Engineering and Technology Journal e-ISSN: 2456-3358
Volume 08 Issue 06 June-2023, Page No.-2350-2359
DOI: 10.47191/etj/v8i6.09, I.F. – 7.136

Turbidity-Hysteretic Response in River Ose, Ondo State, Nigeria

Daramola A. S.
Department of Civil Engineering Technology, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria

ABSTRACT: Concentration-Discharge relationships are a key tool for understanding the sources and transport of material from watersheds to fluvial networks. Turbidity based estimating of suspended sediment concentration is widely used for river studies due to its simply and cheap using. The relation between suspended sediment concentration (turbidity) and discharge is not normally homogenous and often producing hysteretic loop. Therefore, this work identified the hysteresis types of the turbidity-discharge relationships in river Ose. Data were collected at coordinates 7º 18’ 35.5” N and 5º 39’ 52.5” E for two-year period and analysis showed that counter-clockwise hysteresis loop pattern was dominant. This suggested that overland flow is much possible in the study area.

KEYWORDS: Hysteresis, turbidity, discharge, River Ose

INTRODUCTION

The relationships between concentration and discharge provide a fundamental insight into the mobilization and transfer of solutes and sediment from watersheds (Chorover et al., 2017). These relationships give an understanding into the combined effects of sources, footpaths, biogeo-chemical cycles and watershed factors such as lithology, type of soil, climatic conditions and sediment concentrations (Inamdar et al., 2006; Fellman et al., 2009).

Adams et al., (2019) opined that, developing general models of solute and sediment behavior across a range of flow conditions would provide insights into watershed functions as well as valuable guidance for sampling regimes that will most efficiently capture the impact of large events. The changes in sediment (behavior) and availability results in so-called hysteresis effects (Peter Bala 2008).

Hysteresis occurs when concentrations at a given discharge differ on the rising and falling limbs of the hydrography. Clockwise hysteresis is interpreted to reflect pioximal and rapidly mobilized sources; whereas counter-clockwise hysteresis reflects sources that are either proximal to the stream channel with slow travel times or those that are distal to the stream channel (Adms et al., 2019). Clockwise hysteresis relationship is the most commonly describe in studies. The flushing and subsequent exhaustion of sediment from channel or nearby sources prior to peak discharge has been attributed to this type of pattern (Baca 2002; Slattery et al., 2002; Lefrancois et al., 2007). Steegen et al., (200) however suggested that the supply of sediment from distant hillslope sources, which are usually connected with anti-clockwise hysteresis (Klein, 1984; Godwin et al., 2003; Benkhaled & Remini, 2003) produces clockwise hysteresis and not by sediment flushing and exhaustion. Intensities of rainfall at the beginning of storms, and reduction in the erosive effects of rainfall (Doty & Cater, 1965) increased inputs from baseflow after the peak discharge (Baca, 2002), events interval and duration (Wood, 1977) and also the development of a gully network (Dicenzo & Luck, 1997) forms other interpretations of hysteresis. Because of disparity of interpretations of hysteretic loops, Rodriquez-Blanco et al., (year) suggested that it is necessary to obtain direct information on sediment sources and transport in any particular catchment.

Therefore, the purpose of this study is to identify the hysteresis types of the discharge – suspended solid concentration (turbidity) relationship for two years in river Ose, Ondo State, Nigeria.

MATERIALS AND METHODS

Description of Study Area

River Ose is a steram (class H-Hydrographic) in Nigeria, located at an elevation of 136meters above sea level. The study portion of the river is located along the Owo-Oba Akoko expressway in Ondo State. The area lies within the coordinates 7º 18’ 35.5” N and 5º 39’ 52.5” E.

River Ose flows from Egbe-Ekiti in Ekiti State and runs through Owo and Akoko in Ondo State to Edo State. (see figure 1). This river is a seasonal river with long wet and dry seasons. The wet season lasts from April to October, when 80 percent of the annual rainfall falls, with the heaviest rains falling in June and September. The annual rainfall totals 1,830 millimetres. The average temperature ranges from 24 degrees Celsius in August to 29 degrees Celsius in February. The relative humidity is high, ranging between 80% and 100%. (Ondo State Government, 2010). It comprises of a rainforest vegetation close to mangrove belts with significant species like Avecinia Africana, Rhizophora, RAcemosa, NypaFruitcius (palm) and a tropical rainforest environment that is determined by temperature and precipitation. Environmental factors include fishing, agriculture, hunting, and forestry by inhabitants around the river. Apart from being a source for fishing and farming activities, River Ose is an important river to Owo and its environs as it is the source of raw water supply to headworks that supply water to them.

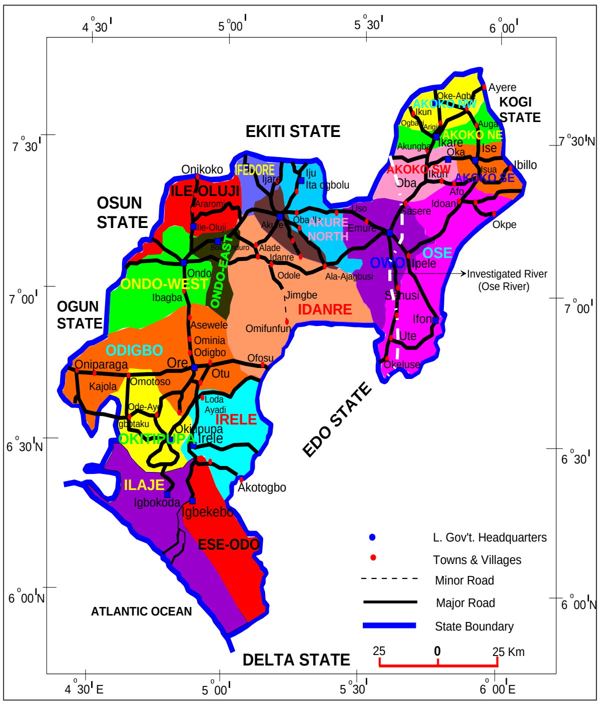

Figure 1. Map of Ondo State Indicating the Investigating River Ose (Ondo State Government, 2019)

DATA/SAMPLE COLLECTION

Data and samples were collected from River Ose (figure 2) over a period of two years spanning through two seasons i.e., dry and wet seasons. Discharge (Q) was obtained by calculating the integral of the river velocity (v) over the cross-section area of the flow(A), where (v) was measured perpendicular to the cross-section.

$$Q = \int v \delta A$$

Where, Q is the discharge in m^3/s; V is the velocity I m/s and A is the cross-section area in m^2. The velocity V was measured in discrete interval along the river cross-section using Vale Port BFM001 open channel flow meter. In order to determine the flow, the channel width was divided into 5 equal sections of 6m X 6m grid, while the 2 edges of the river are 2m from the bank. Thus, measurements and data were collected at seven points moving from the Left River Bank (LRB) to the Right River Bank (RRB) (figure 2). In-situ turbidity was monitored across the river channel moving from LRB to RRB using a high precision Turbid Meter TDS 5031 ESODO to provide direct measurement in unit of NTU (Nephelometric unit, 0-10,000). Turbidities were measured at mid-point of each section as adopted in the measurement grid at a particular time interval tested to match the resolution of the turbid meter.

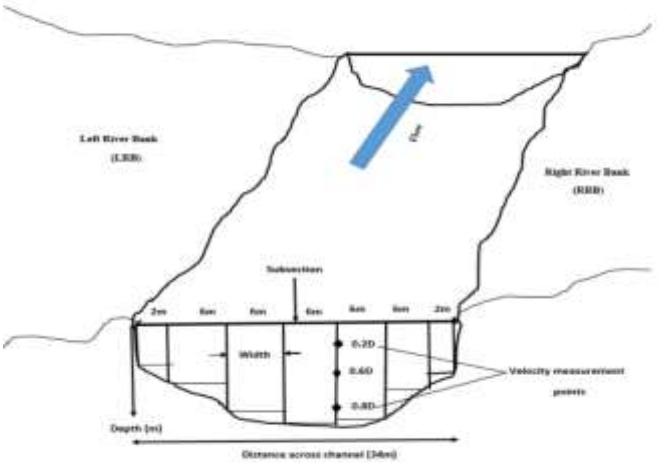

Figure 2. Measurement Grid

Figure 3. River Ose (Google Map, 2018)

RESULTS AND DISUSSION

Table 1-12 below show the summary of result obtained from the study conducted from April 2017 to December 2018 which spanned two seasons (wet and dry). Here, the corresponding values of turbidity concentration and discharge obtained were plotted to show the responses of suspended solid concentration to discharge (figure 1-12)

Table 1. Data and Sample results for the month of April 2017 (wet season)

Section	Flow Velocity (m/s)			Depth (m)	Width (m)	Area (m^2)	Discharge (m^3/s)	Turbidity (NTU)
	0.2D	0.6D (Mean)	0.8D			D x W	0.6DxArea	
1		0.26	0.26	0.6	2.0	2.0	0.52	46
2	0.33	0.3	0.24	1.3	6.0	7.8	2.34	40
3	0.44	0.39	0.30	1.3	6.0	7.8	3.04	16
4	0.65	0.51	0.40	1.4	6.0	8.4	4.28	16
5	0.81	0.62	0.55	1.4	6.0	8.4	5.21	18
6	0.41	0.35	0.22	1.2	6.0	7.2	2.52	43
7		0.28	0.28	0.7	2.0	1.4	0.39	46
Total							18.30	

NOTE: D is the depth of the river at each section.

Table 2. Data and Sample results for the month of May 2017 (wet season)

Section	Flow Velocity (m/s)			Depth (m)	Width (m)	Area (m^2)	Discharge (m^3/s)	Turbidity (NTU)
	0.2D	0.6D (Mean)	0.8D			D x W	0.6DxArea	
1		0.35		0.8	2.0	1.6	0.88	46
2	0.71	0.52	0.33	1.1	6.0	6.6	3.43	45
3	0.80	0.75	0.60	1.3	6.0	7.8	5.85	30
4	1.0	0.80	0.65	1.3	6.0	7.8	6.24	20
5	0.9	0.60	0.75	1.4	6.0	8.4	5.04	25
6	0.8	0.59	0.55	1.2	6.0	7.2	4.25	40
7		0.57		0.7	2.0	1.4	0.80	48
Total							26.49	

NOTE: D is the depth of the river at each section.

Table 3. Data and Sample results for the month of June 2017 (wet season)

Section	Flow Velocity (m/s)			Depth (m)	Width (m)	Area (m^2)	Discharge (m^3/s) 0.6DxArea	Turbidity (NTU)
	0.2D	0.6D (Mean)	0.8D			D x W		
1		0.55		0.8	2.0	1.6	0.88	50
2	0.70	0.44	0.39	1.2	6.0	7.2	3.17	40
3	1.1	0.8	0.77	1.4	6.0	8.4	6.72	20
4	1.43	1.0	0.92	1.5	6.0	9.0	9.0	20
5	1.20	0.8	0.6	1.3	6.0	7.8	6.24	40
6	1.0	0.66	0.42	1.2	6.0	7.2	4.75	50
7		0.57		0.7	2.0	1.4	0.80	60
Total							31.56	

NOTE: D is the depth of the river at each section.

Table 4. Data and Sample results for the month of October 2017 (dry season)

Section	Flow Velocity (m/s)			Depth (m)	Width (m)	Area (m^2)	Discharge (m^3/s)	Turbidity (NTU)
	0.2D	0.6D (Mean)	0.8D			D x W	0.6DxArea	
1		0.44		0.8	2.0	1.6	0.70	13
2	0.69	0.53	0.41	1.0	6.0	6.0	3.18	12
3	0.66	0.55	0.41	1.0	6.0	6.0	3.3	10
4	0.89	0.75	0.65	1.2	6.0	7.2	5.4	10

5	0.93	0.77	0.55	1.3	6.0	7.8	6.01	12
6	0.72	0.56	0.44	0.9	6.0	5.4	3.02	14
7		0.45		0.7	2.0	1.4	0.63	14
Total							22.24	

NOTE: D is the depth of the river at each section.

Table 5. Data and Sample results for the month of November 2017 (dry season)

Section	**Flow Velocity (m/s)**			**Depth (m)**	**Width (m)**	**Area (m^2) D x W**	**Discharge (m^3/s) 0.6DxArea**	**Turbidity (NTU)**
	0.2D	0.6D (Mean)	0.8D					
1		0.45		0.6	2.0	1.2	0.54	12
2	0.63	0.44	0.32	0.95	6.0	5.7	2.51	12
3	0.6	0.5	0.2	1.20	6.0	7.2	3.6	8
4	0.86	0.63	0.54	1.10	6.0	6.6	4.16	8
5	0.69	0.52	0.33	1.10	6.0	6.6	3.43	8
6	0.6	0.41	0.30	0.82	6.0	4.92	2.02	12
7		0.28		0.45	2.0	0.9	0.25	14
Total							16.51	

NOTE: D is the depth of the river at each section.

Table 6. Data and Sample results for the month of December 2017 (dry season)

Section	**Flow Velocity (m/s)**			**Depth (m)**	**Width (m)**	**Area (m^2) D x W**	**Discharge (m^3/s) 0.6DxArea**	**Turbidity (NTU)**
	0.2D	0.6D (Mean)	0.8D					
1		0.29		0.45	2.0	0.9	0.26	12
2	0.63	0.41	0.25	0.72	6.0	4.32	1.77	12
3	0.81	0.51	0.34	0.77	6.0	4.62	2.36	8
4	0.88	0.60	0.41	0.80	6.0	4.80	2.88	8
5	0.86	0.65	0.40	0.80	6.0	4.80	3.12	8
6	0.75	0.58	0.39	0.69	6.0	4.14	2.40	12
7		0.31		0.40	2.0	0.8	0.25	14
Total							13.04	

NOTE: D is the depth of the river at each section.

Table 7. Data and Sample results for the month of April 2018 (wet season)

Section	**Flow Velocity (m/s)**			**Depth (m)**	**Width (m)**	**Area (m^2) D x W**	**Discharge (m^3/s) 0.6DxArea**	**Turbidity (NTU)**
	0.2D	0.6D (Mean)	0.8D					
1		0.36		0.5	2.0	1.6	0.36	20
2	0.39	0.35	0.25	0.7	6.0	4.20	1.47	18
3	0.38	0.35	0.25	0.7	6.0	4.20	1.47	15
4	0.45	0.39	0.30	0.81	6.0	4.86	1,89	15
5	0.40	0.31	0.28	0.75	6.0	4.50	1.39	15
6	0.40	0.30	0.25	0.70	6.0	4.20	1.26	18
7		0.32		0.4	2.0	0.80	0.26	20
Total							8.1	

NOTE: D is the depth of the river at each section.

Table 8. Data and Sample results for the month of May 2018 (wet season)

Section	**Flow Velocity (m/s)**			**Depth (m)**	**Width (m)**	**Area (m^2) D x W**	**Discharge (m^3/s) 0.6DxArea**	**Turbidity (NTU)**
	0.2D	0.6D (Mean)	0.8D					
1		0.48		0.7	2.0	1.4	0.67	66
2	0.68	0.52	0.35	0.9	6.0	5.4	2.81	60

3	0.71	0.58	0.38	1.3	6.0	7.8	4.52	40
4	0.71	0.58	0.38	1.3	6.0	7.8	4.52	40
5	0.9	0.62	0.44	1.4	6.0	8.4	5.21	55
6	0.69	0.55	0.38	1.0	6.0	6.0	3.3	66
7		0.44		0.7	2.0	1.4	0.62	75
						Total	21.65	

NOTE: D is the depth of the river at each section.

Table 9. Data and Sample results for the month of June 2018 (wet season)

Section	**Flow Velocity (m/s)**			**Depth (m)**	**Width (m)**	**Area (m^2)**	**Discharge (m^3/s) 0.6DxArea**	**Turbidity (NTU)**
	0.2D	0.6D (Mean)	0.8D			**D x W**		
1		0.65		0.9	2.0	1.8	1.17	85
2	0.62	0.45	0.35	1.0	6.0	6.0	2.7	85
3	1.20	0.8	0.6	1.3	6.0	7.8	6.24	35
4	1.43	1.10	0.85	1.5	6.0	9.0	9.9	30
5	1.25	0.79	0.6	1.3	6.0	7.8	6.16	35
6	0.68	0.42	0.33	1.0	6.0	6.0	2.52	70
7		0.52		0.7	2.0	1.4	0.73	75
						Total	29.42	

NOTE: D is the depth of the river at each section.

Table 10. Data and Sample results for the month of October 2018 (dry season)

Section	**Flow Velocity (m/s)**			**Depth (m)**	**Width (m)**	**Area (m^2)**	**Discharge (m^3/s) 0.6DxArea**	**Turbidity (NTU)**
	0.2D	0.6D (Mean)	0.8D			**D x W**		
1		0.32		0.45	2.0	0.9	0.28	16
2	0.61	0.43	0.32	0.92	6.0	5.52	2.37	14
3	0.68	0.55	0.37	1.25	6.0	7.5	4.13	11
4	0.90	0.73	0.64	1.38	6.0	8.28	6.04	11
5	0.80	0.69	0.55	1.30	6.0	7.8	5.38	10
6	0.71	0.55	0.38	1.0	6.0	6.0	3.3	12
7		0.28		0.4	2.0	0.8	0.22	14
						Total	21.72	

NOTE: D is the depth of the river at each section.

Table 11. Data and Sample results for the month of November 2018 (dry season)

Section	**Flow Velocity (m/s)**			**Depth (m)**	**Width (m)**	**Area (m^2)**	**Discharge (m^3/s) 0.6DxArea**	**Turbidity (NTU)**
	0.2D	0.6D (Mean)	0.8D			**D x W**		
1		0.29		0.4	2.0	0.8	0.23	14
2	0.60	0.41	0.30	0.83	6.0	4.98	2.04	13
3	0.58	0.38	0.22	1.0	6.0	6.0	2.28	12
4	0.56	0.38	0.23	1.0	6.0	6.0	2.28	12
5	0.7	0.35	0.38	0.9	6.0	5.4	2.97	11
6	0.7	0.52	0.36	0.9	6.0	5.4	2.81	14
7		0.21		0.4	2.0	0.8	6.17	14
						Total	12.78	

NOTE: D is the depth of the river at each section.

Table 12. Data and Sample results for the month of December 2018 (dry season)

Section	Flow Velocity (m/s)			Depth (m)	Width (m)	Area (m^2)	Discharge (m^3/s)	Turbidity (NTU)
	0.2D	0.6D (Mean)	0.8D			D x W	0.6DxArea	
1		0.22		0.33	2.0	0.66	0.15	9
2	0.56	0.32	0.22	0.50	6.0	3.0	0.96	9
3	0.6	0.41	0.23	0.70	6.0	4.2	1.72	8
4	0.81	0.53	0.32	0.81	6.0	4.86	2.58	7
5	0.75	0.56	0.40	0.65	6.0	3.90	2.18	7
6	0.7	0.55	0.41	0.65	6.0	3.90	2.15	12
7		0.25		0.38	2.0	0.76	0.19	12
						Total	9.93	

NOTE: D is the depth of the river at each section.

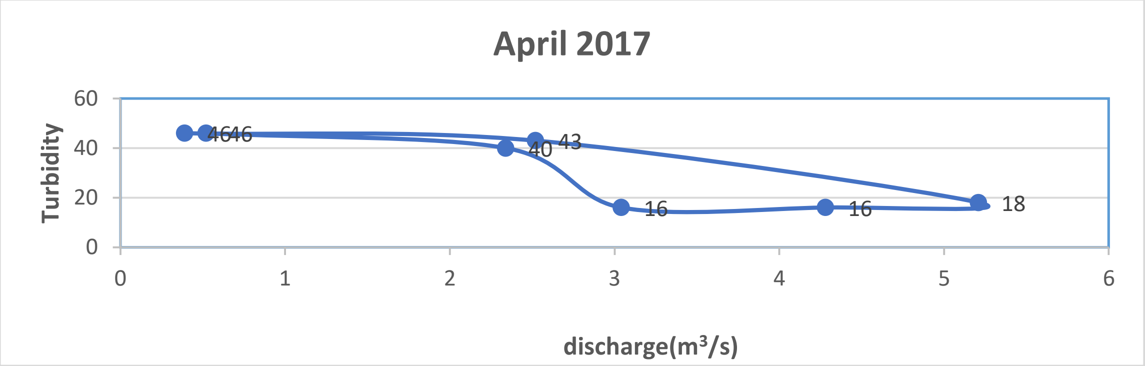

Figure 4. Hysteresis loop for the month of April 2017

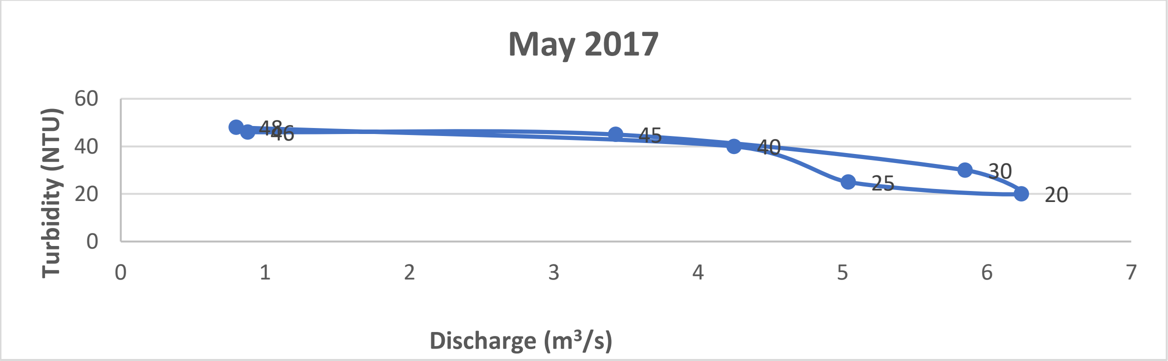

Figure 5. Hysteresis loop for the month of May 2017

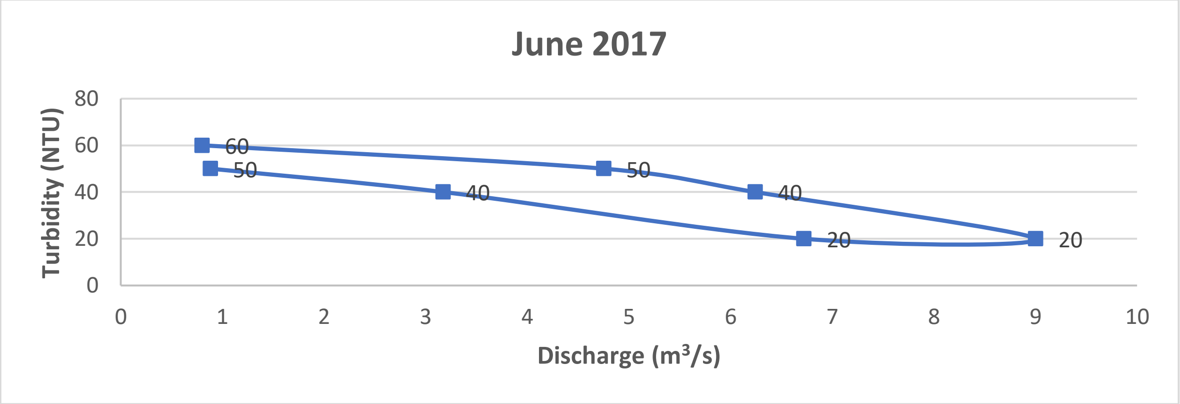

Figure 6. Hysteresis loop for the month of June 2017

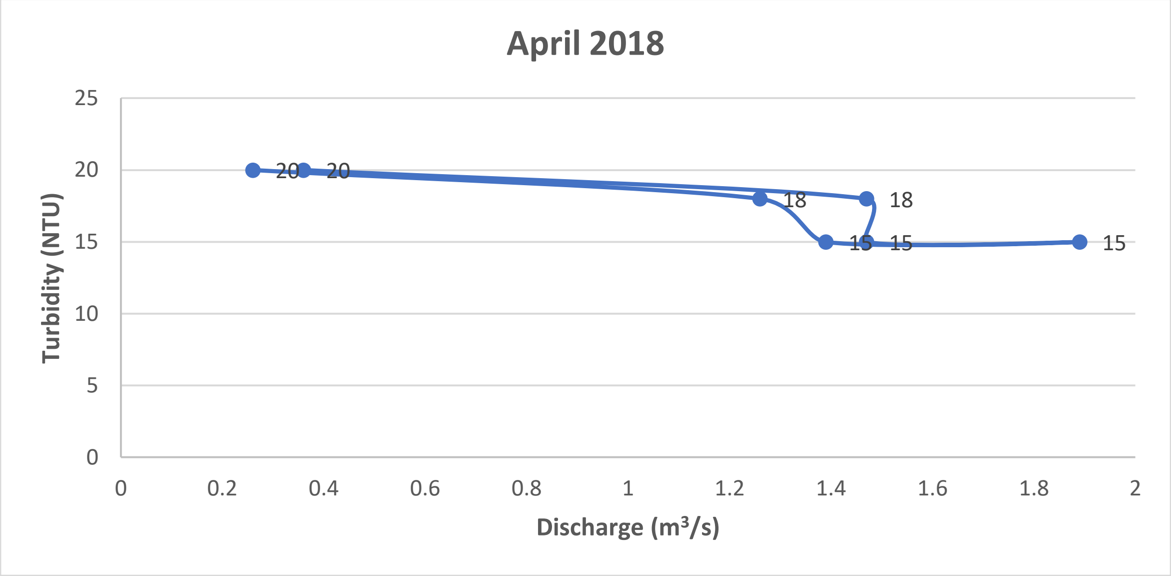

Figure 7. Hysteresis loop for the month of April 2018

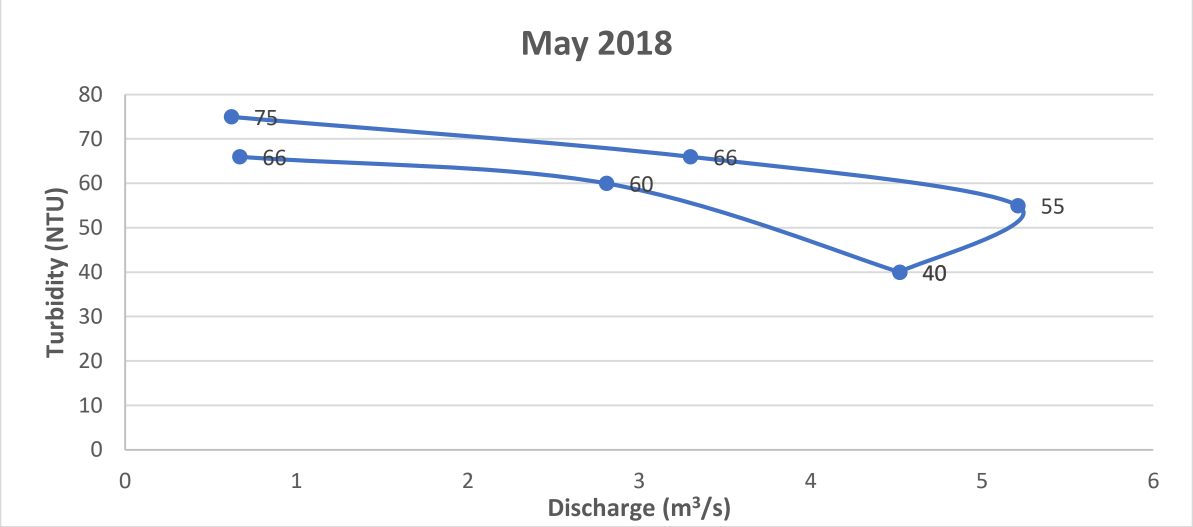

Figure 8. Hysteresis loop for the month of May 2018

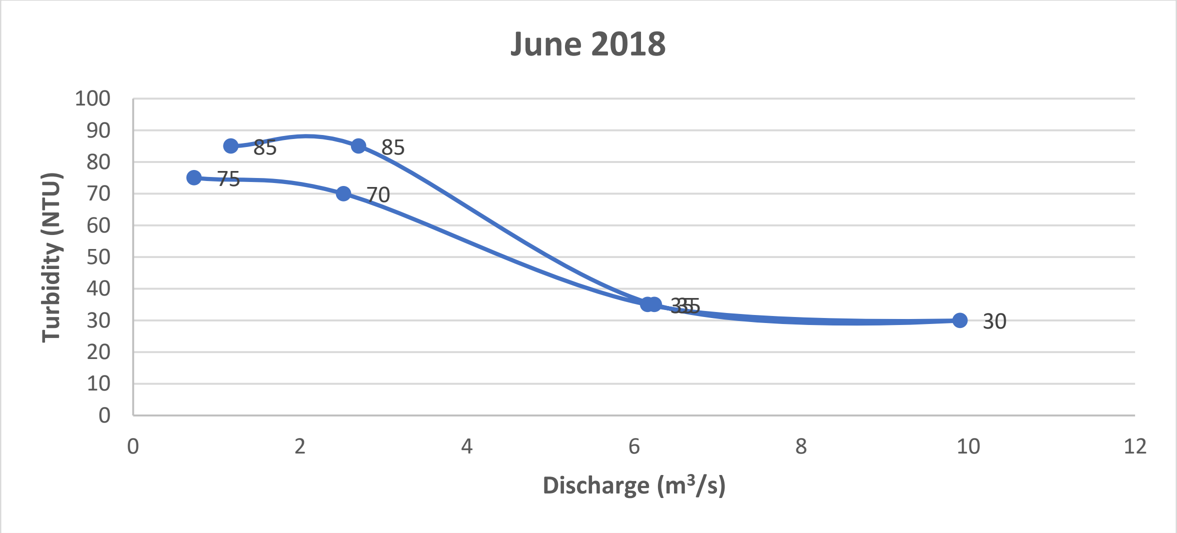

Figure 9. Hysteresis loop for the month of May 2018

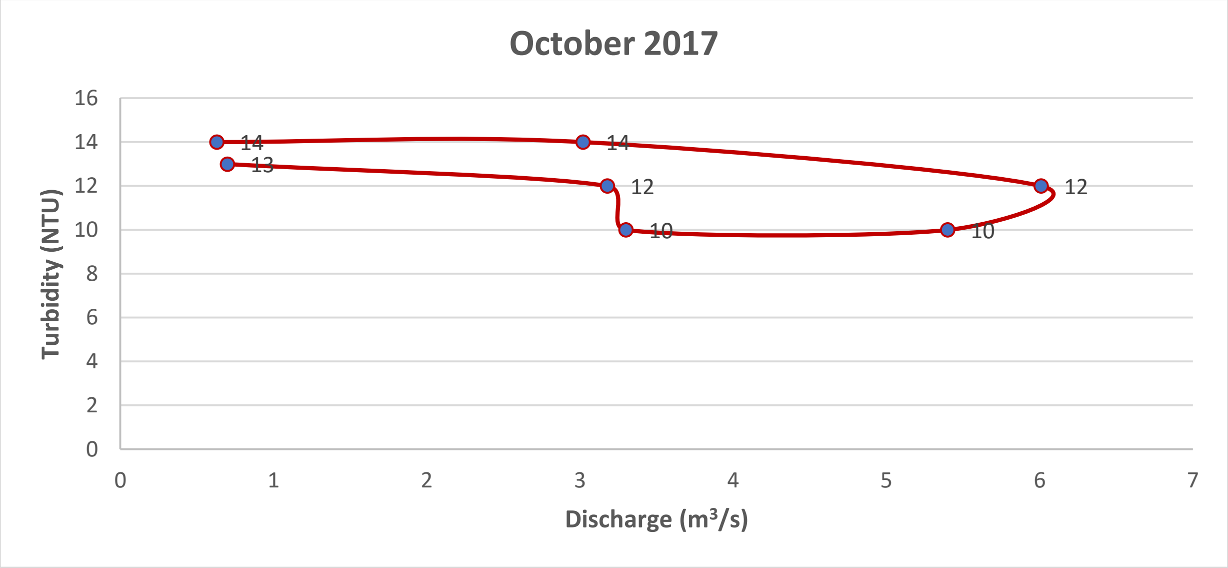

Figure 10. Hysteresis loop for the month of October 2017

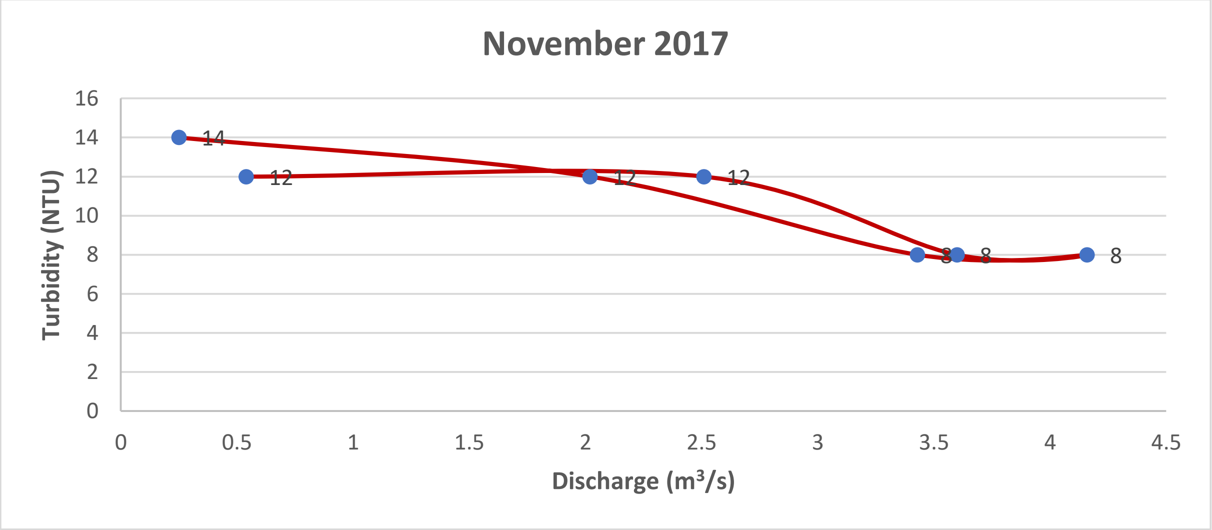

Figure 11. Hysteresis loop for the month of November 2017

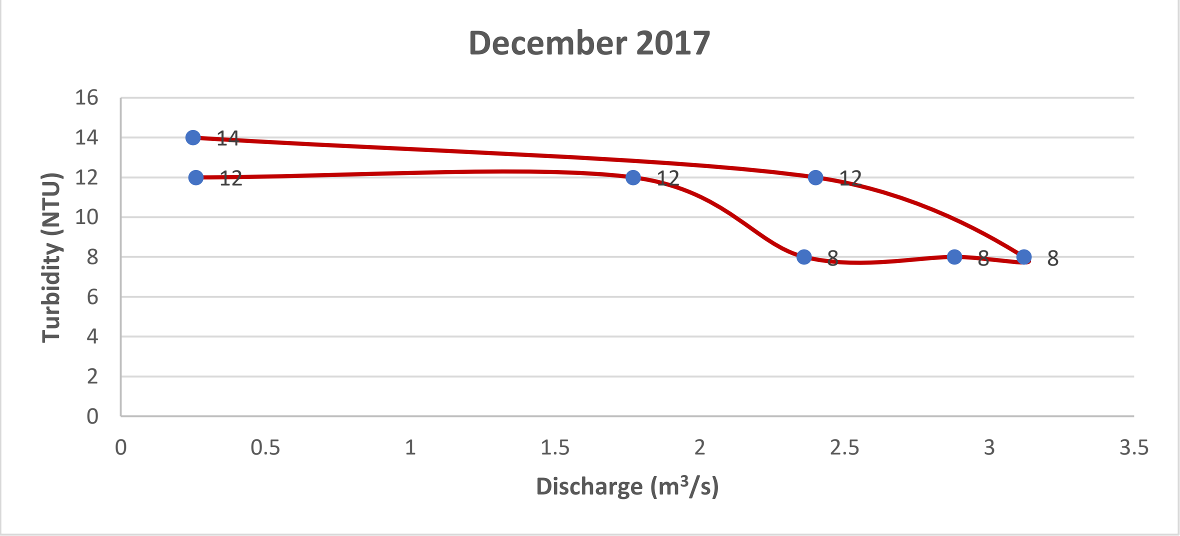

Figure 12. Hysteresis loop for the month of December 2017

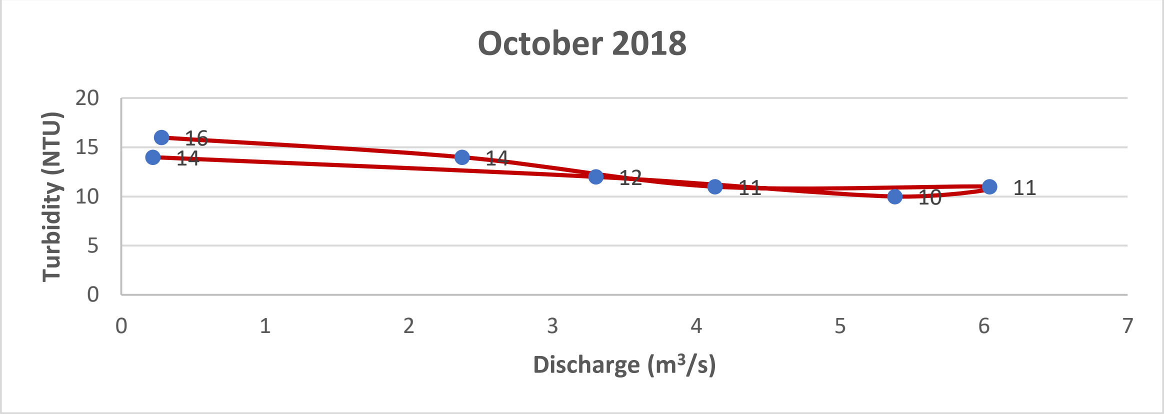

Figure 13. Hysteresis loop for the month of October 2018

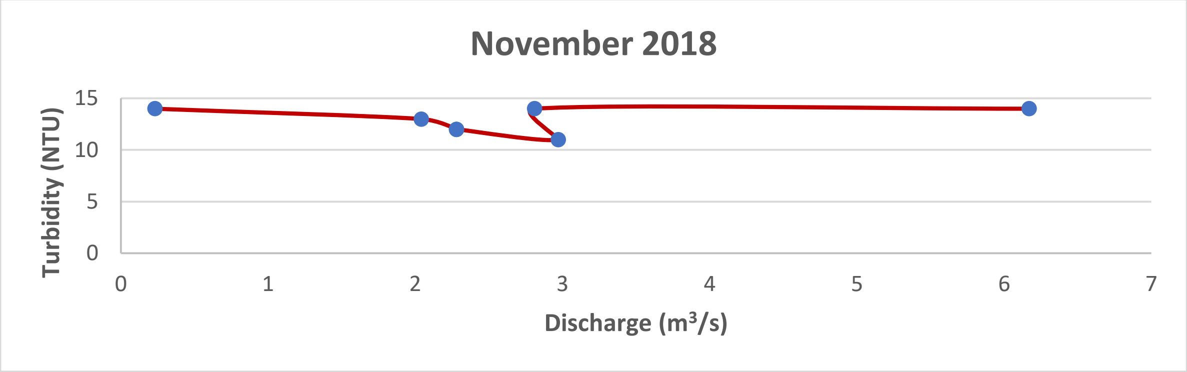

Figure 14. Hysteresis loop for the month of November 2018

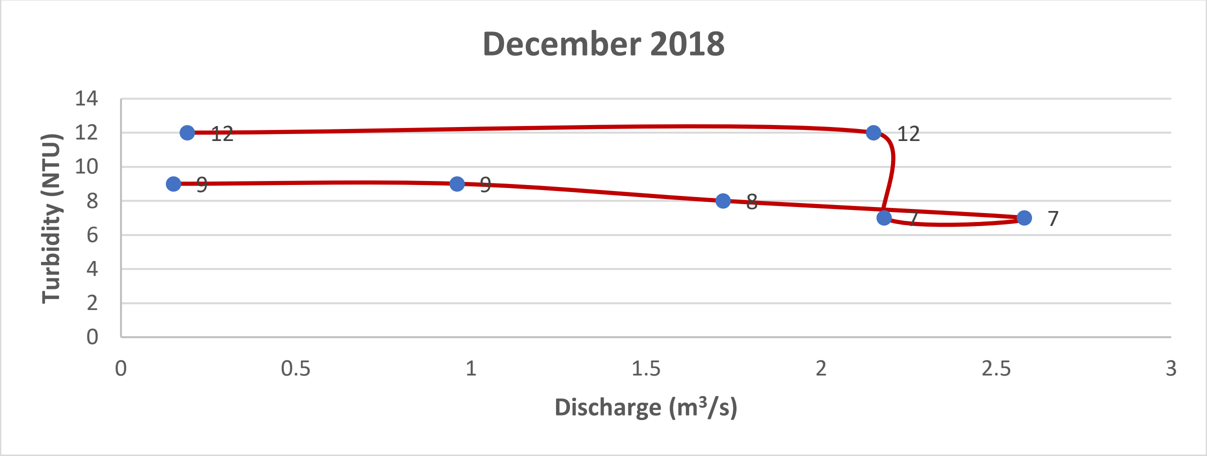

Figure 15. Hysteresis loop for the month of December 2018

DISCUSSION

Hysteresis loops were generated for all the turbidity values measured in the investigated section of the river as seen in the above figures. The loops were classified according to the season and trend. Analysis showed that counter-clockwise hysteresis loop pattern was dominant for the section than other patterns like linear loop pattern.

The hysteresis plots for the raining seasons (April, May, and June) for the study years are shown in the following Figures (4-9). Analysis clearly shows the dominance of counter-clockwise hysteresis loops with the exception of Figure 7 which is linear in pattern.

Figures 10-15 illustrates the hysteresis pattern for the dry seasons of October, November, and December of the years under study. In this study, two kinds of hysteresis loops were observed; a counter-clockwise hysteresis loop pattern can be seen in Figures 10, 11, 12, 13 and 15 while linear is displayed by Figure 14. The intensity of rainfall varies. Rainfall intervals and antecedent conditions can cause a variety of flow responses and, as a result, a range of hysteresis patterns, this is in conformity with the studies of Martin et al., (2014). Also, Soler et al. (2018) demonstrated that counter-clockwise loops were associated with overland flow and suggested distant sediment sources within the catchment.

CONCLUSION

The hysteresis plots were used to provide insight into how the suspended solids responds to the discharge in the river. This is necessary in water quality monitoring and river management. The hysteresis loops generated for all the turbidity values showed that counter-clockwise hysteresis loop patterns were dominant for the section than other patterns. Variation in rainfall intensities, rainfall durations and antecedent conditions may result in a range of flow responses and subsequently a variety of hysteresis patterns. The dominance of counter-clockwise hysteresis loops has implications on flow pathway, it suggests that overland flow is much possible in the study area.

REFRENCES

1. Adam, S. W., Miguel, C. L., James, B. S., and William, H. M. (2019). Hysteretic response of solutes and turbidity atthe event scale across forested tropical Montane watersheds. *Frontiers in Earth Science doi: 10.3389/feart.2019.00126*
2. Baca, P,. 2002. Temporal variability of suspended sediment availability during rainfall-runoff events in a small agricultural basin. ERB and Northern European FRIEND Project 5 Conference, Demanovska dolina, Slovakia.
3. DiCenzo, P. D., Luk, S. (1997). Gully erosion and sediment transport in a small subtropical catchment,*Catena, 29: 161-176.*
4. Doty, C. W., Carter, C. E. (1965). Rates and particles-size distribution of soil erosion from unit source areas. *Trans. Am. Soc. Agric. Engrs., 8: 309-311.*
5. Fellman, J. B., Hood, E., Edwards, R. T., and D'Amore, D. V. (2009). Changes in the concentration, biodegradability, and fluorescent properties of dissoved organic matter during stormflows in coastal temperate watersheds. *J. Geophys. Res. Biogeo. 114:G01021. doi: 10.1029/2008JG000790*
6. Inamdar, S. P., O' Leary, N., Mitchell, M. J,. and Riley, J. T. (2006). The impact of storm events on solute exports from a glaciated forested watershed in western New York, USA. *Hydrol process. 20, 3423-3439. Doi: 10.1002/hyp.6141*
7. Klein, M. (1984). Anticlockwise hysteresis in suspended concentration during individual storms: Holbeck catchment, Yorkshire, England. Catena 11, pp 251-257.
8. Lefrancois, J., Grimaldi, C., Gascuel-ODoux, C., Gilliet, N. (2007). Suspended sediment and discharge relationships to identify bank degradation as a main source on small agricultural catchments. *Hydrol. Process., 21:2923-2933.*
9. Martin, S.E., Conklin, M.H., Bales, R.C. (2014). Seasonal Accumulation and Depletion of Local Sediment Stores of Four Headwater Catchments. *Journal* Water 6,2144-2163; doi: 10.3390/w607244
10. Rodrigueez-Blanco, M, L., Taboada-Castro, M. T., Oropeza Mota, J. L. Suspended sediment-discharge during rainfall events in a small headwater catchment in the NW Spain. *Part of research of REN2003-08143 project PGIDIT05RAG10303PR, funded respectively by the Spanish Ministry of Education and Science (MEC) and the Xunta of Galicia.*
11. Slattery, M. C., Gares, P. A., Philips, J. D. (2002). Slope-channel linkage and sediment delivery on North Carolin Coastal Plain cropland. *Earth Surf. Process. Landforms, 27: 1377-1387*
12. Soler, M., Latron, G., Gallart, F. (2008). Relationships between suspendend sediment concentrations and discharge in two small research basins in mountainous Mediterranean area (Vallcebre, Eastern Pyrenees). *Geomorphology* 98, 143-152.
13. Steegen, A., Govers, G., Nachtergaele, J., Takken, I., Beuselinck L., Poesen, J. (2000). Sediment export by waterfrom an agricultural catchment in the Loam Belt of Central Belgium. *Geomorphology, 33:25-36.*
14. Wood, P. (1977). Controls of variation in suspended sediment concentration in the River Rother, West Sussex,England. *Sedimentogy, 24: 437-445.*