American Journal of Water Resources, 2020, Vol. 8, No. 2, 92-107
Available online at http://pubs.sciepub.com/ajwr/8/2/5
Published by Science and Education Publishing
DOI:10.12691/ajwr-8-2-5

Estimating of Sediment Mass on the Floodplain of Long Xuyen Quadrangle - An Giang, Vietnam

Tran Thi Hong Ngoc[1,*], Vo Khac Tri[2]

[1]Faculty of Engineering-Technology-Environment, An Giang University - Vietnam National University, Ho Chi Minh City, Vietnam. No 18 Ung Van Khiem Street, Dong Xuyen Ward, Long Xuyen City, An Giang Province, Vietnam
[2]The Southern Institute of Water Resources Research, 658 Vo Van Kiet Street, Ward 1, District 5, Ho Chi Minh City, Vietnam
*Corresponding author: tthngocagu@gmail.com

Received March 10, 2020; Revised April 11, 2020; Accepted April 22, 2020

Abstract This paper presents the result of suspended and deposited sediment measurements on the floodplain of Long Xuyen Quadrangle-An Giang (LXQ-AG) along the Cambodia - Vietnam border during a flood event in 2018. GIS and Remote sensing techniques were used to build maps for the flooded areas. Water level and discharge were also measured on main channels and on the floodplain. The two correlation equations between deposition sediment, Suspended Sediment concentration (SSC) and discharge were build. The results of Landsat interpretting showed that inundation area of the floodplain was 35,765 ha. SSC and deposited sediment decreased with distance from the main channels. The results showed thattotal deposited sediment mass brought to the floodplain during a single flood event in 2018 was 5.023 million tons (14.04 kg/m^2).

Keywords: *GIS, remote sensing, floodplain, deposited sediment, suspended sediment, Long Xuyen Quadrangle*

Cite This Article: Tran Thi Hong Ngoc, and Vo Khac Tri, "Estimating of Sediment Mass on the Floodplain of Long Xuyen Quadrangle - An Giang, Vietnam." *American Journal of Water Resources*, vol. 8, no. 2 (2020): 92-107. doi: 10.12691/ajwr-8-2-5.

1. Introduction

In Long Xuyen Quadrangle-AnGiang (LXQ-AG) an area of 353,666.85 hectares, in which there are not only two major rivers, the Mekong River (Tien River), the Bassac River (Hau River) but also many small rivers, canals, lakes and streams; they form a vast river network with a total length of 7,351 km covering most of the province. River density of the whole province reaches 1.6 km/km^2, at the highest level in the Mekong Delta. The hydrological regime depends predominantly on the Mekong River water regime. In rainy seasons, the flow velocity increases significantly, and the river water carries huge amount of sediments [1]. In the flood seasons, at the estuary, SSC ranges from 500 to 1.000 mg/l of river water, while in the floodplain away from the estuary it ranges from 40 to 80 mg/l. In the riparian zone of the Tien and Hau Rivers, annual silt deposits on the soil surface layer are around 5-7cm thick, and 6-7.5cm in the floodplain [2]. Lu et al. (2014) estimated 67 million tons of transported sediment by the floods in 2000 for Hau River [3]. Flooding also improves soil quality by flushing out fields, which reduces acidity and agrochemical residues, while contributing to wetland protection and biodiversity conservation [4,5].

After decades of exploitation, LXQ-AG became rich in agricultural fields with flood mitigation projects such as building 5,393,468m dykes to protect crops [6]. This transformation has achieved remarkable results and changed the face of rural areas today. Although, these embankments have achieved considerable economic benefits, they also have drawbacks. There are many suggestions that the flood prevention dykes system has been causing unforeseen consequences such as soil degradation, increased activity by pests, decreased crop yields due to blocking of annual silt deposits on the floodplains [7], water quality problems [8,9], riverbank erosion [10], and salt water intrusion [11,12]. The quality, quantity and timing of flooding overflows from rivers and waterways into the LXQ has led to a lot of hydrological changes. The water level and its oscillations are no longer seasonal as they are now dependent on the operation of a system of culverts [13]. This decreased sediment, and loss of its associated nutrients, will have a largely negative impact on agricultural production in the floodplain, which will lead to a major impact on the ecological environment, and economic development of the region [14]. Reduced sediment will increase sharply the cost of agricultural production. Agricultural development can provide additional and alternative sources of nutrition for humans, but the exact impact of these activities on the delta are still developing and not yet well understood.

Another problem is that sediment is a major concern across borders in neighbouring countries. The Mekong basin plan is for the construction of 88 hydropower dams by 2030, which will have a very substantial impact on the river's sediment [15]. Manh's 2014 results indicate that hydropower development is the dominant driver of the change to the floodplain sediment dynamics of the Mekong Delta [16]. If these planned developments are realised, overall floodplain sedimentation in the whole Mekong Delta would decrease by approximately 40%, and the sediment mass to the South China Sea would be reduced to half of the current rates [17].

This reduction will likely have profound implications for the productivity of agriculture and the fishery within the lower Mekong River and Delta, as well as the offshore fishery and the sustainability of the Delta landform itself [18]. The silt shortage is not only related to losses of soil nutrient, but also a shortage of material to help protect the southern Mekong delta, the long-term process of adaptation to land loss by rising sea levels [19]. The agricultural productivity depends on the sediment and associated nutrient input to the floodplains by the annual floods. However, no quantitative information regarding their sediment trapping efficiency has been reported [20]. Therefore, the aim of this study is to make an estimation on the total sediment mass of a floodplain in a single flood in 2018 using sediment traps, made of artificial grass, and to evaluate the spatial variability in sediment accumulation in that plain. From those findings, recommendations for planning the sustainable use of water resources and adjustment for operation of a reasonable flood control system in the LXQ-AG will be constructed.

1.1. Study Area

The LXQ-AG is located on the north western side of the delta, on the eastern side of the Vietnam-Cambodia border. It is located from 10°11 'to 10°58' north latitude; and from 104°46' to 105°35' east longitude (Figure 1). The area is low and flat, over 80% of the area lies within elevation of 0-1.0 m; 10% of the ground elevation is from 1.0-2.0 m above sea level; 10% of the area is mountainous focused in Tri Ton and Tinh Bien districts and has elevation from 2-700 m. LXQ-AG is located in the tropical monsoon climate, which is hot and humid all year round. There are two seasons: dry and wet season. The rainy season is from May to November and the dry season is from November to April. The average annual temperature is about 27°C, the average annual rainfall is about 1,130 mm. The annual average humidity is 75 - 80% [21].

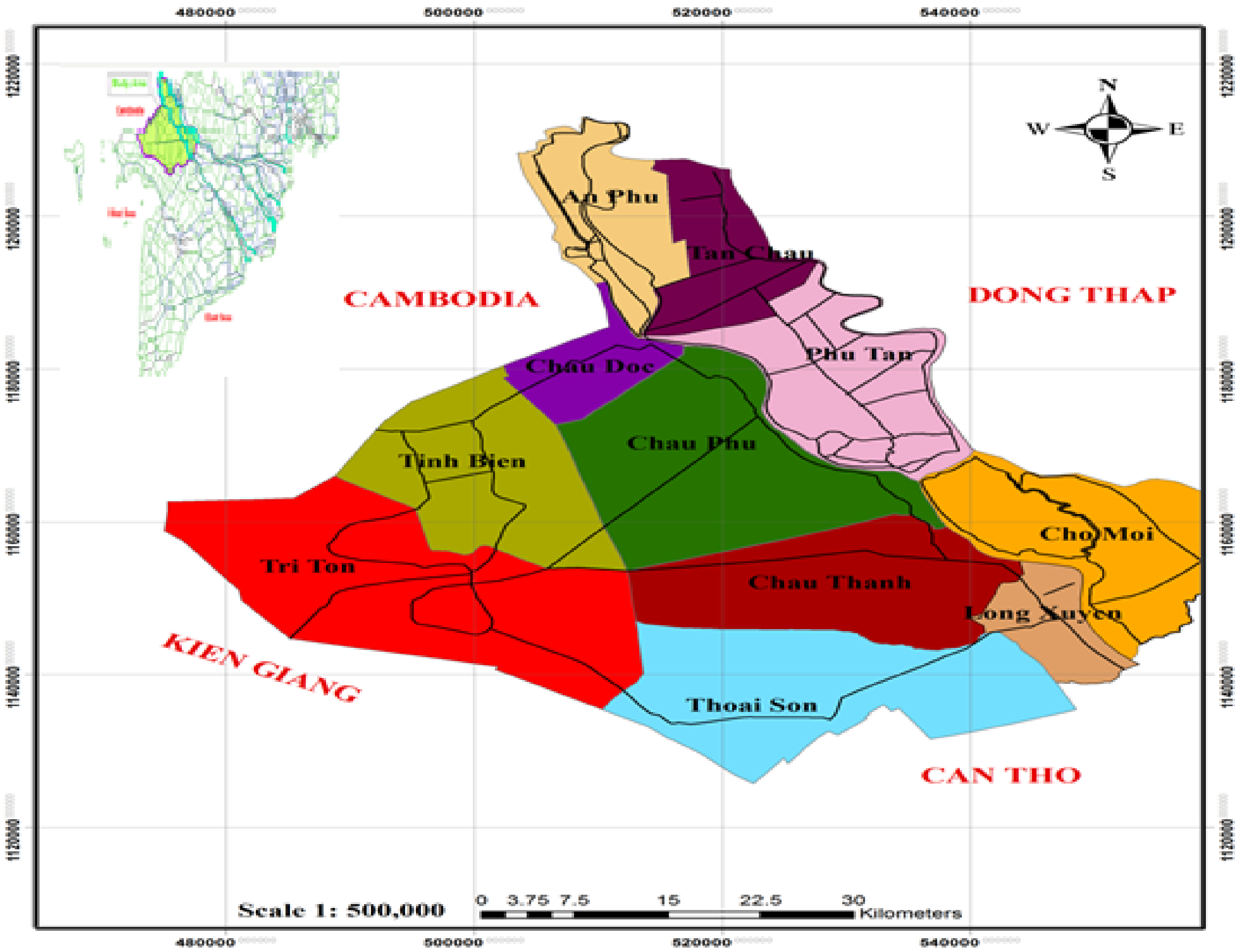

Figure 1. Location of the study area LXQ An Giang

LXQ-AG is the first area to receive and use the water of the Mekong River from Cambodia when it flows into Vietnam through two major rivers: the Hau and Tien rivers. These rivers run parallel to each other from the Northwest to the Southeast to the sea, over almost 220-250 km. Annual average flow of this river system is 13,800 m^3/s, but flows up to 24,000 m^3/s in flood season and in dry season only 5,020 m^3/s. According to the An Giang Centre for Hydro-Meteorological Forecasting, 2019, flows of canals in the floodplain range from 30-130 m^3/s during floods. Annually, area of the whole province has nearly 70% of the flooded area with high water levels of 1-2.5 m for 2.5-5 months, impeding the process of agricultural production and domestic use of the region [6]. Although abundant, water resources are unevenly distributed in space and time. Therefore, although many sub regions have too much water, caused by severe flooding, there are also places where there is a shortage of water for production and households. Both states are more or less affected by the water environment in general.

2. Methods

We collected samples of SSC and deposition sediments, measured water levels and discharge in the study area and then we built the correlation line between sediment and discharge. Since the sediment traps were arranged in a regular grid, including several clusters, spatial interpolation methods were used to determine the total amount of sediment deposited on the floodplain and to model the spatial variation of sediment accumulation. From that, sediment load was determined for the floodplain of LXQ-AG.

2.1. Velocity and Water Discharge Measurement

The flow velocity was determined by rotating current meter, which is based on the proportionality between the angular velocity of the rotation device and the flow velocity. The flow velocity was acquired by counting the number of revolutions of the propeller in a measured time interval,

The water discharge was determined by computing the product of the mean flow velocity (m s^{-1}) and the wet area (m^2) for each segment in the section and then summing these products over all segments.

$$Q = \sum Q_i = \sum A_i V_i \quad (1)$$

Where Q is the water discharge (m^3s^{-1}), Q_i is the water discharge in each vertical segment (m^3s^{-1}), A_i is the wet area of the vertical segment (m^2), and V_i is the average flow velocity in the wet area of each vertical segment (m s^{-1}).

2.2. Water Level Measurement

Fourteen water quality stations were designed for long-term operation and deployed to channels and floodplains. These stations are managed by An Giang Hydro-meteorological Center and float gauges was used to monitor water level. Data collected at these sites are distributed on map Figure 5.

2.3. Suspended Sediment Measurement

There are two occasions of SSC survey: The first one was in mid of July while the second one in mid of September. A total of 110 samples of SSC were collected on floodplain and 110 samples for channels in each time survey. Standard test method was used to measure SSC in the water. The Whitman grade 934AH, 24 mm-diameter filter was used. After filtering, the papers were dried between 103°C - 105°C. They were then weighed on a scale. The net weight of the solid sediments was obtained by subtracting the weight of the filter. SSC was calculated after dividing the net weight by the water volume of 250ml. The instantaneous discharge corresponding to the sampling time was obtained. Thus, a rating curve between discharge and SSC was developed. The calculation of annual suspended sediment discharge can be based on this curve.

2.4. Deposited Sediment Measurement

Artificial grass carpets (Figure 2) were used to estimates of deposition sediment because their surface roughness is comparable to grass in the floodplain, so sediment is not removed by rainfall. This carpet was tied with a cloth bag on the underside - to ensure that the sediment didnot fall out of the cloth bag when brought out of the water, and they were fixed to the ground by 4 piles at the four corners, to avoid being swept away by the water. The size of one carpet was 80 x 120cm. The sediment traps are placed before and retrieved after a flood event (Figure 3). The trapped sediment is washed by a high pressure cleaner in a bucket and then the water is taken out with a sieve and the sediment for a single trap was weighed. At the inundation area (110 traps) and channels (110 traps) were placed. Thus, a relationship curve between discharge and deposition sediment was developed. This process quantified the amount of sediment deposited on a floodplain during a single flood of 2018.

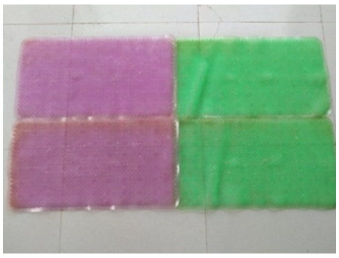

Figure 2. Carpet size 80x120cm

Figure 3. Carpets were retrieved after a flood

2.4. Determining the Area of Water Surface by the Use of Landsat Images

Landsat 8TM satellite images (path/row:126/53; spatial resolution: 30m) on 20th/09/2018 (flood peak) were downloaded from http://earthexplorer.usgs.gov and this image was clipped to the study area based on the appropriate land use maps. This multiband image was then re-projected to UTM Zone 48 North, WGS 84 Datum. After that the image was exported to the ERDAS 2014 EX software to determine the area of the flood in the study area by unsupervised classification.

Normalize Difference Water Index (NDWI) is used for the water bodies analysis. The index uses Green and Near infra-red bands of remote sensing images. The NDWI can enhance water information efficiently in most cases. This index uses the near infrared (NIR) and the Short-Wave infrared (SWIR) bands. NDWI can be calculated by following formula:

$$NDWI = \frac{NIR - SWIR}{NIR + SWIR} \quad (2)$$

Where: NIR: near infrared; SWIR: short wave infrared ArcGIS was used for transformation to TIFF format by Georeferencing in the Geographic Information System (GIS). ArcGIS 10.2 was finally used to compute the inundation and non inundation areas for the study site.

2.5. The Mass of Sediment Deposition

After identifying the area of flooding, and water level as well as collecting data on the length and width of the canals, we determined the mass of sediment deposition of the study area as follows:

$$M_d = D * A * \Delta T \quad (3)$$

Where: where M_d, the mass of sediment deposition (kg); D, deposition rate, (kg/m^2/s); A, the inundation area, (m^2); ΔT, duration of inundation (s).

The total mass of deposition sediment of the study area (kg):

$$\sum M_d = \sum_{1}^{i} \frac{A_i * M_i}{0.96 * \Delta T} \quad (4)$$

Where: $\sum M_d$: Total mass of deposition sediment of the study area (kg); A_i: the area of inundation in each vertical segment (m^2); M_i the volume of sediment deposition (kg) of the inundation areas in each vertical segment; 0,96: area of sampler (m^2). ΔT= duration of inundation.

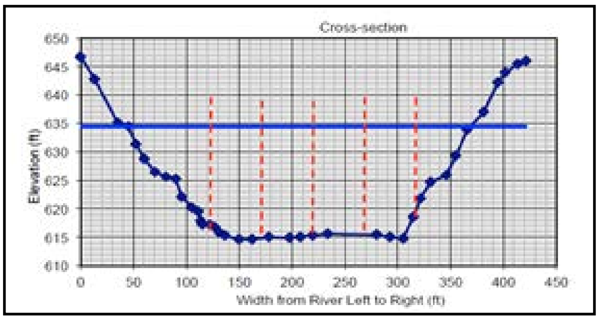

Figure 4. Method for deposition sediment measurement

Method for deposition sediment measurement in channel is showed in Figure 4 and calculate Md for each, as describe in 2.5.

3. Results and Discussion

3.1. Evolutions of the Flood Season in 2018

During the rainy season, floods from the upper Mekong River flow into the Mekong Delta through Tien and Hau rivers. The left bank of Tien river flows into the floodplain of Cambodia, then flows through Dong Thap Muoi of Vietnam and the right bank of the Hau river flows into lowland of Takeo-Cambodia, then flows into the LXQ, Vietnam.

The LXQ-AG is surrounded by 3 large roads (upgraded dikes) and high land of That Son mountain range, together they form 4 closed natural dykes throughout the area, making the LXQ-AG look like a giant reservoir regulating naturally with 2 flood input routes (green arrows in map of Figure 5) and 3 flood output routes (yellow arrows in map of Figure 5).

Floodwaters from Cambodia's lowland flow into the LXQ-AG through the Chau Doc-Nha Bang route and flowing along Vinh Te canal through Xuan To station. This was called the first input route; flood water from Hau river flows into the LXQ called the second input route; Floodwaters from the LXQ drain into the West Sea on Rach Gia-Ha Tien highway called the first output route; The remaining flood water from the LXQ drains out to South Can Tho on Cai San highway (route output 2) and exits the last node of Vinh Te canal (output 3).

Flooding in LXQ-AG occurs generally in the wet season from July to November. On 12th August, 2018 Tha La and Tra Su dams were opened to enable sediment to flow into the fields. But until 15th August, flood started entering the field. Flood peak was in the period from 20th-30th September. The observed results indicated that flood water in 2018 came about 7-10 days early and water level in the early flood season was 30-50 cm higher than in the same period in 2017. This cause is A breakdown of hydropower dams the Xepian-Xenam Noy dam in Laos caused floods in the Mekong River rapidly, the water level at the two upstream stations of the Mekong River, Tan Chau and Chau Doc (An Giang provinces) increased on average from 68cm/day. In fact, the highest water level on August, 12th, 2018 in Tan Chau is 3.67m, higher than the average of many years by about 0.75m; in Chau Doc, it reached 3.12m, higher than the average of many years 0.45m. The 2018 flood was considered a normal flood because it was not like the historical floods in 2000, 2011, 2014. The changes of water level in the study area are also divided into 3 stages, corresponding to the stages on the main river:

Rising stage (July-August): In this stage, the flood regime is controlled by the tidal influence. The highest water level on July 30th on Tien River in Tan Chau was 3.02 m, on the Hau River in Chau Doc was 2.46 m, approximately this was 0.15m higher than the same period in 2017. The southern area of Long Xuyen-Nha Bang and the South of Tri Ton-Nui Sap was also strongly influenced by the tides so the average flooding level was 0.5-1.0m. At the end of August, the water level in Chau Doc usually ranges from 3.5-4.0m, flooding from Cambodia lowland flow into LXQ dominate. North of the highway 91 was directly affected by this flood, the depth of submerged from 1.5-2.0m, many places in the study area are submerged from 1.0 -1.5m.

High stage (the flood peak period on September 20th-30th): with rising water levels, the hydrodynamic processes change. The influence of the tides on the inundation progression is diminishing. At the upstream boundary, the Tonle Sap Lake releases water that flows back into the Mekong River. Figure 7 shows water level time series for stations, representative for floodplain of LXQ-AG from March to September, 2018. It can be seen that the hydrograph characteristics at stations in the floodplain are generally identical. September was the period when the fields were full of water. Tan Chau on the main branch of the Mekong River in Vietnam in 2011 reached the flood stage level of 4.5 m on 25 September (Figure 8). The water level rose further to 4.8 m on 10 October and then receded slowly. In neighboring Chau Doc (Figure 9), on the Bassac River in 2011, water started exceeding the flood stage level on 26 September, rising further to 4.3 m on 8 October and then gradually falling.

Falling stage: From Mid-October the water levels fall gradually. Water is pumped out from the floodplains when the water level in the channels falls below the elevation of the low dikes. This facilitates the timely planting of the first paddy crop of the new cropping season.

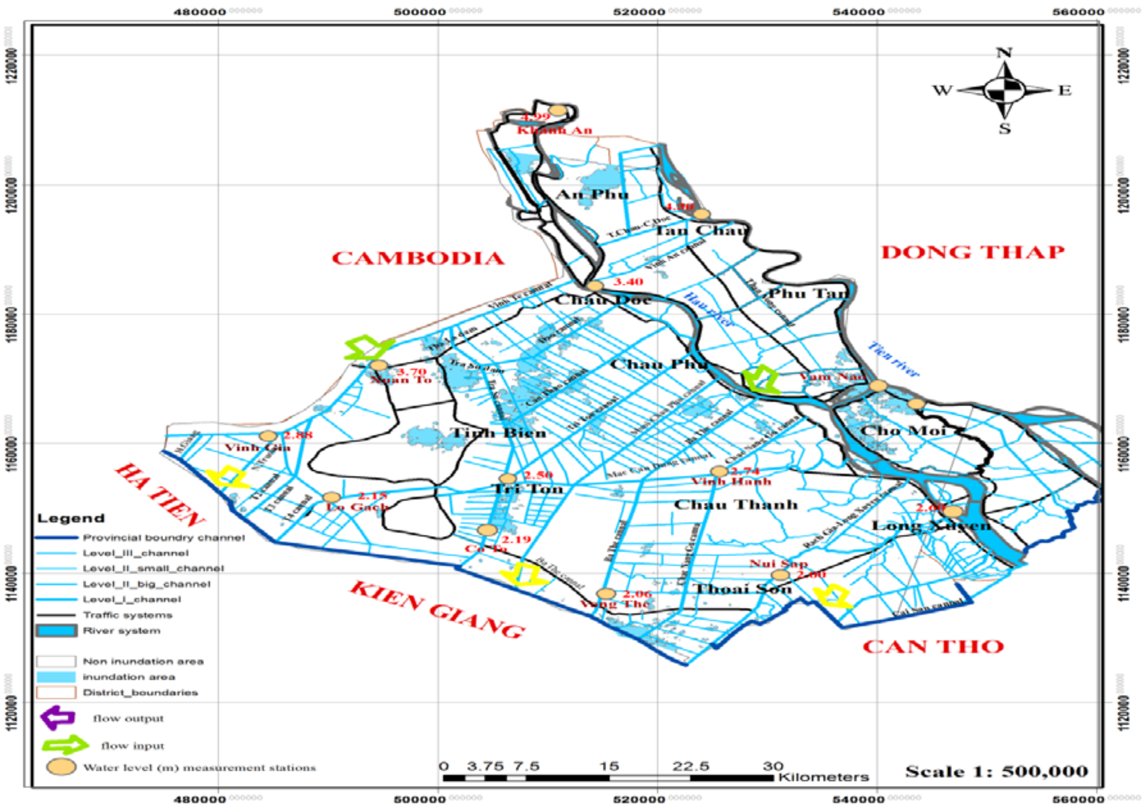

Figure 5. Inundation area (blue) of LXQ- AG, 2018

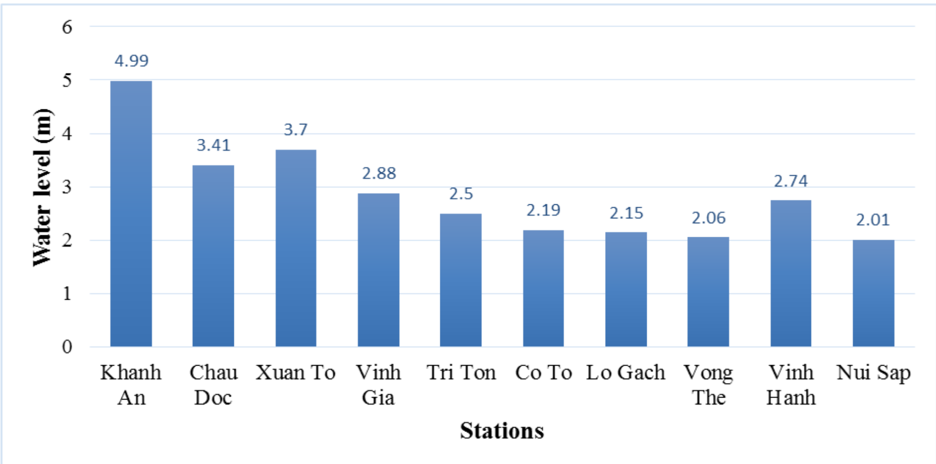

Figure 6. Flood peak water level at stations in floodplain of AG on 20/09/2018.

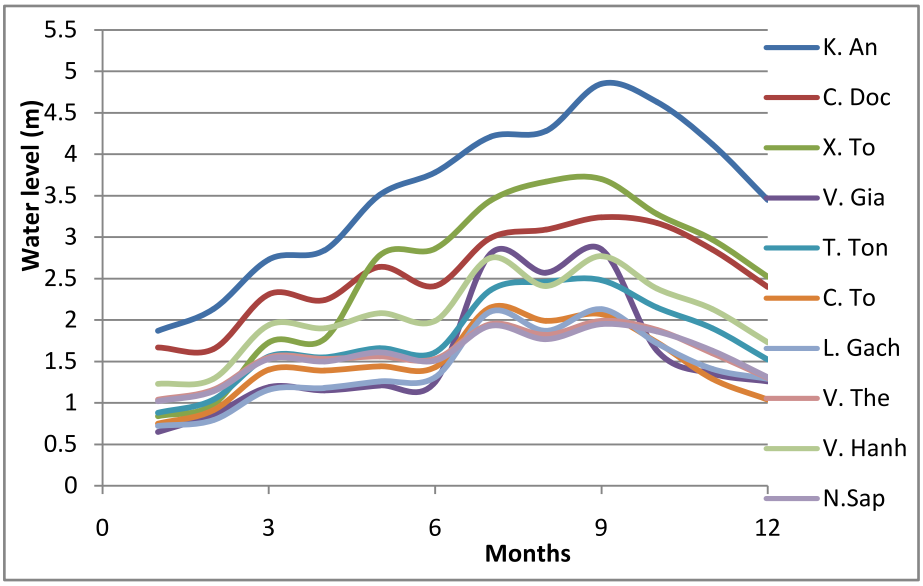

Figure 7. Observed water level for stations in floodplain, LXQ-AG, 2018

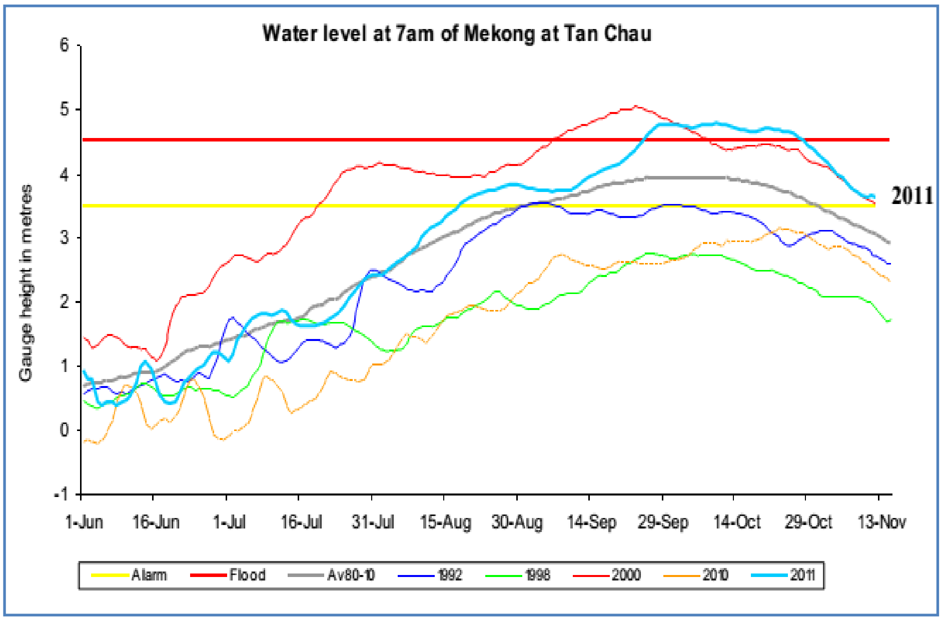

Figure 8. Observed water level time series at Tan Chau station [9]

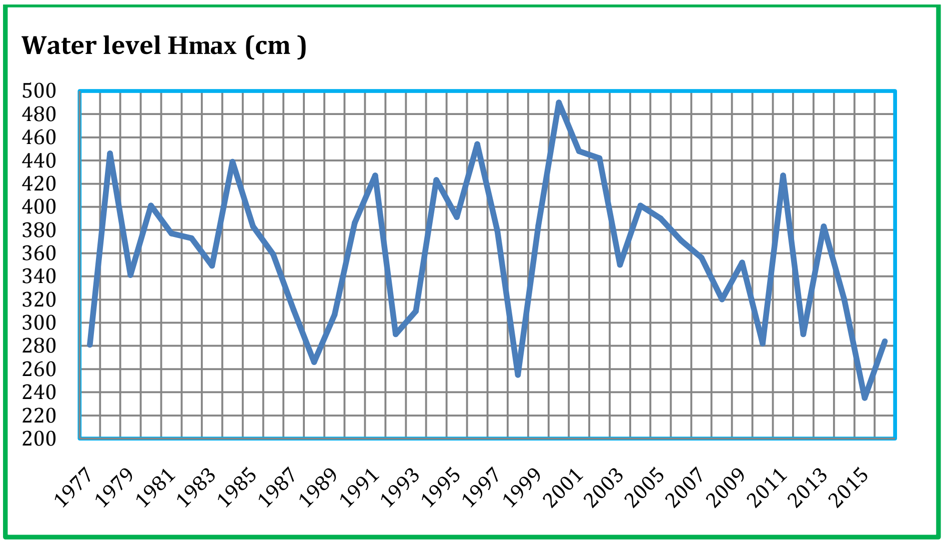

Figure 9. Hmax observed water level time series at Chau Doc station.

3.2. Determine the Flooded Areas

Landsat image sample was taken on 20th of September, 2018. Image interpretation was used by unsupervised methods for 2 classes: water, bare soil by combining the 5.4, and 3 spectrum channels. The results showed that the area of inundation (blue) 35,765 ha (10.15%); non inundation area (white) 316,601.8 ha accounts for 89.85% of total land (Figure 5). The total of area of LXQ-AG was 352,366.80 ha. Finally, classes's distribution map was built for An Giang, 2018 and is given in Figure 5.

Figure 5 showed that floods cannot occur in the central part of LXQ, where a large number of high dike compartments exist and the sluice gates remain closed during the high flood period. Sedimentation in LXQ-AG is mainly concentrated along the border and in close proximity of the Hau River.

From the results of remote sensing image interpretation, we identified the distribution of inundation area for each region. The results of accurate assessment of classification based on the actual data set for the flooding 2018 of Irrigation Department are shown in Table 1. The total of actual inundation area was 36,074 ha (including 6,577ha of canals), an error of 309 ha (0.85%) compared to interpretation results.

3.3. Estimating sediment

Survey results of SSC of canals in floodplain in the early flood period was higher than SSC at flood peaks. In July SSC ranged from 61.7-107.3mg/l, reaching an average value of 85.4 mg/l. Meanwhile, SSC in September ranged from 54.8-95.7 mg/l, the average was 75.84 mg/l. The highest average SSC were at big canals: Vinh Te, Tra Su, Tha La, Vinh Tre. SSC of these canals were in the range of 92.4-107.3mg/l in July, while in September were 73.3-95.7mg/l. The lower SSC were Tri Ton, Muoi Lam, Muoi Chau Phu, 30/4 canals. The average SSC ranged from 54.8-78.2mg/l in two surveys (Figure 10). Results also showed that SSC tends to increase compared to the same period in 2017 and previous years. However, SSC is much lower than the previous big floods like 2009, 2011 and 2000. The Lanh's results for the 2000 flood, SSC at Tri Ton canals in July was round 600-750 mg/l, at Long Xuyen SSC was 320-460 mg/l [22]. Even so, the SSC was still 1.5-8 times higher than the permitted standard.

Table 1. The area of inundation were divided by districts on 20th, Sep, 2018

No	Region Code	Area interpreted from Landsat images (ha)	Observed area (1)+(2)		Error (%)
			Inundation areas in rice paddy (ha) (1)	Surface of canals (ha) (2)	
1	L.Xuyen	962	429	565	3.22
2	C.Doc	2,413	2,037	338	-1.60
3	A.Phu	4,382	4,236	273	2.82
4	T.Chau	2,080	1,712	341	-1.31
5	P.Tan	9,538	9,230	415	1.11
6	C.Phu	1,616	722	908	0.85
7	C.Thanh	960	96	954	8.57
8	T.Bien	2,949	2,510	404	-1.2
9	T.Son	1,813	455	1,367	0.49
10	T.Ton	6,467	6,180	304	0.62
11	C.Moi	2,585	1,890	708	0.50
Total		35,765	29,497	6,577	0.85

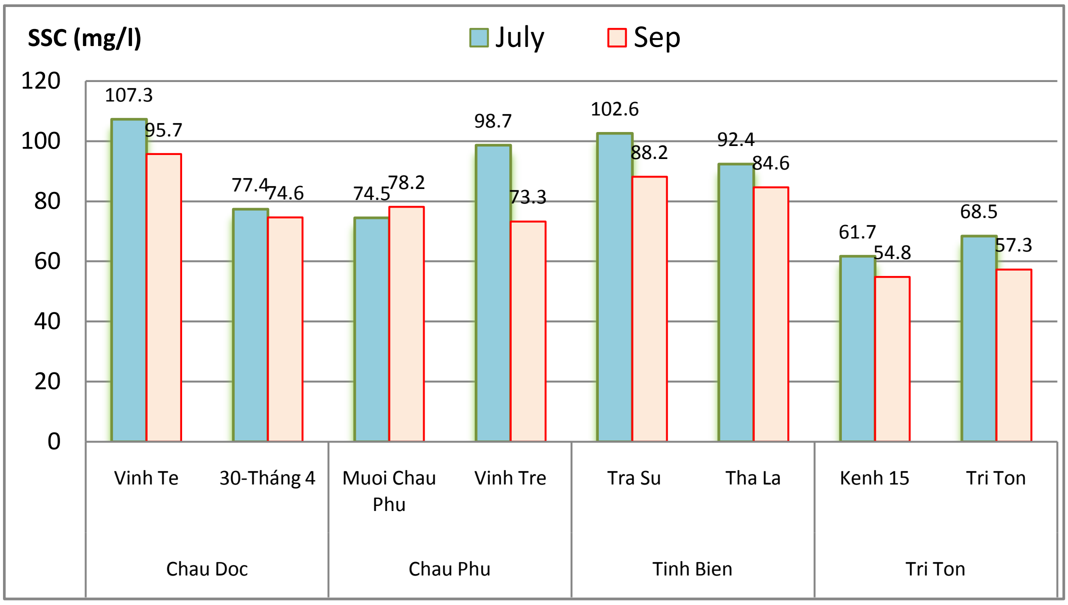

Figure 10. Diagram showing the SSC average value of some channels in the floodplain in July and September, 2018

In recent years, a series of canals have been made to bring flood water into the west of LXQ, but the fact that silt is discharged onto the floodplain is not as much as previously thought. Because, at the beginning of the flood season, the agricultural fields are not flooded and the sediment flows mainly along drainage channels to the coastal areas from Ha Tien to Rach Gia or back to the main river in tidal rhythm. On the fields, when the water level is relatively high, sediment distribution is also greatly influenced by local factors. The flows of less sediment moving from Cambodia across the Vietnamese border stopped short the silt turbid flows from the main river (Hau river) into the floodplain. Consequently, the SSC in July is often higher than in September and continuously decreased in recent years.

Table 2. Average SSC value in the floodplain on 15/09/2018.

Region Code	Sites (N=220)	Average SSC (mg/l)	Duncan's test SSC(mg/l)
L.Xuyen	In fields	43.33±23.3	44.61^{a}±19.2
	Canals	45.9±15.3	
C.Doc	In fields	68.8±10.1	67.17^{b}±12.9
	Canals	65.5±15.8	
A.Phu	In fields	58.2±12.3	58.89^{ab}± 12
	Canals	59.6±13.5	
T.Chau	In fields	82.2±7.5	76.33^{b}±17.8
	Canals	70.4±23.3	
P.Tan	In fields	81,2±10.3	71.44^{b}±18.3
	Canals	61.7±19.7	
C.Phu	In fields	52.3±7.4	54.39^{a}±17.9
	Canals	56.4±24.8	
C.Thanh	In fields	46.7± 5.9	50.39^{a}±13.4
	Canals	54.0±17.8	
T.Bien	In fields	54.2±7.5	49.9^{a}±11.2
	Canals	45.6±13	
T.Son	In fields	38.2±5.2	46.5^{a}±11.2
	Canals	54.8±9.7	
T.Ton	In fields	37.4± 3.9	46^{a}±13.7
	Canals	54.6±14.7	
C.Moi	In fields	48.2±7.5	53^{a}±7.1
	Canals	53.0±7.3	

Note: Average SSC ± standard deviation; a,b,c,d,e,f,g: In the same column, the letters (a, b, c, d, e, f, g) following the numbers are significantly different of SSC at 5% by Duncan's test.

The results of Table 2 showed that SSC in the flood plain in the water-filled period was lower than that of in-field canals at most survey points, except Tan Chau and Phu Tan. Paired Sample Test were used to test the hypothesis "The SSC in the channel is equal to the SSC in the floodplain". The results showed that there is not enough basis to reject the hypothesis. This means the differences was no significant on the SSC mean value between canals and the floodplain at a 95% confidence level, accept Phu Tan (Column 3, Table 2).

The Duncan's test also conducted to compare average SSC values among different region groups in the floodplain. The results showed that a significant difference was observed average SSC among two region groups (near Hau river and far from Hau river group) at 95% confidence level. However, were no a significant difference in average SSC between sites in the same one group (Column 4, Table 2). This means there were a significant difference between the groups of the near Hau river or culverts (C.Doc, T.Chau, P.Tan, A.Phu) and the groups of the further Hau river (T.Ton, C.Thanh, T.Son, T. Bien, C.Phu, C.Moi). In other words, the further the distance from the main river, the lower the SSC and this difference is very statistically significant. Surveys in fact showed that, SSC was concentrated in the areas of the strong flow near culverts (which were opened to get sediment) within a radius of 1km, then the speed decreases to almost zero in the distance away from the culvert. Thus, the suspended sediment decreases rapidly, because the flow velocity rapidly decreases. In addition, the acidic factors causing precipitation (coalesce) also reduce the amount of suspended sediment in water. We know that acid soil is a soil containing alum, ferric chloride, and ferrous sulfate and has a very low pH, only about 4-5. Acid soil in An Giang is distributed in areas adjacent to Kien Giang province, located in T.Ton, T.Bien region and part of C.Phu, with a total area of over 30,136 ha [23] and acid alluvial soil of 90,000ha [24]. Alum, ferric chloride and ferrous sulfate are like types of coagulants to promote contact between the sediment particles. As coalescence or flocculation occurs, the particles increase in mass and settle at a faster rate.

Moreover, since the floodplain of LXQ-AG shows little relief, inundation times are almost the same over the entire inundation areas. There are no (closed) depressions that capture large amounts of sediment when the water level in the main channel is falling. It can therefore be concluded that differences in sedimentation between canals and inundation area mainly due to sediment transporting mechanisms. When overbank flow occurs, sediment may be transferred from the channel to the floodplain by different mechanisms. Coarse sediment may be transported by traction as bedload and will be deposited close to the channel. Fine grained sediment will generally be transported in suspension and will be deposited further away from the channel. Because the flow velocity in the deep main channel is much higher than on the shallow floodplain, the capacity to transport sediment and, hence, sediment are largest in the channel. Differences in flow velocity and SSC result in a transfer of momentum and suspended sediment at the interface between the channel and the floodplain. This transfer of sediment by turbulent eddies is analogous to a diffusion process. Under these circumstances sediment is transferred from high concentrations within the channel towards lower concentrations of the floodplain. Due to the lower flow velocities on the floodplain the transporting capacity of the floodplain flow may be exceeded and sediment will be deposited [25,26]. The coarsest material is deposited first, i.e. near the channel. Sediment diffusion during overbank flow will thus result in a relatively thick accumulation of sediment close to the channel. If high sedimentation along the channel has been taking place in many years, this will lead to the formation of natural levees, which hinder the drainage of the active floodplain, leading to long residence times and high settling rate. The research showed that the thickness of accumulated sediment decreases exponentially with distance from the channel (Figure 11).

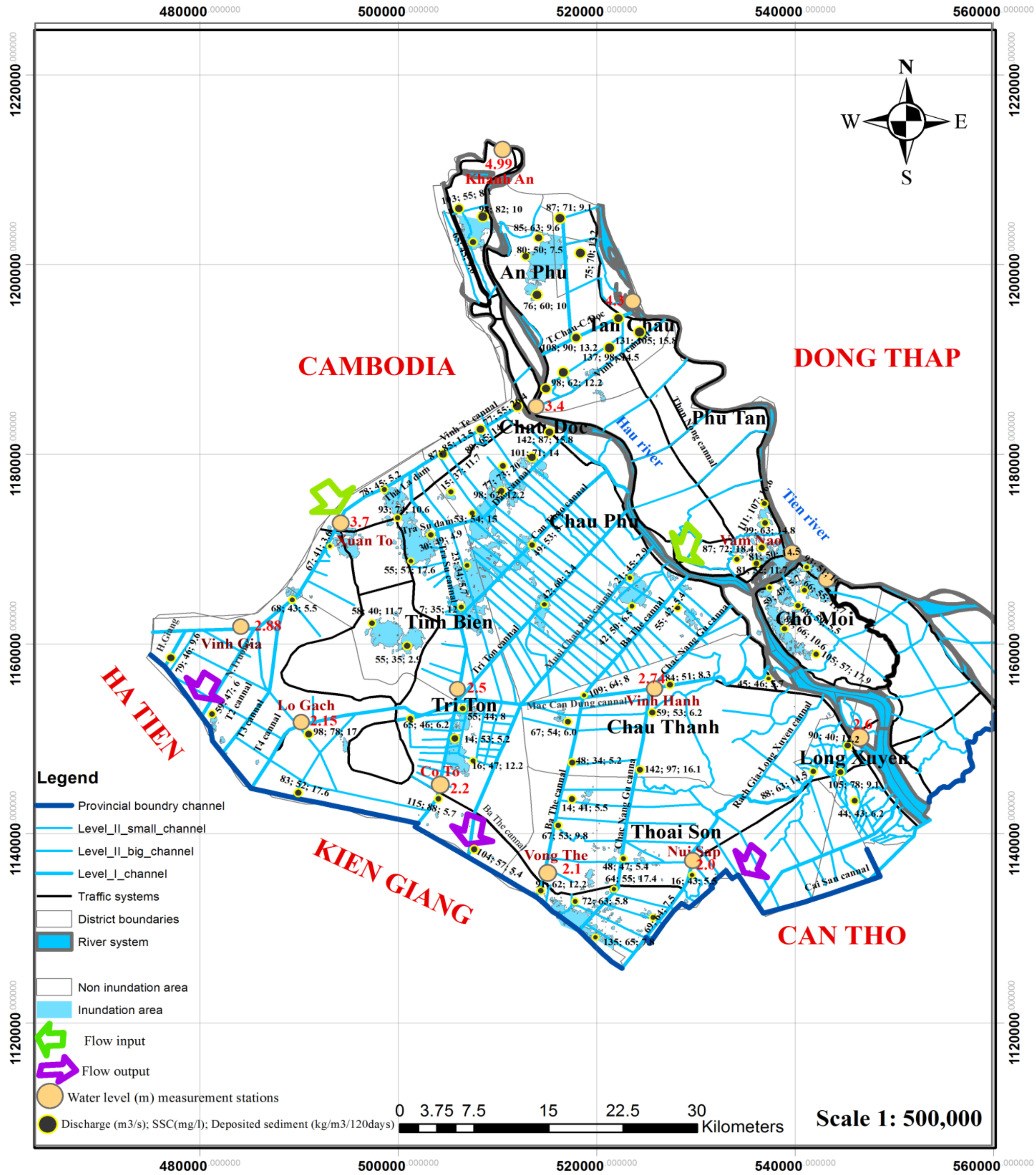

Figure 11. The map shows discharge, SSC, deposited sediment on 20th, September, 2018.

From field survey results, two equations were constructed to predict sediment mass. The results showed that equation form is SSC (mg/l) = $0.0027x^2 + 0.0432x + 37.771$ with correlation coefficient $R^2 = 0.65$. Deposited sediment rate = $0.0007e^{0.0231Q}$, $R^2 = 0.69$, where x(Q)= discharge. This means that SSC/diposited sediment rate is closely related to the discharge factor. Or, in other words, as the discharge increases, SSC/bed load also increases according to the function (Figure 12 and Figure 13). Figure 12 shows the relationship between the discharge and SSC curve and Figure 13 shows the relationship between the discharge and the deposited sediment rate of the LXQ-AG floodplain in the 2018 flood. Rosgen et al developed the FLOWSED model using dimensionless sediment rating curves (DSRC) for the estimation of suspended and bedload sediments for rivers [26,27]. The model can be applied to a wide range of rivers with different environmental and geological characteristics. The good/fair stability streams: Bed load = − 0.0113 + $1.0139x^{2.1929}$; Suspended = 0.0636 + $0.9326x^{2.4085}$. The poor stability channels: Bed load = 0.07176 + $1.02176x^{2.3772}$; Suspended = 0.0989 + $0.9213x^{3.659}$. Where y = dimensionless sediment, and x = dimensionless discharge [26,27].

In order to test the reliability of the above equations, a comparison was made between the measured values and simulated values. The results showed that the simulated value of deposited sediment was slightly different than the survey value and the error was <10.57%. And the error between simulated SSC value and the survey value was <13.8%, Therefore the difference was negligible. This value was still acceptable.

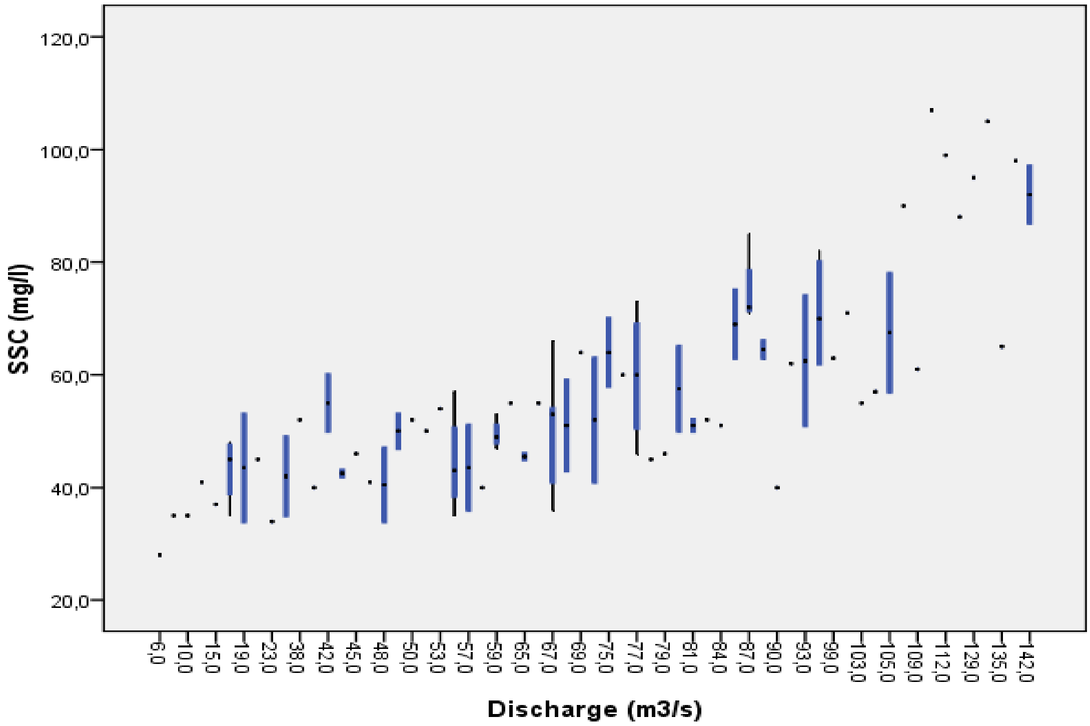

Figure 12. The relationship between the discharge and SSC on floodplain of LXQ in Sep in 2018

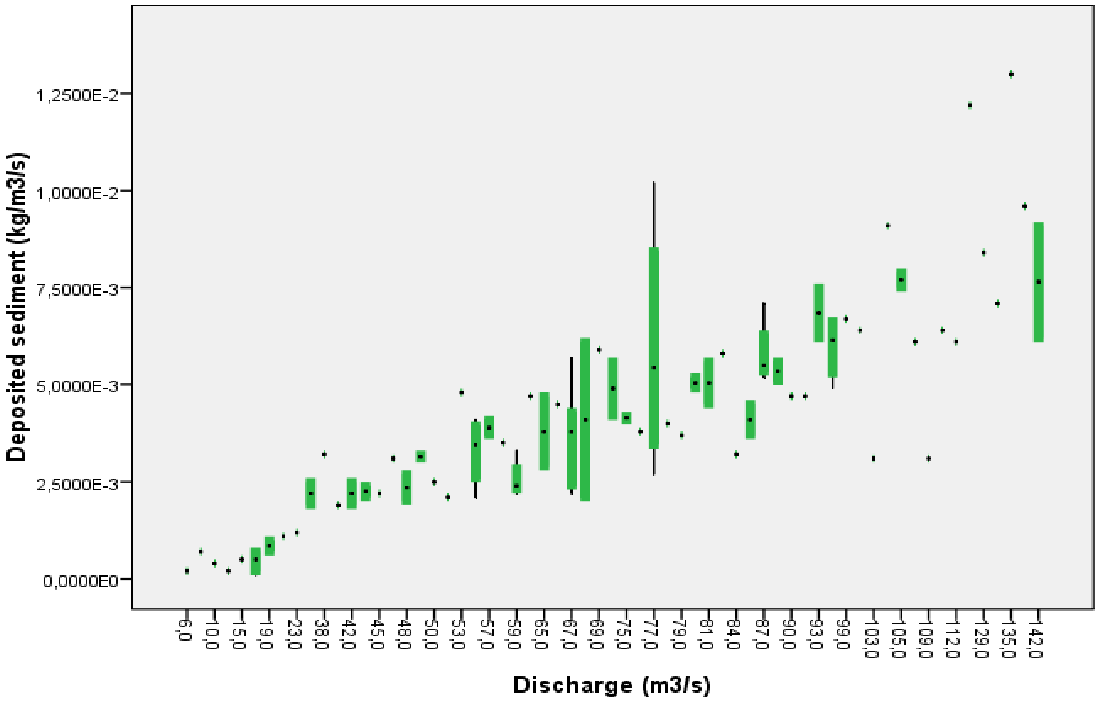

Figure 13. The relationship between the discharge and deposited sediment on floodplain of LXQ-AG in the 2018 flood

Table 3. Total sediment mass of the floodplain of AG during in 2018 flood.

No	Region Code	Inundation areas Rice paddy Deposited sediment (tons) (1)	Canals Depositd sediment (tons) (2)	Total (tons) (1)+(2)
1	L.Xuyen	38,095.2	173,031.3	211,126.5
2	CDoc	278,661.6	83,795.8	362,457.4
3	APhu	696,398.4	103,228	799,626.4
4	TChau	274,776.0	111,890	386,666
5	PTan	982,995.0	115,421	1,098,416
6	CPhu	66,712.8	207,137	273,849.8
7	CThanh	6,883.2	225,581	232,464.2
8	TBien	233,932.0	103,525	337,457
9	TSon	36,991.5	310,422	37,301.922
10	TTon	540,750.0	62,383.3	603,133.3
11	CMoi	162,729.0	207,975	370,704
Total		**3,318,924.7**	**1,704,392**	5,023,316.7

Deposition sediment mass

In the study area, the total weight of sediment deposited per mat (0.96 m^2) during a flood varied between 6.88 and 15.78 kg for inundation areas, and the high values correspond to the traps from the canals (12-21.3kg). Average deposition sediment was 13.96kg/m^2. When the mats were collected from the floodplain, it was observed that even on a single mat differences in sediment thickness were present, suggesting a strong local variability in sedimentation. Over distances of less than 500m, the variability of the sediment quantities can be considerable. In the areas away from the main rivers, the amount of deposited sediment decreases gradually (Figure 11). With inundation area of 35,765 ha on floodplain, deposited sediment mass brought to the floodplain during a single flood event in 2018 was 5.023 million tons (14.24kg/m^2), of which total suspended sediment load was 70.58 thousand tons (0.2kg/m^2), (Table 3).

Therefore, we can conclude that the high spatial variability of sediment transport inside the LXQ's floodplains is a result of the combined impacts of ring dikes, the operation of sluice gates, the magnitude of floods, and tides.

According to previous research results, the mean annual sediment yield at Tien River-Tan Chau was 67 million tones, and at Hau River-Chau Doc was 13-14 million tons [3]. However, according to recent survey data of survey team of the hydrology Mekong Delta, Tien River-Tan Chau silt mass is much smaller, about 40-70 million tons. Research results of Thuyen (2012) show that, the sediment mass of the floodplain ranges from 5-10 million tons for medium and big flood [21]. This result are very consistent with our calculation for the LXQ-AG area of 5.09 million tons for floods in 2018 and are also consistent with Fox's results (9 to 13 million tons sediment accumulates on the floodplain in Mekong Delta) [28]. The decreased sediment, and its associated nutrients will negatively affect agricultural production in the floodplain, which will lead to a major impact on the ecological environment, and economic development of the region [13].

4. Conclusions

The following conclusions can be drawn from our results:

The amount of sediment deposited per unit area in the floodplain field was always 4 to 6 times lower than the sediment in the canals and the main rivers, depending on the location and deposited sediment drastically reduced with the distance from the main river. Mean mass of deposition sediment was 14.04kg/m^2.

The dense sediment was distributed in the direction of decreasing from Northeast to Southwest, particularly in the West (T.Ton) and South (T.Son) SSC were very low. The highest SSC in the field was the beginning period of flood (July). Therefore, the early or late opening and closing of Tra Su and Tha La dams affected the ability to take sediment into the field. Therefore, it is necessary to adjust the time of opening the sluice gate (dams) to get the biggest sediment content.

The correlation model between SSC/deposition sediment and discharge presented in the current study could be used to produce estimates of SSC and deposited sediment for other floodplain similarly An Giang.

Although local variations in sediment accumulation are large, the absolute values and spatial patterns of sediment accumulation within floodplain area can be further analyzed to obtain an indication of the most important processes influencing floodplain sedimentation. Factors influencing sediment deposition include floodplain topography, grain size distribution of the suspended sediment, relative importance of various transporting mechanisms and, over a longer timescale, inundation frequency. Since in this study results of only one flood event are obtained, not all factors can be investigate.

References

[1] Institute of Natural Resources and Environment. "Water Resource Planning of An Giang Province, 2020". 2015. Page 14. [in Vietnamese].

[2] Thang, H. T. “Flood comes Delta”. 2012. http://vinhlong.mard.gov.vn/ContentDetail.aspx?CatId=46&Id=9012.

[3] Lu, X., Kummu, M., and Oeurng, C. “Reappraisal of sediment dy-namics in the Lower Mekong River, Cambodia”, Earth Surf. Proc.Land., 39, 1855-1865, 2014.

[4] Howie, C,. “Co-operation and contestation: farmer-state relations inagricultural transformation, An Giang Province, Vietnam”. Thesis, University of London, England. 2011.

[5] Danh, V. and Mushtaq, S. “Living with Floods”. An Evaluation of the Resettlement Program of the Mekong Delta of Vietnam, in: Envi-ronmental Change and Agricultural Sustainability in the MekongDelta, Advances in Global Change Research, edited by: Stew-art, M. A. and Coclanis, P. A., Springer Netherlands, Dordrecht, 181-204. 2011.

[6] Irrigation Departments in An Giang province. “Report of flood prevention in An Giang Province from 2011 to 2015”. 2015. [in Vietnamese].

[7] MRC - Mekong River Commission. “Multi-functionality of Paddy Fields over the Lower Mekong Basin”, Technical Paper (26), 2010. available at: http://www.mrcmekong.org/assets/Publications/technical/tech-No26-multi-functionality-of-paddy-field.pdf (last access: 7 April 2013).

[8] MRC,. “Diagnostic study of water quality in the Lower Mekong Basin”. MRC Technical. Paper No. 15. 2007. Mekong River Commission, Vientiane, Laos.

[9] MRC. “Annual Water Quality Data Assessment Report”. Flood Situation Report 2011, Technical Paper (36), available at: http://www.mrcmekong.org/assets/Publications/technical/Tech-No36-Flood-Situation-Report2011.pdf (last access: 7 May 2013). 2011.

[10] Hung L. M,. “Research on the causes and solutions to prevent river bank erosion and deposition for the lower Mekong River system, Vietnam”, Ministry of Science and Technology, code KC08-15, 2004. [in Vietnamese].

[11] Sam L. “Research on salt intrusion for socio-economic development in the coastal zone 25 of the Mekong Delta, Vietnam”, Ministry of Science and Technology, code KC08-18. 2004. [in Vietnamese].

[12] Nguyen A.D., Savenije HHG. “Salt intrusion in multi-channel estuaries: a case study in the Mekong Delta, Vietnam”. Hydrology and Earth System Sciences: 10, 743-754. 2006.

[13] Tran, N.N. “Long Xuyen Quadrangle after 20 years of changes, achievements and challenges”. Scientific Conference "20 years of exploitation and social and economic development of LXQ region", pp 179-206. 2012. [in Vietnamese].

[14] Wild T.B., Loucks D.P. “SedSim model: a simulation model for the preliminary screening of sediment transport and management in river basins”, version 3.0: documentation and users manual. Department of Civil and Environmental Engineering. Cornell University. Ithaca. NY USA. 2012.

[15] Lu XX, Siew RY. “Water discharge and sediment flux changes over the past decades inthe Lower Mekong River: possible impacts of the Chinese dams”. Hydrology Earth System Sciences 10: 181-195. 2006.

[16] Manh, NV, Dung, NV, Hung, NN, Merz, B, Apel, H. “Large-scale suspended sediment transport and sediment deposition in the Mekong Delta”. Hydrology and Earth System Sciences 18: 3033-3053. 2014.

[17] Manh, NV, Dung, NV, Hung, NN, Kummu, M, Merz, B, Apel, H. “Future sediment dynamics in the Mekong Delta floodplains: impacts of hydropower development, climate change and sea level rise”. Global and Planetary Change 127: 22-33. 2015.

[18] Kondolf, G.M; Rubin,Z.; Minear, J.T.; Alford, C. “Cumulative sediment reduction to the Lower Mekong River from planned dams”. American Geophysical Union, Fall Meeting. 2012.

[19] Michael Arthur and Demian Saffer. Nutrient Supply to Floodplains. Earth 111: Water: Science and Society. https://www.e-education.psu.edu/earth111/node/823.

[20] Hung, N. N., Delgado, J. M., Guentner, A., Merz, B., Bardossy, A., and Apel, H. “Sediment in the floodplains of the Mekong Delta, Vietnam Part II: deposition and erosion”. Hydrological Processes, online first, 2013b.

[21] Statistical Yearbook of An Giang. Branch of Statistical Office of An Giang province. 2018.

[22] Lanh Đ.T. “Nguyên cứu phân bố lắng đọng phù sa của dòng lũ tràn vùng Tứ giác Long Xuyên”. Luận án tiến sĩ. 2005. Trường Đại học Thủy lợi Hà Nội. [Translate] Lanh, D.T. PhD thesis, "Sedimentation distribution of flood flow over delta in Long Xuyen Quadrangle-An Giang". 2005. Irrigation Hanoi University.

[23] Department of Natural Resources and Environment of An Giang Province. Acid sulfate soil group. 2019. http://sotainguyenmt.angiang.gov.vn/TongQuan_DD1.aspx.

[24] https://vi.wikipedia.org/wiki/An_Giang.

[25] Pizzuto, J. E. “Sediment diffusion during overbank flows”, Sedimentology, 34, 301-317. 1987.

[26] Rosgen, D.L. “A Watershed Assessment for River Stability and Sediment Supply (WARSSS)”. Wildland Hydrology Books, Fort Collins, CO. (In press). 2006a. http://www.epa.gov/warsss/.

[27] Rosgen, D.L. “The application and Validation of dimensionless sediment rating curves”, paper presented at second joint Fedaral interagency conference, subcomm. On sediment., Advis. Comm. on Water inf, Las vegsas, Nev., 27. June to 1 July. 2010.

[28] Fox; Coleen; Sneddon, Chris. “Flood Pulses, International Watercourse Law, and Common Pool Resources: A Case Study of the Mekong Lowlands”. the EGDI-WIDER Conference on Unlocking Human Potential - Linking the Informal and Formal Sectors in Helsinki, 17-18 September 2005. SSN 1810-2611. ISBN 92-9190-699-9. Available from: https://www.researchgate.net/publication/23566060_Flood_Pulses_International_Watercourse_Law_and_Common_Pool_Resources_A_Case_Study_of_the_Mekong_Lowlands [accessed Jul 17. 2019].

[29] Hung, NN. “Sediment Dynamics in the Floodplain of the Mekong Delta, Vietnam”. PhD dissertation Universitätsbibliothek der Universität Stuttgart: Stuttgart, Germany. 2012. Google Scholar.

[30] Nathalie, E., Asselman, M., Hans Middelkoop. “Floodplain sedimentation: Quantities, Patterns and Processes”. Earth Surface Processes and Landforms, Vol. 20,481-499. 2003.

[31] Thuyen X.L. “Sử dụng nguồn phù sa ứng phó với nước biển dâng ở ĐBSCL”. Kỷ yếu hội thảo khoa học “20 khai thác phát triển kinh tế xã hội vùng Tứ giác Long Xuyên”, 2012. [Translate] Thuyen X.L. Using alluvial resources to adapt to sea level rise in the Mekong Delta. Proceedings of scientific conference "20 socio-economic development in Long Xuyen Quadrangle". 2012.

Appendix

Table S1. Deposited sediment in Rice paddy (tons)

No	Code	Area (m^2)	Deposited sediment ($kg/0,96m^2$)	Deposited sediment (kg/m^2)	Deposited sediment in Rice paddy (tons)
1	L.Xuyen	4290000	8.52	8.88	38,095.20
2	CDoc	20370000	13.13	13.68	278,661.60
3	APhu	42360000	15.78	16.44	696,398.40
4	TChau	17120000	15.41	16.05	274,776.00
5	PTan	92300000	10.22	10.65	982,995.00
6	CPhu	7220000	8.87	9.24	66,712.80
7	CThanh	960000	6.88	7.17	6,883.20
8	TBien	25100000	8.95	9.32	233,932.00
9	TSon	4550000	7.80	8.13	36,991.50
10	TTon	61800000	8.40	8.75	540,750.00
11	CMoi	18900000	8.27	8.61	162,729.00
Total		**294,970,000**			**3,318,924.70**

Table S2. Deposited sediment in canal (tons)

No	Code	Area (m^2)	Deposited sediment ($kg/0,96m^2$)	Deposited sediment (kg/m^2)	Deposited sediment in canal (tons)
1	L.Xuyen	5,650,000	29.4	30.63	173,031.25
2	CDoc	3,380,000	23.8	24.79	83,795.83
3	APhu	2,730,000	36.3	37.81	103,228.13
4	TChau	3,410,000	31.5	32.81	111,890.63
5	PTan	4,150,000	26.7	27.81	115,421.88
6	CPhu	9,080,000	21.9	22.81	207,137.50
7	CThanh	9,540,000	22.7	23.65	225,581.25
8	TBien	4,040,000	24.6	25.63	103,525.00
9	TSon	13,670,000	21.8	22.71	310,422.92
10	TTon	3,040,000	19.7	20.52	62,383.33
11	CMoi	7,080,000	28.2	29.38	207,975.00
Total		**6,577,000,000**			**1,704,392.70**

Table S3. Data SSC and deposited_sediment rate and discharge

Discharge (m^3/s)	**SSC (mg/l)**	**Deposited_sediment rate ($kg/m^3/s$)**
41	40	0.0019
80	50	0.0049
65	45	0.0047
103	55	0.0031
98	82	0.0049
87	71	0.0055
76	60	0.0038
85	63	0.0037
75	70	0.0041
67	36	0.0057
85	75	0.0045
77	65	0.0027
131	105	0.0071
98	62	0.0067
50	52	0.0025
108	90	0.0061
137	98	0.0096
57	51	0.0037
55	35	0.0021
78	45	0.004
30	49	0.0019
67	41	0.0024
93	74	0.0075

7	35	7.00E-04
23	34	0.0012
55	57	0.0038
58	40	0.0035
49	53	0.0031
42	60	0.0019
55	42	0.0041
21	45	0.0011
129	95	0.0084
42	50	0.0025
112	99	0.0061
6	28	2.00E-04
57	36	0.0041
16	35	3.00E-04
44	43	0.0024
51	50	0.0021
10	35	4.00E-04
30	35	0.0025
105	78	0.0075
90	40	0.0047
88	63	0.0056
19	34	7.00E-04
87	85	0.0052
77	73	0.0067
15	37	5.00E-04
80	65	0.0052
77	55	0.0102
101	71	0.0064
98	62	0.0057
53	54	0.0048
142	87	0.0091
135	65	0.013
69	64	0.0059
16	43	1.00E-04
72	63	0.0042
14	41	2.00E-04
67	53	0.0038
91	62	0.0047
48	47	0.0027
64	55	0.0047
16	48	7.00E-04
59	53	0.0024
48	34	0.002
44	42	0.0021
67	54	0.0043
45	46	0.0022
109	61	0.0031
84	51	0.0032
142	97	0.0062
68	59	0.0021
59	49	0.0022
38	52	0.0032
49	47	0.0032
46	41	0.0031
88	66	0.0051
66	55	0.0045
105	57	0.0079
93	51	0.0062
87	72	0.0071
75	58	0.0042
81	52	0.0045

77	46	0.0042
67	66	0.0022
81	50	0.0056
72	41	0.0056
111	107	0.0064
99	63	0.0067
55	44	0.0031
104	57	0.0091
115	88	0.0122
19	53	0.001
59	47	0.0033
79	46	0.0037
83	52	0.0058
68	43	0.0061
98	78	0.0066
16	47	7.00E-04
65	46	0.0029

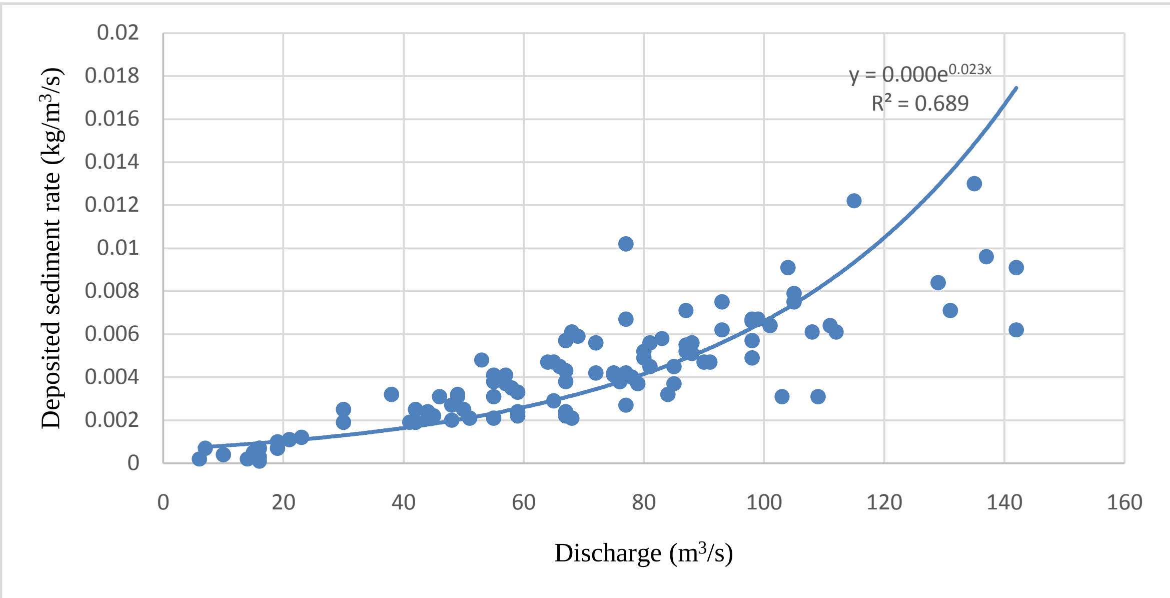

Figure S1. Relationship betweendischarge (m^3/s) and deposited sediment rate ($kg/m^3/s$)

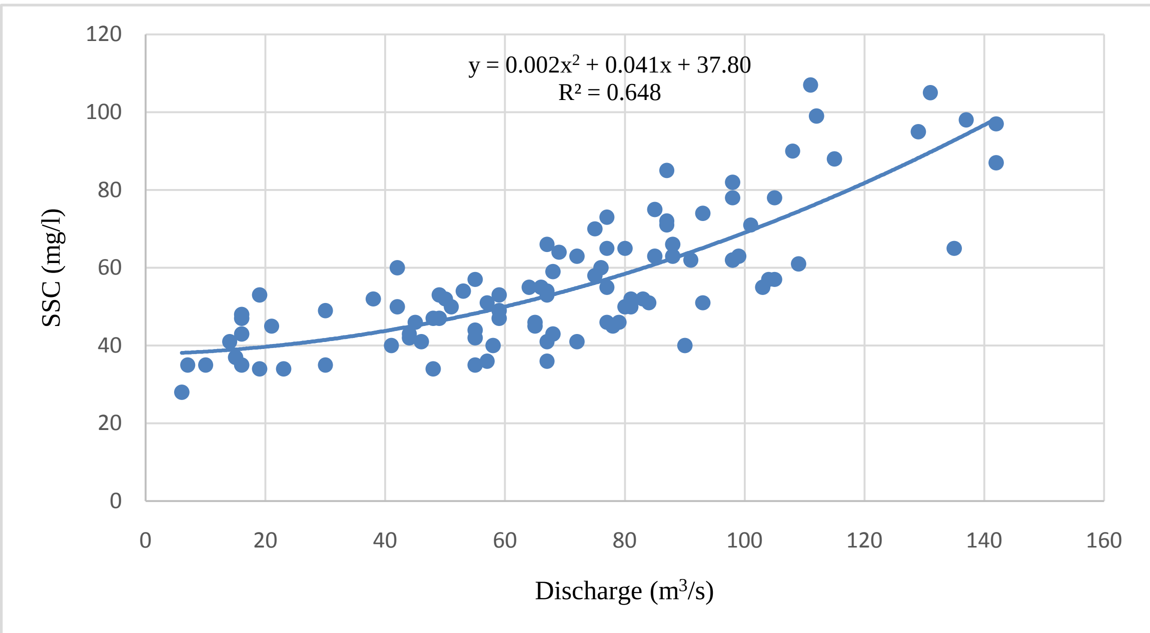

Figure S2. Relationship betweendischarge (m^3/s) and SSC (mg/l).

Table S4. Check the difference of SSC (mg/l) between surveyed areas.

SSC_Total

	Repeat1	N	Subset for alpha = 0.05						
			1	2	3	4	5	6	7
Duncan[a]	TS	20	38,5250						
	LX	20		45,3000					
	TT	20		48,0500					
	CM	20		48,0500					
	CT	20		48,7500					
	CP	20			59,7300				
	AP	20			62,8000				
	TB	20				70,4400			
	CD	20					77,3880		
	PT	20						84,7000	
	TC	20							89,4100
	Sig.		1,000	,144	,152	1,000	1,000	1,000	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 20,000.