quantity of particles differs, specifically at the outlet, where it was 4.7% less on the right bank, 21.6% less in the centre, but 14.0% more on the left bank. Opposite situation occurs in case of particles of 0.05 mm diameter; there is increase on the right bank and in the centre (22.5 and 29.3%, respectively) and decrease on the left bank (20.6%). Fractional distribution of the sediments in the centre of the reservoir corresponds to the rest of the reservoir, just the amount of each category is between the amounts at the inlet and outlet. It should be noted that this amount varies over the years and depends on the hydraulic and hydrological parameters of the flow. Sediment composition varies over the years and this change is in an interval 10–15%. From the analysis of sediment distribution along the GFC drainage length, it is evident that the efficiency of the sediment is relatively low during large water consumption periods.

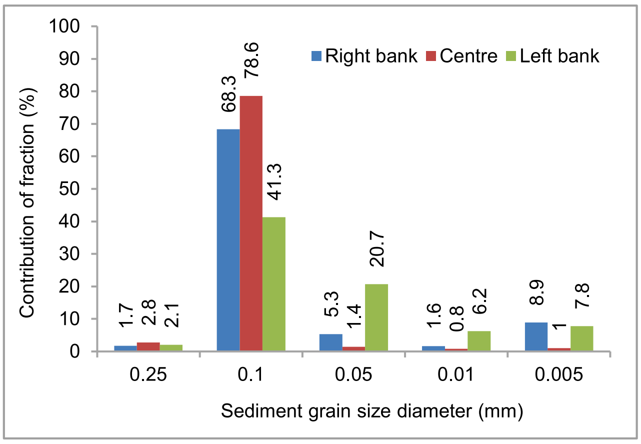

Fig. 2. Histogram of sediment particle size distribution in the inlet; source: own study

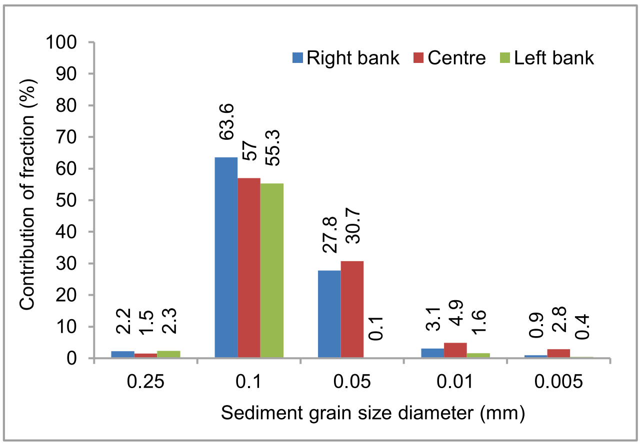

Fig. 3. Histogram of sediment distribution in the outlet; source: own study

The results of the granulometric analysis (Fig. 4) showed that most of the fraction particles are over 0.05 mm (more than 85% in the inlet and more than 50% in the outlet). So, the main component of the sediments is sand which is in the contrast to results from Mirishkor and the Big Fergana Channel [Arifjanov *et al.* 2018]. The average amount of sand in the inlet is 83%, in the central part 66%, and at the outlet 74% (Tab. 2). It should also be noted that the amount varies over the years and depends on the hydraulic and hydrological parameters of the flow [Arifjanov *et al.* 2018; 2019c]. This amount of sand can have a positive effect on soil moisture transfer to the sand fields. Also, higher volume of silt content in the outlet has a positive impact. The physical clay content is approximately at the same minimum value in the whole reservoir (0–5% in the inlet and 1–4% in the outlet). The transfer of these sediments to the cultivated fields does not have a negative impact on the physical properties of the soil [Arifjanov *et al.* 2019c; Julien 2018; Jurik *et al.* 2019].

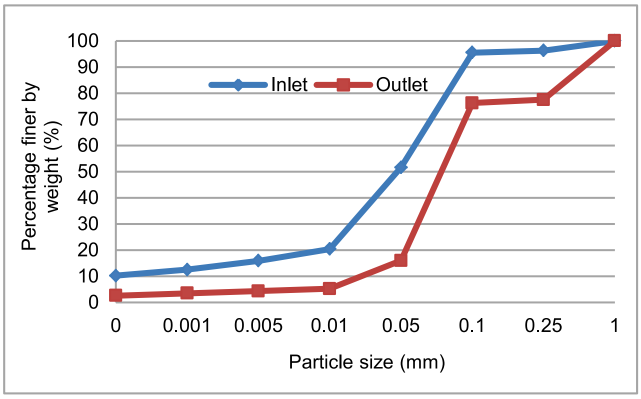

Fig. 4. Granulometric curves representing particle size percentage in outlet and inlet; source: own study

Table 2. Fraction structure of sediment according to US Triangle (in %)

Sampling area	Sand 0.05–2.0 mm	Silt 0.002–0.05 mm	Clay <0.002 mm	Name by FAO
Inlet to the sediment reservoir (right bank)	85	12	3	LS
Inlet to the sediment reservoir (middle of the banks)	97	3	0	S
Inlet to the sediment reservoir (left bank)	66	30	5	SL
Central part of the reservoir (right bank)	70	29	1	SL
Central part of the reservoir (left bank)	62	36	1	SL
Outlet of sediment reservoir (right bank)	66	31	2	SL
Outlet of sediment reservoir (middle of the banks)	59	37	4	SL
Outlet of sediment reservoir (left bank)	97	2	1	S

Explanations: LS – loamy sand, S – sand, SL – sandy loam.
Source: own results.

According to the analysis, the largest amount of minerals in river water is contained in sediments. Irrigation sediments play an important role in capturing a certain portion of sediments discharged by river water and sending it to the crop fields along with irrigation water as a fertilizer rich in essential minerals [Arifjanov *et al.* 2019c]. Sediments can be used to fertilize light soils and to remediate degraded areas in case of sufficient available content of macronutrients which can be recycled in the agriculture [Gałka, Wiatkowski 2010]. Therefore, the chemical composition of the sediment fractions was analysed. From the irrigation importance point of view, special attention was paid to chemical compounds of N-NH_4, P_2O_5, K_2O. It is also important to note that by controlling the amount of sediment in the reservoirs, the amount of the above compounds can be regulated. This is evidenced by the variation in the input and output of the reservoir (Tab. 3). Except the N-NH_4, other agrochemical components of sediments increased at outlet, humus about 149%, P_2O_5 about 18.5% and K_2O about 55.3%. Both amounts, in inlet and outlet, are much lower than amounts presented by Baran *et al.* [2019]. Arifjanov *et al.* [2018; 2019c] determined that with the decrease diameter of the sediment amount of P_2O_5 and K_2O increases but amount of N-NH_4 decreases. Arifjanov *et al.* [2019c] presented that large amounts of mineral fertilizers were found in small river sediments. In case of BFC-Sokh reservoir this conclusion is valid for N-NH_4, but we recognise higher value of P_2O_5 and K_2O with lower ratio of particles smaller than 0.005 mm in outlet. However, Baran *et al.* [2019] investigated that even small amount of sediments can increase the available forms of phosphorus and potassium.

Table 3. Agrochemical composition of sediments from the reservoir

Sampling area	Humus %	N-NH_4	P_2O_5	K_2O
		mg kg^{-1}		
Inlet	0.49	14.3	17.4	56
Outlet	1.22	11.2	20.6	87

Source: own results.

Among the presented chemical compounds, a high percentage of sulphate, calcium, sodium and potassium compounds were recognised (Tab. 4). The ratio of sulphate was the highest and the rest of compounds were almost at the same rate, range between 0.009 and 0.015%. The weight ratios of Ca:Mg, Ca:K, K:Mg and K:(Ca+Mg) can be used to indicate the usability of bottom sediments, as they are important indicators of the ability of soils to supply plants with these elements [Wójcikowska-Kapusta *et al.* 2018]. These ratios are low and in optimal values. The decreasing order of ions Ca > (Na+K) > Mg corresponds to results of Wójcikowska-Kapusta *et al.* [2018]. Analysis of the chemical composition of sediments by FAO characteristics revealed that the sediments were not saline at all (Tab. 4). Even the sediments, as a soil amendment, have an economical and environmental value; each batch intended for environmental use must be subjected to a chemical analysis [Baran *et al.* 2019], mainly to check the content of heavy metals.

Table 4. Chemical composition sediments from the reservoir

pH	Dry residue	Dissolved ions content					
		HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+ K^+
	%						
7.7	0.142	0.009	0.010	0.079	0.015	0.009	0.014

Source: own results.

CONCLUSIONS

The distinctiveness of the GFC-Sokh reservoir is the fractional composition of the river sediments about 89% of the 0.05 mm of the grain size. The chemical composition of river sediments in the digger is rich in the nutrients required for cultivated fields. The study of incoming and outgoing sediments reveals that sediments are isolated by water, separated into natural fractions, and altered by chemical composition. Similar processes can be observed in the GFC-Sokh reservoir outlet.

The analysis of sediment distribution in the GFC-Sokh reservoir was analysed by US triangle and FAO as described above. According to the results of analysis, the amount of sand particles in the reservoir decreased by a percentage of the whole length at the time of sampling. Silt particles increase and the amount of clay particles does not change significantly. Thus, the analysis of the distribution of sediments along the length of the GFC-Sokh sediment shows that during periods of high water consumption, the efficiency of the sediment reservoir is relatively low. Based on the results we can conclude that:

- bottom and suspended sediments from GFC-Sokh reservoir contain useful amount of silt and clay which can have positive effect on soil moisture,
- application of sediments should not have negative effect on the physical properties of the soil,
- clay and partly also silt particles are distributed by the irrigation water to the agricultural fields, therefore their amount within the reservoir decrease the amount of minerals,
- even small amount of sediments can increase the available forms of phosphorus and potassium and thus improve soil fertility,
- the concentration of macronutrients can be arranged in order Ca > (Na + K) > Mg.

FUNDING

This work was supported by the grants APVV-16-0278 and VEGA 1/0747/20.

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