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Assessment of hydromorphological conditions of upper and lower dams of river Teesta in Sikkim

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Abstract

River is a main source of fresh water. Although since past river water and basin morphology both have affected and changed by some natural and human induced activities. Human civilization since time immemorial has been rooted close to river basin. Changing morphology of a river channel has done also by natural causes. The hydromorphological state of a river system replicates its habitat quality and relies on a variety of both physical and human features. The area of study is located in the Teesta river system in Sikkim Himalaya, which comprises of Teesta and its major tributary the Rangit, situated in right bank. The studied sections are located upper and lower dams of each river. Assessment of hydromorphological state of the river is done by a comprehensive field survey. Moreover, a River Habitat Survey also has carried out in the winter season in the year 2015 especially when river register low water flow. The objective of this work is to find out the state of hydromorphological state of rivers under study like Teesta, Rangit etc. which are located both upper and lower the position of major dams. This study also compared the scale of hydromorphological features present in lower and upper dams. According to the result of the work based on Habitat Quality Assessment (HQA) and Habitat Modification Score (HMS), it may be pointed out that dam has not played significant role to modify the hydromorphological status of river. Dams on the studied river basin have sufficient presence of hydromorphological features that further indicates naturalness of river system.

Key Words: *anthropogenic, hydromorphology, River Habitat Survey, Habitat Quality*

Introduction

Rivers are the source of fresh water but since decades many physical and human induced activities have been affected the river basin setup. Human civilization since time immemorial has been rooted close to river basin. Impact of growth of population and its enormous demands especially from industrial revolution culminated the riverine condition of most of the Worlds Rivers. Anthropogenic activities in and around the river basin include construction of large dams, extraction of gravel and sand, mining, extensive forms of urbanization and industrialization, agro-based activities and land use change (Paul et al., 2016, Paul & Sharma, 2016; Singh and Saraswat, 2016). The construction of mega hydraulic structures (dams, weir, embankment, bridges etc) in conjunction with other infrastructural works, are directly associated with morphological alternations of river setting. Similarly, unsystematic gravel extraction can have both immediate and long-term consequences for channel stability. Changes in channel morphology have initiated through the lowering of the riverbed during gravel extraction (Rinaldi et. al., 2005, Manariotis and Yannopoulos, 2014). According to Elosegi, (2010), human activities increasingly change the natural drivers of channel morphology on a global scale (e.g. urbanization increases hydrological extremes and clearing of forests for agriculture increases sediment yield). Over temporal and spatial scale, the river system changed its course and morphology because of extensive expansion of these anthropogenic activities on the riverbed and riverbanks. However, natural and human induced processes can hasten the degree of changes where rate may be gradual or rapid depending on forces acting upon them. Besides these, river hydromorphological features are periodically dynamic and episodic in nature because the river channels shaped by the transport of water and sediments (Elosegi et al., 2010).

Dams have ubiquitous impacts on hydro-morphology in the river across the world affecting channel morphology and sediment dynamics in their vicinity (Elosegi et al., 2010). Alternation of hydrological regimes and sediment transport dynamics downstream from the dams are a well-known impact of constructing dams across a river. Dams create a large impoundment i.e. artificial lake increasing submergence that inundates river channel upstream while it alters natural flow downstream where discharge becomes regulated and rare. According to Graf (2005), impoundment dams alter the natural flow and flood regimes of a river, resulting in accumulation of sediment upstream within the impoundment and channel erosion downstream of the dam. In fact, erection of a large dam across the river channel alters in the hydrological, thermal, hydro-chemical character and the morphology of the river valley and the riverbed. The visible effects of dams on various parameters of river have taken into consideration in numerous scientific literatures from throughout the world. Some significant relative research works highlighting the effects of the dams on river's environment e.g (Kondolf, 1997; Zwahlen, 2003; James & Marcus, 2006; Stevaux et al., 2009; Rhoads & Csiki, 2010 and Anderson et al., 2014). In addition, (Petts, 1979) conducted studies on the evaluation of modification of downstream dam reaches in the temperate river. Burrow in 1987 studied on impacts of tropical reservoirs. Petts and Gurmell (2005) further documented on hydrological and geomorphological modifications over the dams of rivers. However, these studies have not explored the effects of the dam on river morphology in details. Thus, the effects can be chalked out by conducting field investigation, numerical modeling and physical experiments.

Changing the morphology of the river channel is one of the visible impacts of human activities and the processes of change may depend on the magnitude of both natural and anthropogenic factors. The concept of hydro-morphology involves the development of a conceptual basis for improving our understanding of the impact of human's activities on the hydrosphere (Vogel, 2011). The European Water Framework Directives (European Commission, 2000) firstly applied the term and made it popular in river research where it expresses by a different array of morphological elements and hydrodynamic features. The hydromorphological state of a river system replicates its habitat quality and relies on a variety of both physical and human features. Contemporary anthropogenic activities especially building mega-dams across the river in this Himalayan region itself reflects noticeable changes in the channel features of the river system and its vicinity. Human interference in the stream may modify their hydro morphology (Wohl, 2006 and Bucala and Wiejaczka, 2014). It is resulted that a greater proportion of natural elements in the river results in better habitat quality. In contrast, the predominance of anthropogenic elements proves that the river habitat has been noticeably transformed by human activities (Raven et al., 1998; Szoszkiewicz et al., 2006 & Wiejaczka & Strugala, 2014). To quantify the hydromorphological state of the river, the bulk of research in this direction has done in Europe. Lewandowski (2012) documented a review of the hydromorphological method used in Poland and other European countries. In Poland, hydromorphological state of the Carpathian

River has been widely studied and documented in several research publications (Maddock, 1999; Bucała and Wiejaczka, 2014; Wiejaczka and Strugala, 2014; Wiejaczka and Kijowska Strugala, 2015). The said researches conducted based on the River Habitat Survey method that designed by the British Environmental Agency at the beginning of the 1990s). In Europe, it is one of the most popular methods of evaluating a hydromorphological state of the river (Raven et. al, 1998). A detail description of this method enumerates in the study by Environment Agency (2003). However, these critical undergoing issues of hydromorphological changes on the river often caused by dam or reservoir building processes deprived of scientific documentation and only taken into account with respect to the Carpathian River in Poland (Wiejaczka and Kijowska Strugala, 2015). Even in the context of Himalayan Rivers, the affects of human induced activities on the hydromorphological conditions have not taken into consideration by River Habitat Survey method yet. Therefore, the primary aim of this research is to contribute knowledge towards the functioning of the environment of the Himalayan River and to develop a new model with regard to future research on river-related issues.

Numerous survey and modeling methods are available for analyzing the hydrological as well as geomorphologic conditions of the rivers and watershed. For example, SWAT model has been used not only to model hydrological responses and but also to simulate conservation practices to tackle the excess flow and sediment issues (Leh et al., 2018; Singh et al, 2018). Singh and Kumar (2017) also outlined the impacts of input datasets on modeling outputs. In the context of river Teesta, limited attempts found which analyzed the hydro-geomorphologic condition of the river by the River Habitat Survey method. Few have evaluated the hydromorphological state of the Himalayan river to determine the role of human activity in shaping their hydro-morphology (Wiejaczka et. al, 2014). They have conducted the study in order to generalize the impact of human activity on the Teesta river hydro-morphology in the valley of the Teesta. Referring to the Teesta river in general, the extent of hydromorphological alternation with the conjunction of contemporary anthropogenic activities has become significant over the past few decades. Further, the morphology of river has been widely impacted by the channelization of river course for hydropower generation. Therefore, in the upper catchment of the Teesta, the construction of numerous cascading dams will lead to the disappearance of the hydromorphological features of the valley. However, attempt on investigating the intense pressure of anthropogenic activities on the Teesta river channel by building dams and river quarrying activities is also dearth. This research work is an endeavour in the Teesta river system in Sikkim to access the role of anthropogenic activities and their effects on river morphology.

The present research was conducted based on the River Habitat Survey method (RHS) in the Teesta river system of Sikkim. The aim of this work was an attempt to evaluate the hydromorphological state of the Teesta river system above and below the location of major dams and at sand extracting sites**.**

Research area and methodology

Research area

The area of study is located in the Teesta river system in Sikkim Himalaya (Fig 1). The system comprises the Teesta and its major right bank tributary the Rangit. The studied sections are located above and below the dam and one sand and gravel removing site from each river. Each sections were taken below and above the Dikchu Dam (marked as A (above dam) and B (below dam) in the Teesta river. Similarly, two study sites from Rangit river above and below Rangit Dam near Legship (marked as X (above dam) and Y (below dam) were considered. In addition, two sand and gravel extraction sites (marked as C (Near Rangpo) and Z (Near Jorthang) from each river were considered for study.

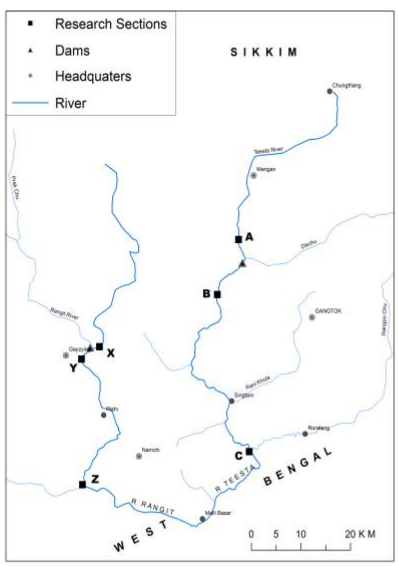

Figure.1: Location of study area in Sikkim

The bed material of the study sites comprises boulders, cobbles and pebbles of schists, gneisses and quartzites in a sandy/silty form. The Sikkim Himalaya, it is protruding above 6000-8500m a.s.l, is highly characterised by active rate of erosion, sediment transport and fluvial sedimentation processes, which in turn reflect the high monsoon precipitation (4000-6000 mm), the high relief energy and the effects of deforestation and poor land management (Froehlich & Starkle, 1993; Froehlich &Walling, 2007). In this region, fluvial processes are predominant and the channel network is being actively changed (Coleman, 1969). The river Teesta is the largest river in this region, originates from Pauhunri peak (7127 m amsl). The Teesta is characterized by a complex hydrological regime (Wiejaczka et al. 2014). The Teesta river system drains nearly 95% in the mountainous state of sikkim. In this region, the river is turbulent and fastflowing with high velocity in deep gorges and valleys. The region has been classified into five geomorphic unit based on the development of distinct landform and climatic variation from north to south (Mukhopadhyay, 1998). The elevation abruptly varies between 300 to 8598 meters above the mean sea level. The Teesta river system is well connected by dense network of numerous perennial streams. The region is notable for their incredible floral and faunal diversity with distinct topographic expression.

Research Methodology

The two major rivers of Sikkim the Teesta and Rangit were selected for study. All together, six study sites, each section measuring 500 meters, were set up on various location. There are various methods adopted across the globe to assess the hydromorphological state and the habitat quality of river but have shown dissimilarity in approach. However, one of the most common and systematic methods in Europe is the British River Habitat Survey (RHS) method. It was developed by British Environmental Agency in the early 1990s. The detail guideline of this method in order to conduct research has been presented by (Raven et al. 1997). The evaluation of the hydromorphological character of river was presented in this paper by applying the British RHS method. The field survey was conducted in the winter of 2018 when river register low flow. The collected data were used to compare the hydromorphological character of river below, above the dam, and sand mining site.

In this system, data has been collected taking a standard 500-meter section of river channel at 50-meter interval. The characterization of river hydromorphological features were compared with equally placed 10 cross profiles (spot checks). In case of channel bank features the total number of cross profiles come to be 20 (adding up either bank observation points). As per the RHS rules, only dominant habitat features (e.g. flow type, channel substrate, bank material, riverbank vegetation etc) should be recorded in each observation points. This method is entirely based on a general description of natural elements for e.g. bank material, flow types (but not in a volume sense), structure and types of vegetation in the channel, riverside land use etc. The main purpose of this method is also to describe anthropogenic elements (river channel modified by human activities), that includes riverbank and bottom artificially modified.

The field survey can be conducted in two stages (Raven et. al. 1998) on a standard 500-meter river section. The first stage includes identification of channel and marginal features including land use in every 10-spot check. The second stage of data collection includes 'sweep up section' a general description of various physical aspects of river channel and other transformation, which were not documented in the first stage. The quantitative scores were calculated based on the percentage share of particular natural and anthropogenic elements in the whole 500m research section. In RHS Method, hydromorphological state involves elements such as physical, anthropogenic and vegetation should be examined. The purpose of this data generation is to calculate the Habitat Quality Assessment (HQA) and Habitat Modification Score. These synthetic indices were calculated as per collected data related to physical habitat of each selected sections. With the help of HQA and HMS indices hydromorphological state of river have been evaluated statistically. Here, HQA index value refers to river's naturalness and habitat diversity. In contrast, HMS is a synthetic score, which reflects the magnitude of anthropogenic transformation in a river. In facts, a river posse an optimal hydromorphological state when HQA indices exceeds HMS values. The HQA and HMS indices of each examined sites were generated by adding up all sub scores total.

Results:

In Sweep-up section general information were recorded from the selected sites (Table 1). It was conducted in the second stage of field research while walking along the 500m river section immediately after the completion of the spot check form. In this case, only those elements were recorded which were not included in spot check. The main habitat features with regard to land use within 50m of banktop (it may be defined as the first major break in slope where developmental activities would be feasible) were recorded during field survey in all six studied sites. Some of the significant features, which were recorded within 50m of banktop, include both physical and anthropogenic elements as well. The physical elements such as valley form, bank profile, extent of trees and associated features, extent of channel and bank features, channel dimension and the features of special interest were enumerated in the study sites. Likewise, the extent of anthropogenic elements e.g. re-sectioned profile, reinforced bank, embankment and poached bank were evaluated, and the nature of their concentration has been quantified (Table 2)

The broadleaf/mixed woodland (vegetation type predominantly containing deciduous broadleaved trees) ('E' extremely occurring along ≥33% of bank length) constitutes as the main landuse type in all studied sites except in Z (Jorthang) that is because of urban development along the river bank.

Table: 1. The main habitat features recorded during RHS survey in Sweep-Up section at various research sites in the Teesta river system

Land use within 50m of Banktop	Dikchu Dam (Stage V)				Rangit Dam (Stage III				Sand Mining Sites			
	Downstream (A)		Upstream (B)		Downstream (Y)		Upstream (X)		Jorthang (Z)		Rangpo ©	
River bank	L	R	L	R	L	R	L	R	L	R	L	R
Broadleaf/mixed woodland (Semi natural)	E	E	E	E	E	E	E	√	√	√		E
Scrub & Shrubs	√	√	√	√	√	√		√	√	√		E
Tall herbs/ rank vegetation	√	√	E	√	E		E					√
Suburban/ urban development			√		√	√		√	E	E	E	
Parkland or Gardens										√	√	
Bank profile (Natural/unmodified)												
Predominant valley form	**V**		V		V		V		V		V	
Steep (>45° slope)	E		E	E	E	E	E		E		√	
Gentle		√										E
Composit		√						E		√	√	
Artificial/ Modified												
Resectioned (reprofiled)	√			√	E		√		√		√	
Reinforced whole										E		
Reinforced top only									√	√	√	
Reinforced toe only	√								√			
Embanked									√	√		
Poached bank								√			√	

Used (√) for features present (< 33%) and (E) Extensive (≥ 33%) of studied section. (V) Deep Vee valley form

Sources: Compiled from field survey, 2018

In sweep-up section natural/unmodified river bank slope were also recorded. It is observed from the field that river valleys of all study sections predominantly constitute by steep slope (Bank slope >45° angle, but not predominantly vertical). While only right bank side of C has gentle slope due to the presence side bar. In some of the sites, composite slope has also been registered in A, C and Z but its degree of extension ranges from 1-33%. However, a greater length of river section at X is composed by composite slope. The presence of artificial features was also recorded in a considerable part of a river bank that indicates the influence of anthropogenic activity.

This vegetation type extensively covers both the bank of studied sites such as A, B (Teesta) and Y (Rangit). Scrub and Shrubs is the second landuse category present ('√' when it extends for 1-33% of bank length) in all either bank of the research sites. Besides that, the land use within 50 m of the banktops of the research sections were covered extensively by suburban/ urban development in Z and also present in all section with the exception site A. In Z and C (extensive gravel and sand mining sites) parkland and gardens were observed since the areas are located adjacent from the town. An extensive form of reinforcement and resectioning were identified in the study sections Y and Z respectively. These human-made structures are there for the protection of river bank (Table 1).

Hydro-morphological state of the Teesta River System above the dams

The Teesta river system is characterized by heterogeneous hydromorphological condition. The research section located above the dams A and X on the river Teesta and its major tributary the Rangit respectively composed up varying types of natural and anthropogenic elements. The indispensable proportion of the bank material (left and right) includes boulders, defined in the RHS method as large rocks >256mm in diameter (larger than head size). More than 90% and 50% river section constitutes boulders in A and X respectively. Both banks of former study section (A) is covered by very huge size of boulders while same were not recorded in latter section (X) this is generally because of boulders collecting activity. The loose materials comprising coarse gravel, including pebbles 16-64mm in diameter); fine gravel (2-16mm in diameter); and sand (<2mm in diameter) represents 5% channel length of A and 15% of X were recorded **(**Table 2**)**. In addition, cobbles (material size ranging from 64-256mm in diameter (half to large head size) constitutes a significant part of the river banks nearing 15% of the Rangit.

Similarly, on the Rangit (20%) of the studied river length is composed of bedrock (solid rock exposure as defined in RHS manual).

The presence of reprofiled with toe reinforcement indicates the extent of bank modification. It was observed that a very negligible of parts of riverbank has been resectioned and reprofiled. Concerning upstream part from dam, only 10% at A and 5% length at X has been modified. It means that more than 90% of channel length in both the examined section is almost natural. That a small percentage of the bank were reinforced in order to protect road infrastructure and to prevent river bank from erosion.

Diverse morphological elements were observed in natural banks and marginal features in both the studied sectioned. Nearly (15%) of A section is composed of eroding cliff (bank profile predominantly vertical, near vertical, or undercut showing 'clean' face) on the other hand stable cliff (bankface without apparent signs of recent erosion) comprised (20%) of all cross profiles in Rangit. The natural morphological riverbank features recorded in these studied sites comprised Vegetated side bars (distinctive depositional river features if ≥50% surface area has plant cover) which constituted 40% and 20% of all cross profiles in Teesta and Rangit river respectively. Likewise, distinctive river depositional morphological features composed of consolidating riverbed material such as unvegetated side bar (define unvegetated when <50% surface area has pant cover) and vegetated point bar (depositional feature exposed at low flow generally located on the inside of distinct meander bends) were observed in Rangit river studied section only.

The river substrate (bottom) of the examined section is composed of varied forms of materials (Plate 1). In RHS method, channel substrate materials are categorized according to Wentworth (1922) grade scale. In section A, boulders (>256mm in diameter) (50%) dominates, the channel bottom remaining (50%) was not visible because the channel was too deep and high velocity where it could not determine the predominant channel substrate. On the other hand, channel substrate of X research section composed of diverse materials such as boulders (40%), cobbles (rocks fraction with diameter 64-256 mm) (20%), bedrock (20%) and sand/gravel (20%) of all cross profiles. In this case, diverse morphological elements were recorded due to flat valley bottom accompanied by low flow velocity.

In the RHS method, nine distinctive types of flow can be recognize based on the characteristics of surface, velocity, flow direction and the influence of riverbed configuration. In this method, only predominant flow type that normally occupying at least 50% of the wettest channel can be recognized. The broken standing waves (types of flow where water appears to be trying to flow upstream or simply a white-water dipping waves) (plate 1) were noticed in 60-70% of the profiles in these two research sections A-X (Table 2). In addition, an unbroken standing waves (flow associated with babbling sound which as upstream facing wavelets) were also frequently observed in A (30%) that is accompanied by the occurrence of rippled flow (flow that contain distinct small ripples only a centimeter or so high) (10%) and (30%) profiles of X site respectively. In fact, the frequent occurrence of broken standing and unbroken standing waves flow types were often caused by the presence of in -channel boulders and cobbles as channel substrate. Moreover, it is caused by a considerable increase in channel gradient across some of the cross profiles. Among the natural channel features, which were traced out during field survey on individual researched sections, exposed boulders (naturally occurring fragmented rocks having 'head size' or large bulging above the water) was found dominantly over 70% of sections in both the cases. Exposed bedrock (large sized rock projected above the water at low flow condition) was also found in (20%) and mid-channel bar comprised 10% of X research stretch.

As relates to land use in the 5-meter along riverside corridor from the banktop (abrupt break in slope where development is possible as defined in RHS) shows contrasting result of the examined sites located above the dam. In a 5-meter stripe from the banktop broadleaf/mixed woodland (vegetation type containing predominantly deciduous broadleaved trees) were the dominant landuse categorized comprising 15-90% of the analyzed research sections. Next to it, tall herbs dominating (10-30%) land use along the river stretch of Teesta V and Rangit III respectively. Moreover, a significant proportion of adjacent banktop land use comprises suburban/urban development (15%) and tilled land (40%) of the evaluated upstream Rangit river section.

In accordance with RHS method, bank and bank face vegetation structure is classified into four categories depending on vertical layering on the bank. In this method, vegetation structure is separately determined for a bank top and a bank face. The bank top vegetation structure of the studied river section was covered predominantly by complex (covered with four or more vegetation type including scrubs and trees) 10-65% of all examined profiles. A simple (predominantly 2-3 vegetation along with other scrubs and trees) type comprised 15% of all the profiles of the Teesta V and 35% of the Rangit III respectively. Some parts of these sections nearly 20-35% of river cross profiles also have uniform (one vegetation type) and bare (unvegetated bare earth) vegetation types. Concerning about the bankface vegetation of the Teesta V and Rangit III upstream section are characterized by a great diversification of vegetation structure because they are located in distinctive ecological setting. More than 65% of former researched site was covered by complex vegetation structure followed by 10% in the next section. On top of that, 15-35% profiles under simple vegetation structure domination and 20% bare surface were reported along the examined section.

Table: 2. Hydromorphological character of river in various research sections in the Teesta River system in Sikkim (% of all profiles)

Location/River/Research Points	Above Dam		Below dam		Sand/gravel extraction sites	
	Teesta	Rangit	Teesta	Rangit	Teesta	Rangit
	A	X	B	Y	C	Z
Bank Materials						
Boulders	95	50	60	65	45	45
sand and gravel	5	15	20	0	25	15
Cobbles	0	15	0	10	10	25
Bedrock	0	20	20	25	20	15
Bank Modification						
None	90	95	90	55	85	55
Re-sectioned	10	5	10	40	15	25
Reinforced	0	0	0	5	0	10
Embankment	0	0	0	0	0	10
Bank Features						
None	45	30	75	70	30	45
Eroding cliff	15	0	10	5	50	0
stable cliff	0	20	15	15	20	30
Unvegetated side bar	0	5	0	0	0	25
vegetated side bar	45	20	0	0	45	0
Unvegetated point bar	0	25	0	0	0	0
Channel Substrate						
none	50	0	0	0	20	50
Boulders	50	40	20	40	60	40
cobble	0	20	30	20	0	10
Bedrock	0	20	0	30	20	0
sand/Gravels	0	20	50	10	0	0
Flow type						
Broken standing	60	70	20	0	30	0
unbroken standing	30	0	0	0	0	0
Rippled	10	30	20	0	50	0
Smooth	0	0	60	5	20	20

Not Perceptial	0	0	0	95	0	80
Channel Modification						
none	100	100	100	100	100	100
Channel features						
Exposed Boulders	70	70	40	70	50	60
None	30	0	0	0	20	40
Exposed bedrock	0	20	0	30	20	0
Un-vegetated Mid-channel bar	0	10	60	0	0	0
Bank top land use						
Broadleaf	90	15	75	65	0	0
Tall herb	10	30	25	25	10	0
Suburban	0	15	0	15	50	100
scrub and shrubs	0	0	0	0	40	0
Tilled Land	0	40	0	0	0	0
Bank top structure						
Complex	65	10	65	40	10	0
simple	15	35	25	35	0	55
Uniform	20	35	10	20	90	30
Bare	0	20	0	5	0	15
Bank face structure						
complex	65	30	55	50	15	0
simple	15	45	0	20	35	30
Uniform	20	25	45	15	0	35
Bare	0	0	0	15	50	35

Sources: Compiled from field survey, 2018

The hydromorphological features recorded below the dam in the examined sections i.e. B and Y shows contrasting variation. The right and left banks of the riverbed in the studied sections below the dam B-Y were primarily composed of 60-65% boulders, where large fragments of big boulders were exposed due to low flow volume. In the case of section B, sand/gravels constitute nearly 20% of the cross profiles, which resulted from the complete non-appearance of sand/gravel collecting activity. On the other hand, bedrock exposed was recorded across 20-25% of all observed points in both the section and 10% cobbles were found at site Y. Site B where only 10% river section out of 500 meters was modified with the presence of resectioning wall. A major form of anthropogenic pressure concerning the bank modification was recorded over a considerable part of riverbank in site Y of Rangit river. In this section, particularly channel right bank has been modified with about 2km long concrete re-sectioning wall and re-profiling of riverbank was observed in all the cross profiles. Through these anthropogenic processes nearly 40% riverbanks of this section were modified by re-sectioning and 5% is caused by re-enforcement respectively. However, clues of recent channel modification were not found in any of the studied cross profiles.

In bank and marginal features, eroding cliff and stable cliff were the predominant natural elements, degree of occurrences ranging from 5-15% in the analyzed research section. The vegetated side bar also presents at Y (10% of profiles) and as such, none of the distinctive natural marginal features was recorded in other remaining section.

The bottom of analyzed sections below the dam was principally comprised of boulders, which constitutes from 20% at B and 40% at sections Y respectively. The cobbles were the second material present on both the sites ranging from 30-40% of the all observed profiles. Additionally, sand/gravels were the significant channel bottom materials comprising 50% and 10% of the profile respectively. Moreover, exposed bedrock was also reported on the 30% profiles of section Y. Broken standing waves, rippled and smooth flow (with no turbulent flow where water movement does not produce a disturb surface) were the dominant flow types detected in B study site. The proportion of their occurrence varies between 20 to 60% of examined profile.

On the other hand, flow type in the subsequent studied site (Y) is composed of rippled (30%), smooth (50%) and no perceptible (it is difficult to perceive any surface water flow) (20%). The smooth and no perceptible flow were recorded below the dam is caused by huge impoundment of river water above dams. Among the natural channel features observed on river encompass 60-90% boulders were predominant. Cobbles (10%); exposed bedrock (40%) and mid-channel bars (60%) were also detected from section B.

From the bank top in a 5-meter strip belt of river, the dominant form of land use consists of broadleaf/mixed woodland covering 65-75% profiles. In addition, presence of tall herbs up to 25% as a dominating land use and suburban development (15%) of all profiles were recorded from B and Y sites respectively. Sections below the dam, simple (25-35%), complex (40-65%), uniform (10-20%) and bare (5%) vegetation structure were dominant on the banbktop (Table 3).

As far as bankface vegetation structure is concerned, majority of cross profile below the dam at B site has complex and uniform structure. In contrast, at Y examined section on the other hand complex (50%), simple (20%), uniform (15%) and bare (15%) respectively of all the analyzed profiles.

The hydro-morphological state of the river in sections with intense sand/gravels extraction

In these two study sites located far-off downstream from the dam composed of varying form of bank materials comprising 45% boulders, but in this case size of boulders varying from small to medium. In both the research sections (C and Z) cobbles constituted (10-25%) and sand/gravel including pebbles comprised (15-25%) of all cross profiles as far as dominant bank materials is concerned. Like other sections, nearly (20%) of C and (15%) of Z study sites bank material is primarily composed by bedrock.

Concerning about bank modification, a considerable part of examined river section at Z has been modified with re-sectioned (25%), re-enforcement and embankment (10%) respectively. Section C, on the other hand, where a negligible proportion of its bank has been modified (15%) as compare to former site. The bank features of these sites involve eroding cliff (50%), stable cliff (20%) and vegetated side bar was observed in (45%) profiles of site C and unvegetated side bar was also detected in (25%) at site Z respectively.

Table 3. The river categories on the basis of Habitat Quality Assessment (HQA) and Habitat Modification Scores (HMS)

HMS Values	Types of Habitat	HQA Values	Quality of Habitat
0-2	Pristine	80-100	Very High
2—8	Semi-natural	60-80	High
8-20	Little Changed	40-60	Sufficient
21-44	Muched Changed	20-40	Low
Above 45	Highly Changed	0-20	Very low

Source: Walker et al. 2002

Boulders 60% and 40% predominantly composed the channel bottom of C and Z respectively. In C, about 20% of all profiles where bedrock was observed, and cobbles dominated (10%) profiles of next study site. Channel substrate in the majority of the profile at Z was invisible due to stagnant in river water. While research section at C, flow type comprised broken standing waves (30%), rippled (50%) and smooth (20%) respectively. Concerning in-channel morphological elements majority of the studied profiles were mainly comprised by exposed boulders (50%) accompanied with (40%) cobbles and (10-20%) exposed bedrock were recorded at Z.

If we consider a 5-meter strip from the banktop, the dominant form of land use comprised sub-urban (50%) at C and (100%) at Z accordingly.

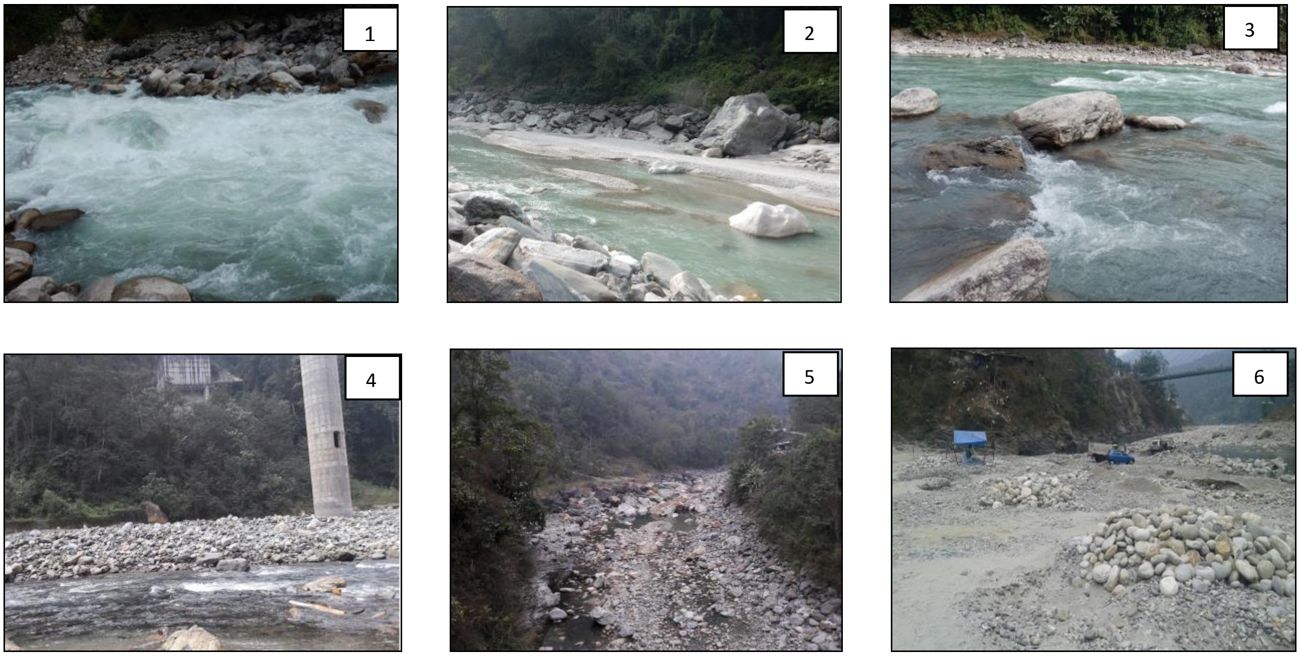

Figure 2: Examined sections with noticeable impacts of dam on the Teesta river system in Sikkim.

Turbulent flowing Teesta above Teesta Stage V nearly 2 km above Dikchu bazar (site A) ***2****. Teesta with very low flow volume nearly 2.5 km below Teesta Stage V in Lower Samdong (site B)* ***3****. Thread-like Teesta flowing in extensive sand and gravel extracting site near Rangpo (site C).* ***4****. The Rangit about 1.5km above Rangit Stage III in west Sikkim (X).* ***5****. completely dried-up gigantic Rangit below Rangit Stage III near Legship(Y).* ***6****. Rangit with no perceptible flow in excessive sand and gravel extraction site (Z) near Jorthang.*

Remaining 50% adjacent land use at C comprised tall herbs and scrubs and shrubs. In the studied sections, uniform banktop vegetation structure comprised (30-90%) of all profiles. Around (10%) profiles were covered by complex vegetation structure while about (15%) comprised bare surface caused by urban development. All types of bankface vegetation structure were recorded in both the examined sections mainly composed of bare (35-50% profiles) surface that is caused by riverbank re-sectioning and re-profiling. In addition, about 30-35% of all profiles were covered mostly by simple vegetation and 15% profiles at C comprised complex structure respectively (Fig 2).

The Habitat Quality Assessment (HQA) and Habitat Modification Scores (HMS) indices calculated for the studied sections in the Teesta river system in Sikkim

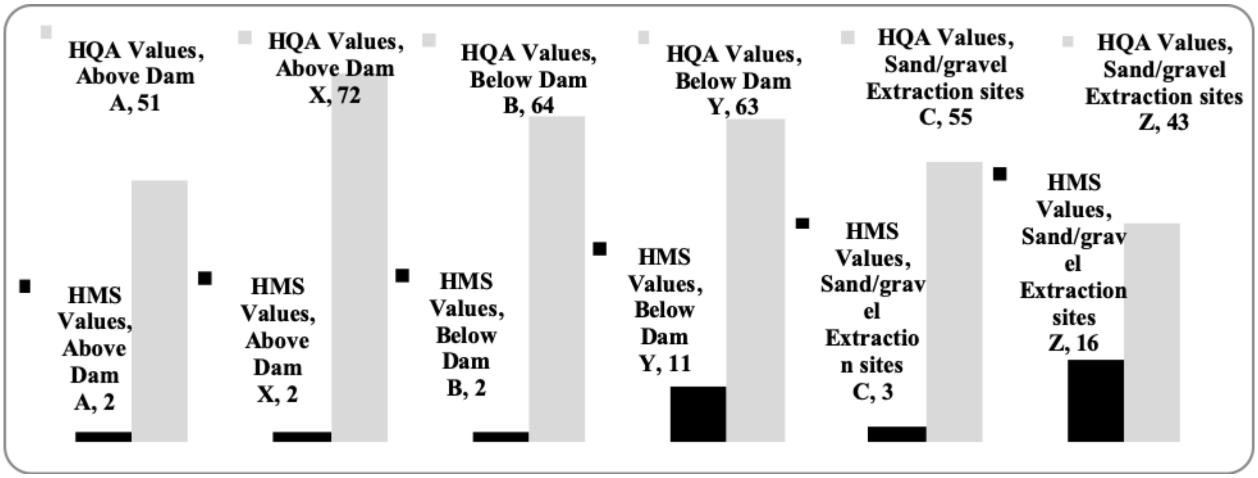

Figure 3. Values of the Habitat Quality Assessment (HQA) and Habitat Modification Scores (HMS) indices calculated for the individual research sections in the Teesta river system.

The habitat Quality Assessment (HQA) is a scoring system designed, for measuring the diversity and 'naturalness' of the habitat condition of a particular site. This index indicates a wide degree of diversification of natural hydromorphological elements in the river habitat. It was calculated for individual six selected research sections across the Teesta river system in Sikkim (Fig 3). The obtained HQA values range between 65-70 in above and below (X-Y) the dam in Rangit river. Score in these sections is high because of diversity of hydro-morphological features recorded. In case study site Y below the dam, where HMS scores is comparatively high, but the habitat quality is still good (Fig.3). According to the classification by Walker et.al (2002) for British river, the naturalness of habitat of the stream section can be classified as High habitat quality. On the other hand, study site C, where the value of HQA index equaled 55 due to less morphological diversity and noticeable human interference as compare to earlier case. The HQA indices obtained from Z examined section shows less diversity in habitat condition where score is just 42. The calculated HQA index values obtained from individual research sections were determined based on diversity in physical habitat and it was greatly influenced by the variation of channel substrate, flow type, vegetation structure and other physical elements.

The HMS index values, in contrast, reflect the degree of anthropogenic transformation in the hydromorphology of a river. The result which reveals that the study site B (below dam) and Z (gravel extraction site) have been modified to some extent. The HMS values of these sites ranging from 11-16 respectively, which, according to the method of classification proposed by

Walker et al. (2002) signifies a little or slightly changed river section. This change is a result of the presence of bank modification practices including artificial re-sectioning, re-inforcement and embankment that were constructed to defend the residential building and road infrastructure from river erosion. The three other examined sections i.e. A, B (below dam) and X (above dam), where the HMS index values equalled 2, it suggests that the hydromorphological habitat in theses sections are almost natural. HMS score is 3 at C study site. It comes under least modified river section with semi-natural habitat condition (Fig 3) resulting from small transformation of river bank morphology.

Discussion and conclusions

The result of the study shows that there is no such difference in terms of HQA and HMS scores in different research sections. According to the result of the work based on HQA and HMS scores it may pointed out that dams and sand removing activity does not significantly influence the hydro-morphological status of river. The result reveals sufficient to high Habitat Quality in majority of the research sites. However, a significant difference was found in HQA and HMS scores as per the result of the previous study conducted by (Wiejaczka et al, 2014). To check the findings, further comprehensive evaluation would be appropriate since majority of the works in this direction have been undertaken from European countries e.g. (Maddock, 1999; Raven et al 1999; Wyzga et al. 2009, Lewandowski, 2012; Bucala and Wiejaczka, 2014) etc. Even at global scale, a very limited research has been conducted to assess the hydromorphological condition of river under the influence of human activities. This study is based on RHS method; however, several assessment methods have been tested in Europe to explore the hydromorphology of river such as LAWA-vor-Ort method, French SEQ-MP (Lewandowski, 2012), European Standard method EN-14614, (CEN, 2004). But Asian countries are poor in measuring hydromorphological status of river even though majority of people and towns are along the riverbank. Few studies have tried to explore (Chien, 1984; Yang et al, 2006 and Wen et al, 2016). In India, it is crucial to measure the degree of human influence on river hydromorphology, however, rare efforts have been made e.g. (Tiwari et al, 2014; Mauhrya et al, 2014).

Further research is required in the Himalayan context in general and the Teesta river in particular for validating the findings obtained from this study using RHS method. Since the method was firstly tested in European environment (Raven et al, 1999) and applied once in the Teesta river (Wiejaczka et al, 2014) in Darjeeling Himalaya. This work might be a second attempt to investigate the hydromorphology of the Teesta river. However, we observed that it would be more important to undertake the identical research in the Teesta river system in Sikkim and in other regions of the Himalaya adopting some other unanimous hydromorphological state assessment methods. Suitable method that can be applied in this environment is needed to undertake further research in this regard. For this, prudently, a scientific co-operation is requiring from diverse field of natural sciences.

- This would be the first comprehensive work using unique and scientific (River Habitat Survey) method of data collection in the context of sikkim especially in exploring the hydro-morphology of river.
- As a result of this work, degree of influence of human activity on river parameters can be judged.
- It helps in classifying rivers of sikkim Himalaya into different class on the basis of their quality for example (Prestine river, partially changed river, changed river or completely changed river).
- This particular work with the application of River Habitat Survey fosters interest of the recearch community toward river research which is lacking indeed in sikkim.
- Based on River Habitat survey data collection format designed by Britain's Environment Agency new modified form of formate can be developed considering local and regional river parameter into account. That could be possible through collaborative research action from diverse scientific background.

Availability of data and material

The dataset completely based on primary field survey.

Competing interests

The authors declare that they have no competing interests

Authors Contributions

Conceived and designed the experiments: DS and IES. Performed the experiments: DS and IES. Analyzed the data: KP. Contributed reagents/materials/analysis tools: DS and KP. Wrote the paper: DS IES KP SM.

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