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Identification of Flash-flood Potential Regions through Morphometric Analysis: a case study of the Arkasa Watershed in the Eastern Pedimental Complex of West Bengal, India

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Abstract

Basin morphometric characteristics have a vital role in the hydrological procedures as they essentially standardize the hydrological responses of a catchment system. Therefore, analysis of morphometric aspects becomes even more significant while studying the nature of run off as a response to intense rainfall, especially in case of a flash flood-prone watershed, like Arkasa. The Arkasa is a right bank tributary of Dwarkeshwar river system in West Bengal, which is the lifeline of about 11 villages containing about 2000 people. The current study gives a holistic assessment of the hydrologic responses of different morphometric parameters of this watershed. The flash flood-prone regions have been delineated based on the composite scores of the weighted normalized values of the morphometric indices. Out of the 11 villages, 6 (containing more than 800 people) were found potentially dangerous for any flood events. The analysis of remote sensing data in GIS platform/environment gives an unique spatial view of the potentially flas flood-prone sub-watersheds of Arkasa.

Introduction

Flashflood is among the catastrophic threats in the world, which leads to loss of human life, property, and infrastructure (CEOS, 2003). It is defined as an abrupt increase in discharge of river water, having high damage potential in the affected parts of lower catchments caused by intense rainfall events or through breaching of embankments or dams (Azmeri*et al.,* 2016). The magnitude and extent of flood vary from one year to another; however, there is an increasing trend over the past couple of years (Askari and Shayannejad, 2016). The increasing global land surface temperature by 0.6 ± 0.28 º C during the early 19th century (IPCC), 2007) and in recent times by 0.72º C to 0.85 º C (IPCC, 2013) put adverse effects upon the drainage basin and its morphological patterns. The uncertainty of climatic phenomena, like monsoon anomaly, seasonal shifting of rainfall pattern, above-normal temperature, are the major forces leading to accelerated flood events of high intensity and expansion (Kininmonth, 2004, Nicholls and Lowe, 2006, Chow, 2018) in monsoon affected regions of India (Mirza,2002). The global climate change also adversely impacted the Himalayan cryosphere and led to numerous flash floods (Mahessar *et al.,* 2013). Rivers originating from the Himalayas are fed by glaciers and snow and often causes flooding during high monsoon thereby causing catastrophic damages, e.g. Leh floods of 2010 (Juyal 2010, Bhan et al. 2015). Such floods are also be caused through hydro-meteorological triggers and topographic predisposition (Allen *et al.,* 2016). Heavy rainfall can fill the high elevation lakes, which can breach as soon as the water exceeds the capacity of its dam to hold it, for instance the second spell of flood in Kedarnath, 2013 (Allen, 2016). On the contrary, non-perennial rivers are also at high risk of flash flooding during abrupt monsoon rainfall on unfavorable bed structure.

The north and east Indian states e.g. Bihar, Jharkhand and West Bengal have a history of hydro-meteorological floods (Sanyal and Lu, 2005). Some of the recent examples are Assi Ganga valley, Leh, Bhagirathi and Yumuna valley, Mandakini and Kali valley (Gupta et al, 2013)). According to Irrigation and Waterways Department (IWD) (2009), the Bankura district, West Bangal has been experiencing sudden and increasing flash floods and severe droughts in recent decades. Besides climate change, the morphometric properties of the watershed and landuse / cover characteristics can play an important role in generating flash floods and the associated damage potentials (Juyal, 2010). Morphometric properties include mainly the drainage network properties, e.g. drainage density, bifurcation ratio, stream frequency and over land flow as well as sub-watershed characteristics (Farrukh*et al.,* 2013). Landuse / change can modify the river run off patterns, erosion patterns and to some extent the temperature and rainfall, which can intensify the magnitude, extent and impacts of flash floods.

The Study Area

The study area is the Arkasa watershed, a right bank tributary of Dwarkeshwar river, which rises from north-western part of Paharpur village of Hura C.D.block, Purulia district, West Bengal. It then flows south-easterly and easterly direction and joins the Dwarkeshwar river near northern part of Rangametya village of C.D. Block Bankura-I of Bankura district of West Bengal (Fig.1).The watershed is located in western part of the Bankura district and bounded between 23º10´50"N to 23º21´00"N and 86º37´50"E to 86º55´50"E, with a surface area of about 305 km^2.

Geomorphologically, the Arkasa watershed is one of the important drainage systems of the upper pedimental zone of Bankura Purulia peneplained surface. It comprises five micro units, *i.e.* 1) undulating upland with residual hillocks and mounds, 2) undulating buried pedimental plains, 3) shallow, medium, deep, washed plains, 4) alluvial valley fills and 5) lower flood plains. The general drainage pattern of the Arkasa watershed is dendritic in nature. Rocks in the region are highly sheared (Plate-1), brecciaed and mylonitized resulting in a highly porous and permeable subsurface (Das *et al.,* 2013). Presence of rock-knobs are frequentthe study area (Plate -2).

Climatologically, the watershed is characterized by sub-tropical monsoon climate, with annual rainfall ofabout 1303.7mmbetween1991 and 2003 (Das *et al.,* 2013). Much of the rainfall is received during monsoon months (80%), rest 20 % rainfall is observed in winter months. The mean temperature in the study area rises up to 40ºCin summer, while wintersobserves very low mean temperature i.e.7ºC (Das *et al., 2013*). Although, the study area is located in the sub-arid climatic region, the watershed occasionally receive an enormous amount of rain water during rainy season (Das *et al.,* 2013). About 50% of the rainfall may turn into flashflood to the outlet of this watershed, instigating disastrous effects on the existing infrastructure and surrounding environment.

Objectives

With the understanding that micro-level investigations of flash flood area are urgently required in the Arkasa watershed, West Bengal, this study aims to analyze the morphometry and land use/cover to identify the potential flash flood region.

Database and Research Methodology

In the present study, geomorphometric properties and landuse have been analyzed for understanding the flashfloods in the small *Arkasa* watershed. Spatial information technologies, the remote sensing and Geographical Information System (GIS) have proved to be efficient for delineating the flood prone regions and deriving flood management systems and mechanism based on multi-criteria decision support system. GIS has been extensively used for geomorphometric and environmental investigations and applications (Dawod and Mohamed, 2009, El Bastawesy *et al.,* 2010, Rao, *et al.,* 2010, Dawod and Mohamed, 2008, and Dongquan *et al.,* 2009, Bajracharya *et al.,*2017). The assessment of flood prone areas through remote sensing and GIS can greatly help reduce loss of property, life and infrastructure (Hsu *et al.,* 2003).

The study is based on satellite data (IRS- P6, LISS-III, 2011), Survey of India (SOI) topographical map (73M/6) at 1:50,000scale, and intensive field observations in 2013. The methodological flow included preparation of basemap, followed by morphometric investigations and mapping by visual interpretation of satellite image. The topographical sheets supplemented the field investigation and ground inspection of our study results. The prioritization of each sub-watersheds regarding their relative influence was done by employing normalized value of morphometric parameters (Youssef*etal*.,2009, Pradhan,2010, Lingadevaru *et al.,* 2015, Abduladheem *et al.,*2015), as follows:

$$x_j = \frac{(R_j - R_{Min})}{(R_{Max} - R_{Min})}$$

Where, x_j: is the normalized score , R_j: is raw score, R_{Min}: is the minimum score R_{Max}: is the maximum score

Watersheds of high stream frequency and high drainage density tend to collect more runoff that increases the rate of flow- discharge, thereby resulting in a high flood risk value (Farrukh*et al.,* 2013). In the study area, the rate of infiltration and percolation is assumed to be very low due to hard rock bed (Photo 1 and 2). The low bifurcation ratio of drainage network with high drainage density and high stream frequency certainly produces high risk of flood. Watersheds with higher circularity and elongation ratios (Rc and Re) tend to have higher flash flood potentials. Circular watersheds are also more susceptible to flash floods. (Farrukhet al., 2013) The results have been verified in the field and based on existing problems of flash flood in the study area, micro regions of potential flash flood have also been identified.

Discussion and Results

It is observed that the landuse / cover in the study area is heterogeneous in nature due to both natural and anthropogenic factors. Major landuse / landcover classes observed in the study area includes protected forests, open scrubs, settlements, stony wastes, acacia plantations, other plantations, gullied land, cultivable wastelands, lateritic upland, wastelands, cultivated land, roads and rivers. The rapidly growing population has brought about significant changes in landuse / landcover that eventually gives rise to the natural hazards in the Indian sub-continent (Singh, 1998). It also adversely affects the morphometry of the landscape leading to unprecedented weather events. The inappropriate landuse practices also contribute to flash floods. Major part of study area is covered by the cultivated wastelands (more than 80%), followed by protected forests, open scrubs, stony surfaces, lateritic uplands and gullied land (Fig.2). The stony wastes, lateritic uplands and the gullied landscape along with rocky knobs in the river channel largely contribute to an accelerated flashfloods in the study area.

There is a strong diversity of different morphometric parameters in the sub-watersheds. Their shape is an important parameter that controls the geometric and hydrographic character of the watersheds. Several indices have been used to describe the shape of the Arkasa watershed e.g. circularity ratio, elongation ratio, from factor and compactness constant. Sub-watersheds range from 8.5 km² (sub-watershed no -10) to 43.5 km² (sub-watershed no-3), while the watershed perimeter vary from 14.5 km (sub-watershed no - 13) to 30.5 km(sub-watershed no - 3). There is a wide range of variation in the elevation of the watershed (Table-4), which varies from 112 to 281 m (Fig.4). The relief ratio (m/km) ranges from 5m to 121m. It is interesting to note that sub-watershed no-1 has the highest relative relief and relief ratio, steep morphometric characteristics and topographical complexity.

The circularity ratio is the relation of the watershed area to the area of the circle having the same circumference. It varies between 0.087 to 1.0. Sub-watershed no-13 has the highest circularity ratio even though it is a small sub-watershed. This is considered as a hazardous indication, since it suggests that the high flashflood volume could affect over a small area. The assessment of elongation ratio epitomizes how close a watershed to a rectangular shape is. Seven sub-watersheds have elongation ratio less than 0.5, whereas the remaining seven have more than 0.5. The texture ratio of the sub-watershed varies between 0 and 1.0. For five sub-watersheds, it is above 0.5 indicating average texture.

Stream ordering has been used to denote the hierarchical relationship between stream segments. Fig.3 denotes spatial variation of stream order in Arkasa watershed. There is an inverse proportional relationship between stream lengths and stream order (Table-2). The designation of stream orders is the first step in drainage basin analysis. It is based on hierarchic ranking of streams as suggested by Strahler (1964). The first order streams have no tributaries, when two first order streams meets, a second order stream is generated. Therefore, the second order streams have only first order stream as its tributaries. Higher order streams are estimated in the same way. The Arkasa river is a 5^{th} order watershed and it has a total of 433 1st order streams , 95 2nd order, 18 3rd order and 9 4th order streams. The mean stream length of the watershed is a dimensional parameter depicting the distinctive size of drainage linkage components and its contributing watershed surfaces (Strahler, 1964). The mean stream length has been calculated by dividing the total stream length of order by the number of streams (Table- 1). Chorley (1969) suggested that the lower the bifurcation ratio, the higher the risk of flooding. Lower bifurcation ratio has been found in the sub-watersheds no-12, 10 and 6 indicating higher risk of flooding.

The elevation difference between the highest and lowest points on the valley floor of a sub-watershed is its total relief, whereas "the ratio of maximum relief to horizontal distance along the longest dimension of the parallel to the principal drainage line is relief ratio (Rh)" (Schumm, 1956). It measures the overall steepness of a drainage system, which can be used as an indicator of intensity of flooding. Analysis of relief ratio in the Arkasa watershed shows a considerable spatial variation, where the lowest value is observed in SW-10, and highest value noted in SW-1. Similarly a wide range of variation is noticed in gradient ratio. The highest value is observed in SW-14 and lowest in SW-1. The distance of overland flow is the extent of water over the ground before it gets rigorous into definite stream channels (Horton,1945). It relates inversely to the average slope of the channel and is an indication of the length of sheet flow to a large degree (Horton,1945).

In order to study the relationship between the geomorphometric properties of the watershed and their hydrological impacts, composite index of normalized value of morphometric parameters have been used (Table-5). The sub-watersheds no 1,6,7,9 and13 have higher composite index of relief ratio and relative relief, thereby implying higher probability of flash flood. Similarly, sub-watersheds no-3,8, 11 and 14 fall in medium category of composite index, whereas sub-watersheds no- 2, 4, 5, 10 and 12 are with low category. The areas with higher potential of flash flooding have the highest drainage density, a fine drainage texture, with minimal length of overland flow across steep slope and high stream channel gradients (Fig.5). In these sub-watersheds, the rate of infiltration of water is low leading to higher run off. Highly dissected terrain with high relief watersheds have a high flood potential. Conversely, the low relief watersheds with low dissection have a low flood potential. Similar relationship is also found between linear and other morphometric parameters.

Morphometric Parameters and Flashflood

There is strong relationship among morphometric parameters and flood occurrence during June, 2012 and August, 2013 respectively. The rock exposure and surface topography do not allow percolation that results in higher run-off during high monsoon rain thereby producing catastrophic floods in the surrounding regions. More than 30% of this watershed is covered by rocky knobs and undulating topography. So, during rain, most of the water drains into the streams leading to flash floods. Sub-watershed nos. 1, 6, 7 and 9 are potentially dangerous for the sudden floods during rainy season based on their share of influence through composite priority index. The watershed morphometry (Table-1) and surface topography are the key outfits for the flash flood. Out of the 11 villages, 6 are potentially vulnerable to flash flood due to abrupt rainfall incidence. The June 2012 floods caused huge damage to the infrastructure and property in the study area.

Conclusion

The present study demonstrates the utility of remote sensing and GIS for identifying potential flash flood-prone areas at watershed-level on the basis of morphometric properties.

Thus, the study identified the areas to be considered for watershed management. It is useful for agro-environmental planning for any micro-region or sub-watersheds. Remote sensing provides landuse and other required data. The sub-watersheds with high potentials of flash floods are SW-1, SW-6, SW-7, SW-9 and SW-13, followed by the 2nd-level sub-watersheds of SW-3, SW-8, SW-11 and SW-14. These sub-watersheds may be considered for effective soil and water conservation measures. There is a wide range of variations in the different parameters of the hydro-morphometry. Some parts of the Arkasa watershed are more susceptible to flooding and erosion. It is recommended that human activities that could impact negatively on the drainage network should be restricted. Proper landuse planning is needed so that modified surface and sub-surface runoff can be checked. Forest degradation should be immediately stopped and afforestation measures taken to check the huge run off. Conservation measures like construction of check dams, contour bundling also helps in finding the holistic solution of such issues.

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Table-1: Input Parameters for flash flood analysis

Techniques used	Derivations	Postulator
Stream Order(Nu)	Hierarchical rank	Strahler (1964)
Bifurcation Ratio(Rb)	Rb= Nu/Nu+1 Where Nu = Total number of stream segment of order u Nu+1= Total number of stream segments in next higher order	Schumm (1956)
Mean Bifurcation Ratio(Rbm)	Rbm = Average of Bifurcation ratio of all orders	Strahler (1964)
Mean stream length	Total stream length divide by total number of streams	Strahler (1964)
Stream Frequency(F)	F = Nu/Au where Nu=total number of stream segments of all order Au=Basin area	Horton (1945)
Drainage Texture(T)	T= Dd x F Where Dd= Drainage Density, F= Stream Frequency	Smith (1950)
Circulatory Ratio(Rc)	$Rc=4\pi A/ P^2$ Where, Rc= Circularity Ratio, A= Area of the Basin(km^2) P = Perimeter (km)	Miller (1953)
Elongation Ratio(Re)	Re =(d/Lb)* 2A/π /L Where,d= diameter of circle of the same area as the basin, Lb= Length of basin(km), A = Area of the basin(km^2) L=maximum length of basin	Schumm(1956)
From Factor(Rf)	$Rf = A/Lb^2$ Where A = Area of the basin(km^2) Lb^2 = Square of the basin length	Horton (1945)
Texture Ratio(T)	T = Nu/ P Where Nu = Total number of streams of all orders P = Perimeter(km)	Horton (1945)
Compactness Constant(Cc)	Cc = 0.2821 P/A*0.5* Where A = Area of the basin (km^2), P = Perimeter of the basin (km)	Horton (1945)
Basin Relief(Bh)	Bh = H- h Where H = Maximum height of basin h = minimum height of basin	Schumm (1956)
Relief ratio(Rh)	Rh =H/Lb, Where H=Total height Lb=maximum basin length(km)	Schumm (1956)
Length of the over land flow(Lo)	Lo = 1/D*2 Where Lo= Length of the over land flow, D= Drainage Density	Horton (1945)

Table-2:Stream Analysis: Orderwise Number, Length and Mean Lengths of Streams

Sub watersheds	Parameters	Stream Order				
		I	II	III	IV	V
SW-1	No. of Stream	67	15	4	1	-
	Stream Length(km.)	45.5	12	8	11.5	-
	Mean Length(km.)	0.68	0.8	2	11.5	-
SW-2	No. of Stream	31	5	1	-	-
	Stream Length(km.)	20.5	7	6.5	-	-
	Mean Length(km.)	0.66	1.4	6.5	-	-
SW-3	No. of Stream	55	11	2	1	-
	Stream Length(km.)	44	13	7	6	-
	Mean Length(km.)	0.8	1.1`8	3.5	6	-
SW-4	No. of Stream	26	6	1	-	-
	Stream Length(km.)	22	3.5	6.5	-	-
	Mean Length(km.)	0.84	0.58	6.5	-	-
SW-5	No. of Stream	22	6	1	1	-
	Stream Length(km.)	15	6.5	2.5	6.5	-
	Mean Length(km.)	0.68	1.08	2.5	6.5	-
SW-6	No. of Stream	26	6	2	2	1
	Stream Length(km.)	16.5	5	3.5	3	2
	Mean Length(km.)	0.63	0.83	1.75	1.5	2
SW-7	No. of Stream	34	5	-	-	-
	Stream Length(km.)	18.5	8	-	-	-
	Mean Length(km.)	0.54	1.6		-	-
SW-8	No. of Stream	28	7	1	-	-
	Stream Length(km.)	19.5	6	5	-	-
	Mean Length(km.)	0.69	0.86	5	-	-
SW-9	No. of Stream	43	7	2	1	-
	Stream Length(km.)	25	9	5.5	4	-
	Mean Length(km.)	0.58	1.29	2.75	4	-
SW-10	No. of Stream	8	2	-	1	1
	Stream Length(km.)	5	2	-	3.5	5
	Mean Length(km.)	0.63	1	-	3.5	5
SW-11	No. of Stream	16	5	1	-	1
	Stream Length(km.)	10.5	4	3	-	7.5
	Mean Length(km.)	0.66	0.8	3	-	7.5
SW-12	No. of Stream	38	12	3	1	1
	Stream Length(km.)	28	12	7.6	6	2
	Stream Length(km.)	0.74	1	2.5	6	2
SW-13	No. of Stream	15	3	-	1	-
	Stream Length(km.)	11	8.5	-	3	-
	Stream Length(km.)	0.73	2.83	-	3	-
SW-14	No. of Stream	24	5	-	1	-
	Stream Length(km.)	13.5	8.5	-	2.5	-
	Stream Length(km.)	0.56	1.7	-	2.5	-

Source:Author's computation using SOI Topographical Sheets and Satellite Imageries (Precision Geocoded (FCCs) of IRS- P6 & LISS-III, 2009)

Table-3:Bifurcation Ratio and Mean Bifurcation Ratio

Sub-watershed	Order wise Bifurcation Ratio				Mean Bifurcation Ratio
	I/II	II/III	III/IV	IV/V	
SW- 1	4.45	3.75	4	1	3.3
SW- 2	6.2	5	1	-	4.06
SW- 3	5	5.5	2	1	3.83
SWC 4	5.2	5	1	-	3.73
SWC 5	3.7	6	1	-	3.6
SWC 6	4.33	3	1	-	2.78
SWC 7	6.8	-	-	-	6.8
SWC 8	4	7	-	-	5.5
SWC 9	6.14	3.5	-	-	4.82
SWC 10	4	-	-	1	2.5
SW-11	3.2	5	-	-	4.1
SW-12	3.17	4	3	1	2.79
SW-13	5	-	-	-	5
SW-14	4.8	-	-	-	4.8
Total	4.61	5.22	2	2.25	3.52

Source: Author's computation using SOI Topographical Sheets and Satellite Imageries (Precision Geocoded FCCs of IRS- P6 & LISS-III, 2009)

Table-4:Characteristics of Relief and Gradient, and Ruggedness Number

Sub watershed	Relief Aspects					Ruggedness Number	Gradient Aspects				
	Elevation(m)		Total relief	Basin Length	Relief Ratio		Elevation(m)		Fall in Height(a-b)	Basin Length	Gradient ratio
	Max	Min					Source (a)	Mouth (b)			
SW-1	281	160	121	13.8	0.088	0.24	180	160	20	13.8	0.014
SW-2	200	159	41	10.6	0.039	0.053	200	159	41	10.6	0.039
SW-3	214	160	54	10.5	0.051	0.087	180	120	60	10.5	0.057
SW-4	160	150	10	8.25	0.012	0.017	160	120	40	8.25	0.048
SW-5	160	139	21	7.25	0.029	0.033	180	140	40	7.25	0.055
SW-6	160	140	20	6.65	0.030	0.036	160	140	20	6.65	0.03
SW-7	160	134	26	9	0.029	0.035	160	134	26	9	0.029
SW-8	160	136	24	8.55	0.028	0.039	160	120	40	8.55	0.047
SW-9	160	118	42	7	0.06	0.081	160	120	40	7	0.057
SW-10	125	120	5	5.5	0.0009	0.000 91	125	120	5	5.5	0.0009
SW-11	148	127	21	6.25	0.034	0.042	140	120	20	6.25	0.032
SW-12	161	120	41	12.35	0.033	0.07	161	120	41	12.35	0.033
SW-13	160	112	48	6	0.08	0.077	160	112	48	6	0.08
SW-14	140	112	28	7.5	0.037	0.047	140	120	40	7.5	0.533
Total	281	112	169	65	0.026	0.29	260	112	148	65	0.023

Source:Author's computation using SOI Topographical Sheets and Satellite Imageries (Precision Geocoded False Colour Composites (FCCs) of IRS- P6 & LISS-III, 2009)

Table-5:Morphometric Parameters for Prioritization

Sub Watershed	Normalized Value of Different Morphometric Parameters										
	Mean Bifurcati on Ratio	Dd	Sf	Tr	Com. C	Rc.	Re	Bh	Rh	Lo	Composite Priority Valu
SW 1	0.18	0.96	0.47	1.0	0.18	0.087	0	1.0	1.0	0.067	4.94
SW 2	0.36	0	0.043	0.18	0.18	0.48	0.2	0.31	0.44	1.0	3.19
SW 3	0.31	0.46	0.24	0.19	0	0.43	0.73	0.42	0.58	0.47	3.83
SW 4	0.29	0.56	0.34	0.27	0.24	0.67	0.4	0.043	0.13	0.33	3.27
SW 5	0.26	0.39	0.19	0.15	0.21	0.63	0.67	0.14	0.32	0.53	3.17
SW 6	0.065	0.75	0.89	0.68	0.35	0.57	0.73	0.14	0.33	0.2	4.71
SW 7	1.0	0.26	1.0	0.77	0.56	0.22	0.13	0.18	0.32	0.67	5.11
SW 8	0.69	0.51	0.63	0.49	0.35	0.37	0.27	0.16	0.31	0.4	4.18
SW 9	0.54	0.90	1.0	0.79	0.18	0.72	1.0	0.32	0.68	0.13	6.26
SW 10	0	0.75	0.053	0.04 2	1.0	0.087	0.4	0	0	0.2	2.53
SW-11	0.37	1.0	0.51	0.38	0.56	0.35	0.53	0.14	0.38	0	4.22
SW-12	0.067	0.59	0.35	0.28	0.21	0.19	0.07	0.31	0.37	0.33	2.77
SW-13	0.58	0.46	0	0	0.29	1.0	0.73	0.37	0.91	0.47	4.81
SW-14	0.53	0.57	0.79	0.59	0.71	0	0.27	0.19	0.414	0.33	4.39

Source:Author's computation using SOI Topographical Sheets and Satellite Imageries (Precision Geocoded False Colour Composites (FCCs) of IRS- P6 & LISS-III, 2009)

Plate-1: Rocky surface and undulating topography
(Photo taken at source of the Arkasa watershed by the author, 2013)

Plate-2: Rock-knobs in the middle course of Arkasa river
(Photo taken from newly construct bridge by the author, 2013).
The water level during 2012- flashflood raised to nearly 5.6m
and washed away the old bridge.

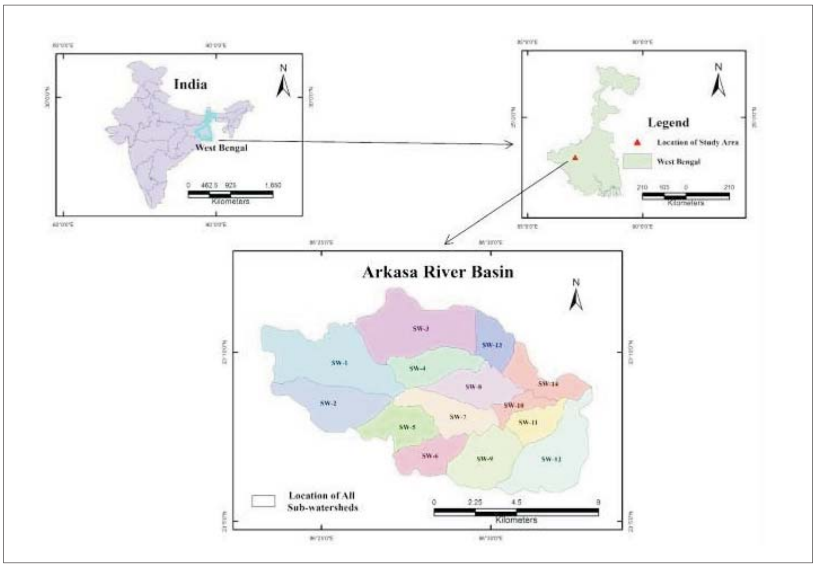

Fig-1:Location of Arkasa Watershed, West Bengal, India

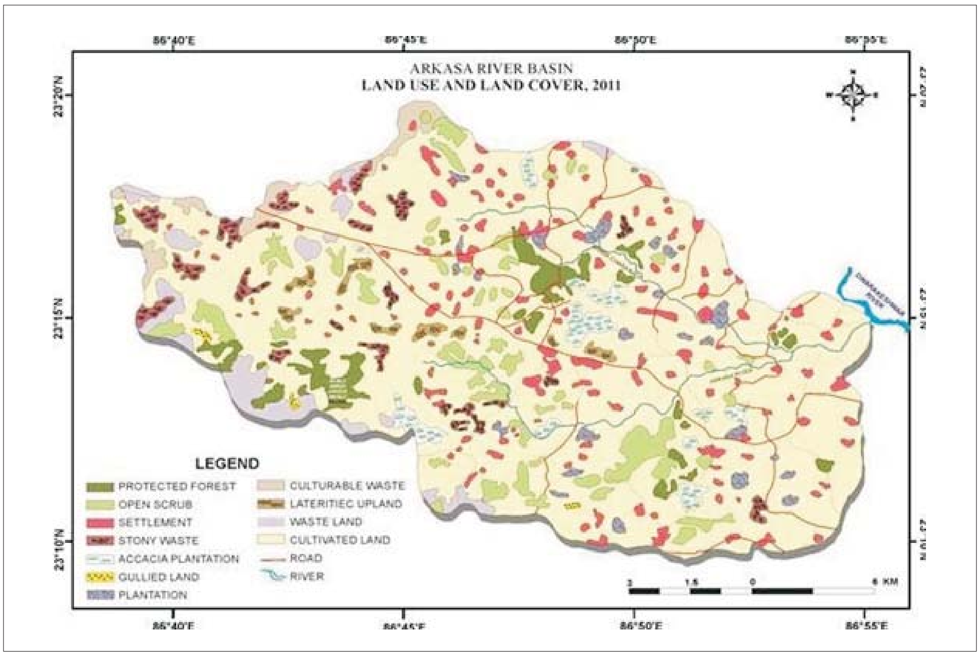

Fig-2:Landuse/cover of Arkasa watershed
(Prepared from S.O.I. Topographical Sheet and verified from LISS-III Satellite Image, 2011)

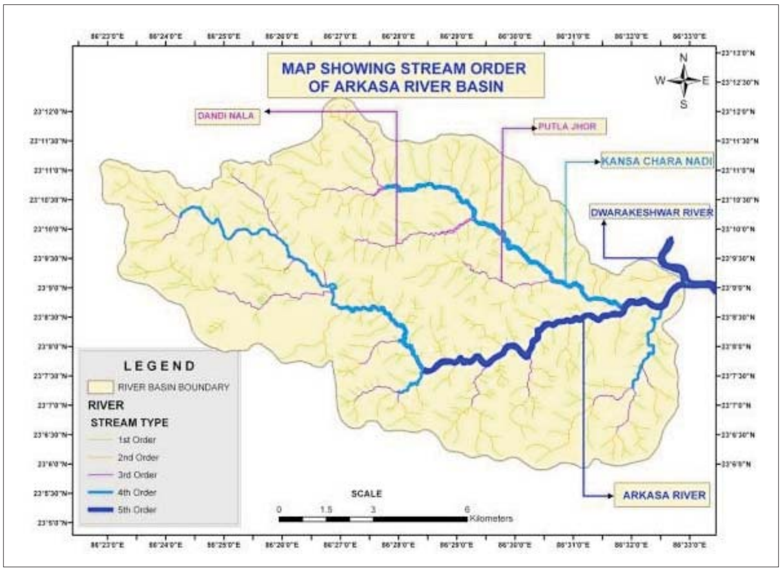

Fig-3: Stream order of the Arkasa Watershed

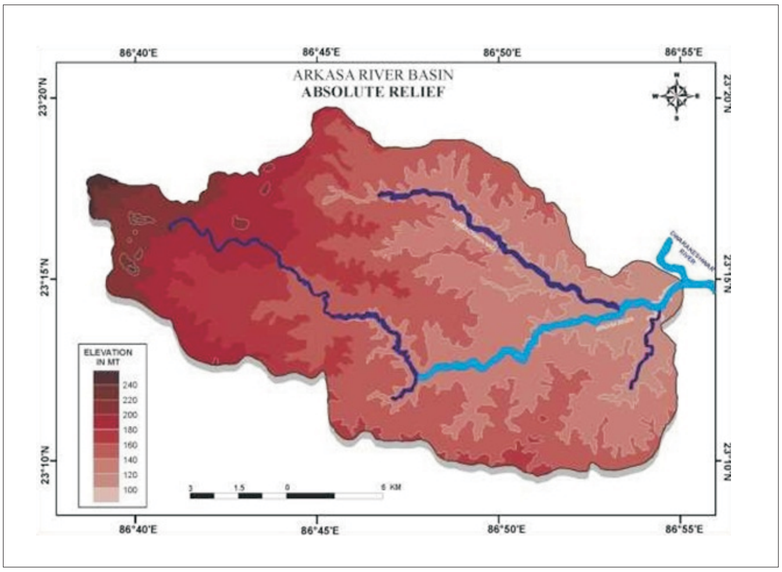

Fig-4:Elevation Zones of the Arkasa Watershed

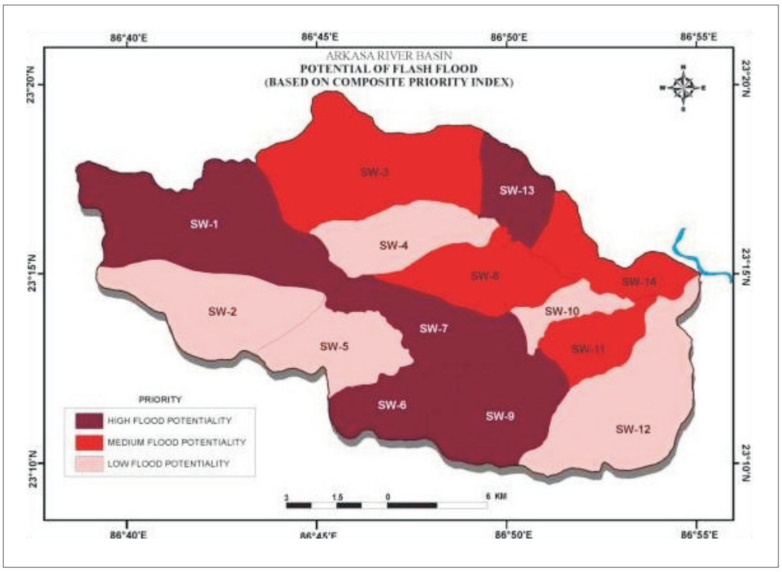

Fig.5: Priority Index of Sub-watersheds of the Arkasa Watershed
(Based on Normalized Co- efficient Values)

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