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Fluvial Functioning Index (FFI): Assessing Freshwater Habitat in Tamor River Basin, Nepal

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Abstract

The purpose of this study is to evaluate the river habitat conditions in Tamor River basin (TRB; Area = 6051 km^2) in the eastern part of Nepal using Fluvial Functioning Index (FFI). The FFI is one of the emerging river habitat quality evaluation methods. The obtained results indicate that in TRB, the rivers have FFI score ranging from 285 (Excellent) to 95 (Poor). Except, Leuti Khola tributary (FFI 95), all other studied sites were between Excellent (FFI 285) to Fair (FFI 128) conditions, indicating that the functionality of the river coursesare somehow better, however the presence of more than 44% of Fair and 6% Poor quality river sections indicated a lower ecological quality of the overall river system that could be at risk in the near future. Ghunsa sub-basin in the upper reach of the basin was rated as Excellent (FFI 285) condition due in large extend to less disturbance from anthropic impacts. The results suggest that the basin's fluvial water bodies need particular management attention to prevent them from further degradation as well and sustainable development of the aquatic ecosystem.

Keywords: Fluvial Functioning, Tamor River, Habitat, Basin Management.

Introduction

Tamor River Basin (TRB) in eastern Nepal is one of the ecologically and economically most significant sub-basins[1] of the Koshi basin that contribute annually 11.3 billion m^3 water to the Koshi River, representing nearly 5% of the annual water volume in Nepal (225 billion m^3)[2]. Tamor River provides water to critical ecosystems and to sustain the livelihood of million people in downstream valley. These water resources are mainly used for household consumption and sanitation, livestock, irrigation, and hydropower of the basin. Increasing demand for energy and food under growing economy and changing environment are expected to put stress on the water resources and the river habitat of the basin. To reduce vulnerability, biodiversity conservation, improve food, and energy security in the TRB, it is essential to understand the river habitat conditions.

A wide variety of tools have been proposed for assessing the river habitats to meet different purposes[3-5]. Among different other assessment tools, the FFI is capable of explaining the ecological functional quality of rivers[5]. This index was tested in the varieties of conditions and can help determine the approach to present and future management of rivers. It can provide an integrated strategy for river protection, management, and restoration[6].

The Fluvial Functioning Index (FFI) is a method developed for evaluating the ecological functions of rivers[7]. This method provides a judgment based on a wide range of hydromorhological characteristics of the river ecosystem. It can effectively be used for monitoring, evaluation, and as a planning tool. The FFI was published by the Provincial Agency for Environmental Protection in Trento in Italy in 2000 with the aim of assessing the ecological aspects of the whole course of a river such as riparian areas, morphological characteristics, and biological features[8] following the underlying principle of the European Commission water framework Directive[9]. In this context, this paper evaluates the river habitat conditions in Tamor River basin using the FFI method with the aim of supporting for an integrated river basin management objective.

Study site: The TRB (Area: 6051 km^2) is located on the eastern boundary of the Koshi basin in the eastern Nepal, extending from 26.848° to 27.955° N and 87.158° to 88.202° E (Figure-1). The basin area extends from an elevation of 135 m asl. at Barahachhetra to 8586 m asl. at Mt. Kanchenjunga, the third highest peak in the world and covers four districts of Nepal: Taplejung, Terhathum, Panchthar, and Dhankuta.

Despite a short latitudinal distance, the basin includes the highest diverse climatic conditions due to the strong altitudinal gradient and complex topography. The climate of the basin ranges from sub-tropical to Nival and mainly controlled by south Asian monsoon system[10]. Minimum and maximum temperatures in the basin range from below 0° (at the higher altitudes) to > 30 °C (in the lower reaches of the basin). More than 85% of the precipitation in this region is concentrated as rainfall during four months (June-September) during the summer monsoon. Annual precipitation varies strongly by

altitudinally and latitudinally under the influence of topography. An increasing temperature (mean, minimum, and maximum) trends and a decreasing precipitation trend are reported in and around the basin since the beginning of the 1990s[10].

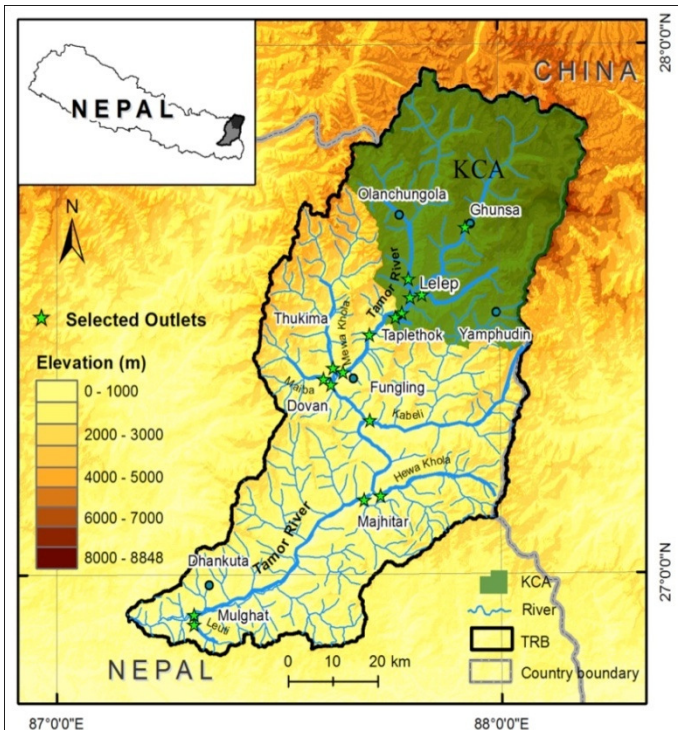

Figure-1
Major sites of water bodies in Tamor River basin

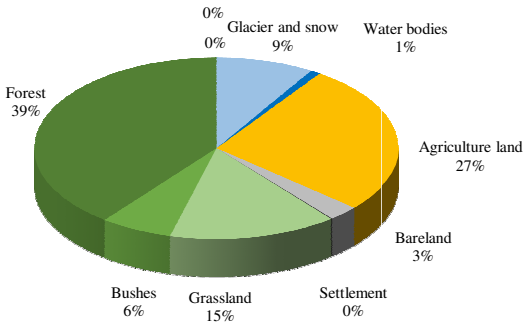

Figure-2
Land use (%) of Tamor River basin

Figure 2 represents the landuse of the basin. TRB has an agro-pastoral-based economy. It hosts 521,577 inhabitants in 112,933 households, including Limbu (33%), Rai (12%), and Tamang (6%) as major ethnic groups[11].

In TRB, there are more than 60 rivers and tributaries, including Tamor, Ghunsa, Simbuwa, Kabeli, Mewa, Maiba, Hewa, and Leuti. Tamor, the prime river of the basin (> 150 km length), originates from Tiptala Lake near the border with China and flow southward to join with Sunkoshi Koshi River together with the Arun River at Tribeni. The glacierized, and ice and snow-capped mountain areas of the northern part of the basin is the headwaters of Tamor River. About 30 % of the total runoff in the Tamor River basin constitute from the snowmelt whereas about 70 % contributed by the rainfall[12].

Materials and methods

The Fluvial Functioning Index (FFI)[8] was used as the methodological tool for this study. For implementing the FFI method, data were generated and analysed from field observations, remote sensing, and review of the literature.

The FFI Method: The FFI is a method for the evaluation of the functional state of fluvial environments based on hydromorhological characteristics, considering both physical and biological features. The FFI method is a stochastic approach and used less as deterministic approach. The FFI has been widely applied in all over the Italy in every kind of stream types by Regional Environmental Protection Agencies[13].

The FFI method uses 14 questions. In each question, it includes 4 predefined answers related to ecological characteristics of the waterline (e.g., River). Questions 1-4 were related to: Bank vegetation, land uses pressure, extent of riparian area, 5-6: physical and morphological structure of bank, 7-11: about the structure of riverbed (especially for capacity of the river for self purification), and 12-14: key biological characters like periphyton, macrophytes, macro benthos, etc. The answers are expressed numerically in classes of numbers with a minimum value 1 and a maximum value 30, considering the differences in quality and finally, summed up to get an overall FFI score for the section of river habitat.

Sampling Site Selection and Field Activities: Tamor River and its major tributaries were divided into different sections and the river habitat survey was conducted at 16 sites distributed in the basin (Table 2). The detail field observation sites were mostly selected along the Tamor River course from Ghunsa (3382 m asl.) in Taplejung district to Mulghat (242 m asl.) of Dhankuta district.The field campaign was conducted during May 2015 before the start of the summer monsoon and substantiated with the information obtained during another visit in February-March, 2016. A standard data format (in appendix) having questions on 14 indicator parameters was used during the field. Before going to field campaign, it was important to gather information regarding the major pressure in the basin, data on the hydrological regime, satellite imagery, and maps.

Table-1 scheme[6] was used for final decision-making on functionality level based (Excellent to Very Poor) on the obtained FFI scores of the river section which was useful to assess the most important ecological aspects of the whole river course such as riparian areas, morphological characteristics, and biological features. Later, the output of the FFI was a river

stretch map, using the Geographic Information System (GIS), for indicating the functionality level of the river stretches.

Table-1
Conversion table for the fluvial functioning levels.

Class	Level	Score	Judgment	Level Colour
1	1	261-300	Excellent	
2	1-2	251-260	Excellent-Good	
3	2	201-250	Good	
4	2-3	181-200	Good –Fair	
5	3	121-182	Fair	
6	3-4	101-120	Fair-Poor	
7	4	61-100	Poor	
8	4-5	51-60	Poor-very Poor	
9	5	14-50	Very Poor	

Spatial Analysis: Remote sensing data (ASTER GDEM and Satellite imagery) were used for GIS analysis to obtain the land uses, making field plan for site observations, and mapping and visualization of the river habitat quality. Medium-high resolution (30 m) Landsat OLI image of 2014 was used together with Google™ earth for visual inspection of the river habitat. Land Cover Map of Himalayan Region (2009)[14] was used for obtaining the land use of the basin, downloading from *www.fao.org/geonetwork/srv/en/metadata.show?id=37286&currTab=simple*. The database was produced under the Global Land Cover Network – Regional Harmonization Program (FAO) using 2000 Landsat satellite imagery as reference.

Results and Discussion

Tamor River and its tributaries were classified into different class on the basis of their threats and disturbance. Table-2 and Figure-3 presents the FFI-based assessment results, calculated for different reaches of Tamor River and its tributaries. The studied river sections had FFI scores ranging from 285 to 95. Among eight Tamor River sections, the highest FFI value of 255 was observed for Lungthung and the lowest value of 170 for Dovan (Figure-3). Among the tributaries, Ghunsa had the highest FFI value of 285 and LeutiKhola had only FFI value of 95. Higher the FFI scores, better will be the habitat condition. In this regard, LeutiKhola exerted the worse and GhunsaKhola exerted the best quality among the studied rivers in TRB.

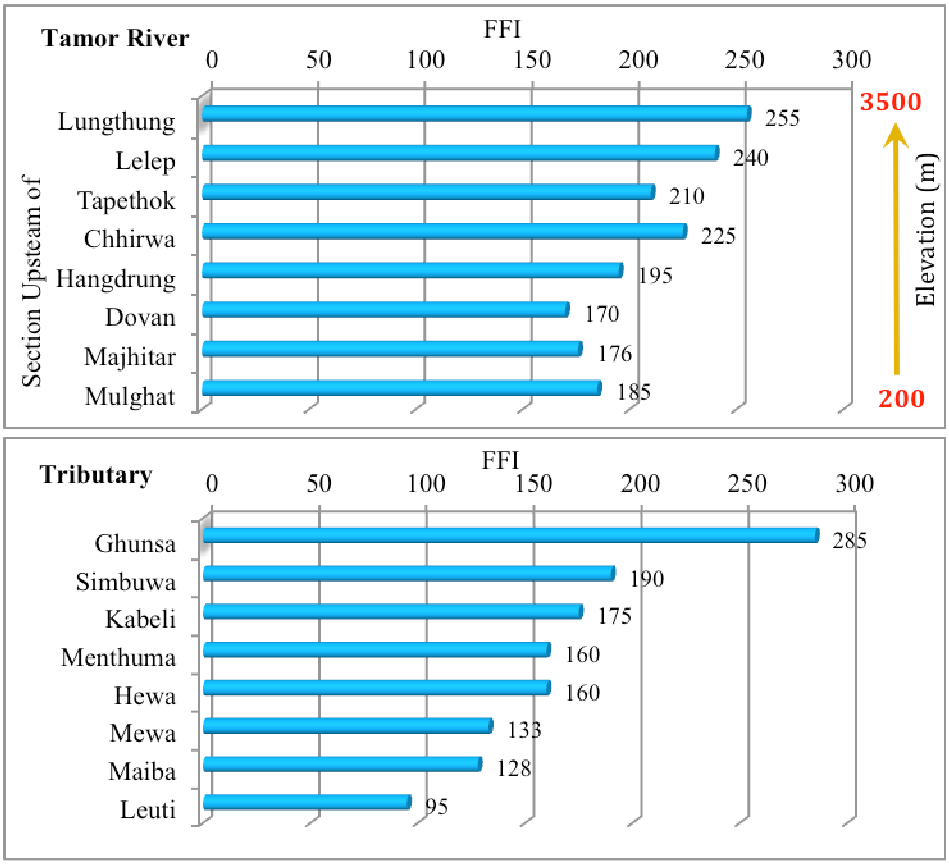

Figure-3
FFI value of different sections in (a) Tamor River and (b) its tributaries

After the conversion of FFI score to quality level classes, six quality classes (Excellent, Excellent-Good, Good, Good-Fair, Fair, and Poor) were obtained from the studied river in TRB. Out of 16 studied sites, 1 site were in each Excellent, Excellent-Good, and Poor class; 3 sites in each Good and Good-Fair class; and 7 sites were lying in Fair class (Figure- 4).

Except, Leuti Khola (FFI 95), all other studied sites were between Excellent (FFI 285) to Fair (FFI 128) conditions (Table-2). The Leuti Khola in the Dhankuta district is scored as Poor quality class. The results indicated that the functionality of the majority of river sections in the TRB is somehow acceptable quality, however, more than 46% sites in with the Fair quality indicates a higher risk of degrading the ecological quality of overall river system in the near future. The results suggest that the basin's fluvial water bodies need particular management attention to preventing them from further degradation as well and sustainable development of aquatic ecosystems.

All tributary streams (Menthuma, Mewa Khola, Maiba Khola, Kabeli, Hewa Khola), except Ghunsa Khola, have lower FFI scores ranging between 95 and 190 and lying in Fair to even Poor class category that indicated a need for management intervention to prevent from further deterioration of the river habitat (Fig. 3b). The Ghunsa Khola, located in the uppermost area of the basin, was categorized as Excellent (FFI 285) condition. A very dense vegetation in the left and right of the river, good extension of primary as well as secondary perifluval zone, well developed riperian vegetation all have combined effect on the functional score of the river. Further, less human disturbance to river habitat should have contributed to the higher value of FFI for Ghunsa Khola. Direct and indirect human influence can cause the modification in the river functionality. Further, changes in the quality, quantity, and timing (flow regime) of the river flow have direct or indirect impacts on the river and riverine habitat. They can lead to changes in the composition of the biotic community in the river[15].

Table-2
FFI Index of the Tamor River sections and tributaries

SN	River Section	Section Outlet				FFI
		Location	Latitude (°N)	Longitude (°E)	Elevation (m)	
1	Ghunsa Khola	Ghunsa	27.660	87.927	3382	Excellent
2	Tamor River	Lungthung	27.555	87.795	1719	Excellent-Good
3	Tamor River	Lelep (Confluence of Ghunsa-Tamor)	27.533	87.802	1545	Good
4	Simbuwa Khola	Hellok	27.526	87.805	1531	Good-Fair
5	Tamor River	Tapethok	27.492	87.772	1353	Good
6	Menthuma Khola	Tapethok	27.492	87.767	1363	Fair
7	Tamor River	Chhirwa	27.489	87.747	1227	Good
8	Tamor River	Hangdrung	27.377	87.632	708	Good-Fair
9	Mewa Khola	Hangdrung (Confluence of Tamor-Mewa)	27.379	87.627	676	Fair
10	Maiba Khola	Dovan	27.367	87.619	647	Fair
11	Tamor River	Dovan	27.365	87.623	643	Fair
12	Kabeli	Tribeni	27.286	87.723	527	Fair
13	Tamor River	Majhitar	27.154	87.708	450	Fair
14	Hewa Khola	Majhitar	27.157	87.713	411	Fair
15	Leuti Khola	Laabarbote (Budhomorang)	26.919	87.313	319	Poor
16	Tamor River	Mulghat	26.928	87.318	242	Good-Fair

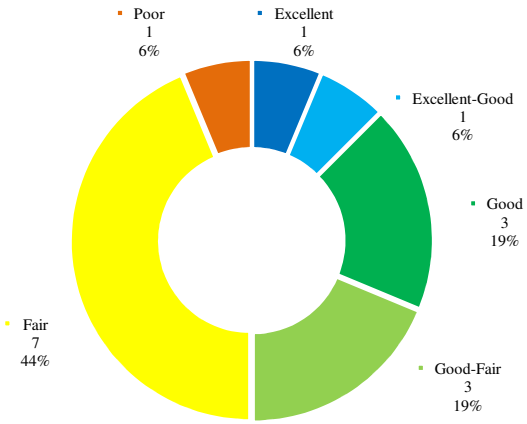

Figure-4
FFI quality classes of the rivers. Levels in the callout represents- FFI quality class, Number of sites, and % of total sites, respectively

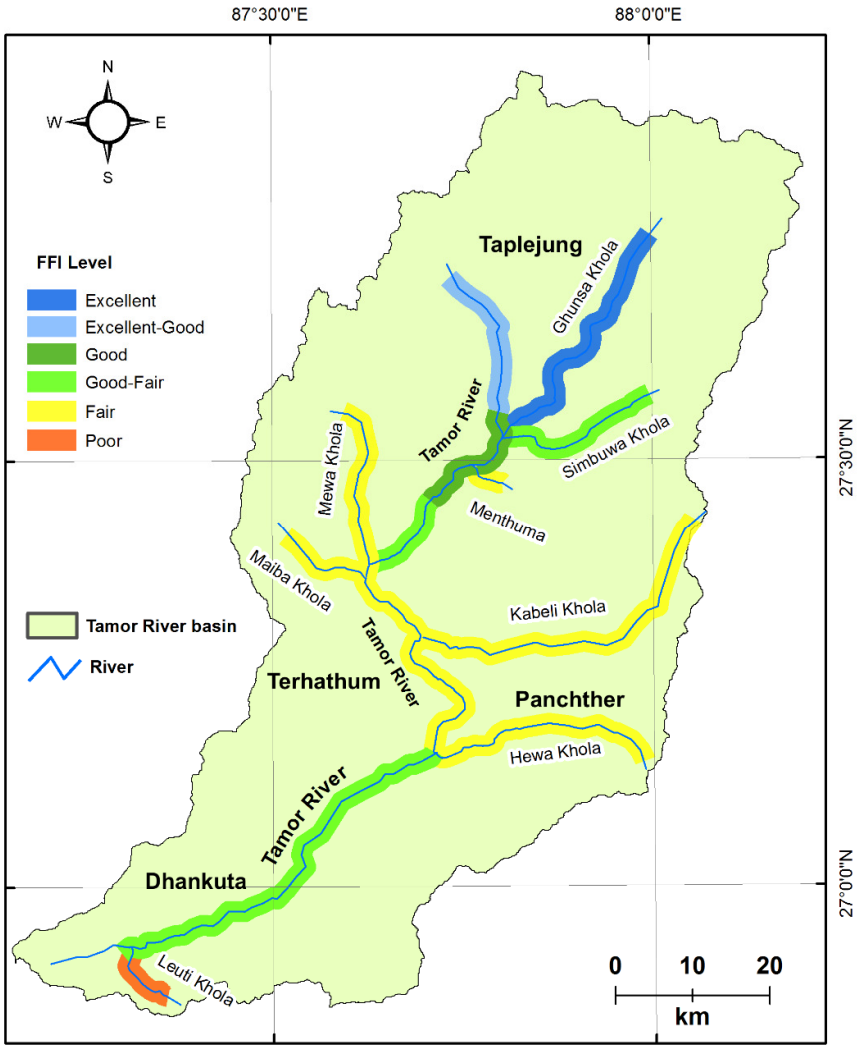

Figure-5
FFI level of Tamor River sections and the tributaries

In Figure-5, the river habitat functionality levelsare visualized. General pattern of habitat functionality level indicates that there are three distinct ecological belts in the TRB. In the uppermost belt of the basin, the habitat functionality level are better, while the river quality are relatively poor in the lower belt of the basin. The middle belt of the basin is most heavily affected. There could be different reasons for this kind of behaviour in the basin. One of the most prominent factor is probably due to high human settlement and their interaction with the river system. The lower parts of the basin are densely populated. The demographic data indicates that the upper parts of the basin have low population density with sparsely distributed settlements due to complex mountainous terrains. Taplejung district that covers the northern most areas of the basin covering an area of 3646 km^2 have a population density of 42 people per km^2, while in the low lying districts: Terhathum (679 km^2), Panchther (1241 km^2), and Dhankuta (485 km^2), the population densities are 113, 143, and 221 people per km^2, respectively[11]. Further, the distribution of the vegetation was not same on the left and right side of the river that could be related to the topographic effects[16].

There are numerous methods to assess the physical or geomorphological condition of rivers. Those methods are geared towards either for biological or physical assessment of river condition. To ensure the healthy biotic community or a healthy river ecosystem[17], it is essential to have an integrated approach covering different components: biological, chemical, and other hydromorphological characteristics. The FFI method can be a useful tool to assess the most important ecological aspects of the whole course of a river considering morphological characteristics and biological features. It is also useful to support an appropriate river basin management[8] and river restoration[9] activities.

Figure-6

Different reaches of Tamor River and its tributaries. Pictures of Tamor River from (a) near Tamor River and Ghunsa Khola confluence in Lelep, (b) Majhitar, and (c) Mulghat, and three tributaries- (d) Ghunsa Khola, (e) Mewa Khola, and (f) Leuti Khola. The calculated FFI level of each river section are represented by coloured circles

The study results suggest that there should be different strategy for management interventions and development works in the different elevation belts (south to north) of the basin. Based on the habitat knowledge, the location and required management options can be explored for management intervention. In the current legal provision of the country for developmental activities, Environmental Impact Assessment is most for approval for implementation of the proposed development project. Any development works related to river water should consider the hydraulic and ecological aspects[18]. In this regards, any decision should be based on the assessment of the fluvial processes for ensuring healthy river environment.

Conclusion

This study demonstrated that the FFI can be useful to rapidly evaluate the health of river habitat in the mountainous region like, Tamor River basin in eastern Nepal. The FFI values for different river sections were ranging from Excellent (285) to Poor (95). Only one tributary (Leuti Khola) of the Tamor River was assessed as Poor quality. The river sections in the middle to lower belt of the Tamor River basin have relatively lower FFI values (128 to 195; most of them at Fair level) indicating that the middle belt of the basin is more dynamic and disturbed. The tributaries are of lower quality than the main river sections due to higher human access and use to them. The results suggest that the basin's fluvial water bodies need particular management attention to preventing them from further degradation as well and sustainable development of the aquatic ecosystem. FFI is able to capture the degradation gradient of river habitat in Tamor River basin. Several methods available to access the ecological conditions of the fluvial system, however the FFI has evolved as a tool that can be implemented in short span of time to gain a wider perspective of the ecological condition of fluvial systems. A combination of this tool with others can provide a comprehensive knowledge and wider perspecitive about the freshwater system.

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Appendix: Format of FFI

FFI FORM

Basin……..……Stream name ……..……

Location……..……

Stretch (metres)……. …… Width (metres)…….. ……Altitude……..…...

Date……Record no……Photo no……..Code…….……

Table-1
The FFI form, question 1 to 14

Bank	Left		Right
1) Land use pattern of the surrounding area			
Undisturbed forests, woods and/or natural wetlands	25		25
Meadows, pasture, woods, a few areas of arable and uncultivated land	20		20
Mainly seasonal cultivation and/or mixed arable and/or permanent cultivation	5		5
Urbanised area	1		1
2) Vegetation of primary perifluvial zone (fluvial zone around watercourse)			
Arboreal riparian formations	30		30
Shrub riparian formations (shrubby willow thicket) and/or reeds	25		25
Non-riparian arboreal formations	5		10
Made up of non-riparian or herbaceous or absent shrub species	1		1
3) Extention of the perifluvial vegetation zone			
Perifluvial vegetation zone >30 m	20		20
Perifluvial vegetation zone 5-30 m	10		10
Perifluvial vegetation zone 1-5 m	5		5
Perifluvial vegetation zone absent	1		1
4) Continuity of the perifluvial vegetation zone			
Continuous perifluvial vegetation without gap	20		20
Perifluvial vegetation zone with gap in vegetation	10		10
Frequent gaps or only continuous and consolidated herbaceous vegetation	5		5
Soil without or with thin herbaceous vegetation	1		1
5) Water conditions of the river bed			

Width of the annual peak flow bed less than three times than the wet river bed		20	
Annual peak flow bed more than three times than the wet river bed with discharge fluctuations with seasonal variation		15	
Annual peak flow bed more than three times that of the wet river bed with discharge fluctuations with frequent variation		5	
Wet river bed non-existent or almost non-existent or presence of impermeabilisation of the river bed		1	
6) Stream bank structure			
Bank with arboreal vegetation and/or stones	25		25
Bank with grass and shrubs	15		15
Bank with a fine grassy layer	5		5
Bare banks	1		1
7) Retention structures of trophic matter			
River bed with large boulders and/or old trunks firmly embanked or presence of reeds or hydrophyte strips	25		25
Boulders, cobbles and/or branches present with depositing of sediment or scarce and not extensive reeds or hydrophyte	15		15
Retention structures free and mobile during flooding or absence of reeds	5		5
River bed with sandy sediment without algae or smooth artificial profile with uniform current	1		1
8) Erosion			
Little evident and not important	20		20
Only at bends and/or narrow passages	15		15
Frequent with cutting of the banks and of roots	5		5
Very evident with undercutting of banks and landslips or presence of artificial intervention	1		1
9) Cross-section			
Natural		15	
Natural with some artificial intervention		10	
Artificial with some natural elements		5	
Artificial		1	
10) Stream bottom			
Diversified and stable		25	
Movable in stretches		15	
Easily moveable		5	
Cemented		1	
11) Riffles, pools or meanders			
Clearly distinguished and recurrent		25	
Present at different distances and at irregular intervals		20	
Long pools which separate short riffles or vice versa, few meanders		5	

Meanders, riffles and pools absent, straightened path		1	
12) Vegetation in the wet river bed			
Periphyton only noticeable on touching and/or low covering of macrophytes		15	
Periphyton visible and/or small covering of macrophytes		10	
Periphyton fair, presence of filamentous algae and/or monotonous macrophytes		5	
Periphyton thick and/or macrophytes relatively unvaried		1	
13) Detritus			
Presence of leaves and woods, vegetable fragments recognizable and fibrous		15	
Leaves and woods scarce, vegetable fragments fibrous and pulpy		10	
Pulpy fragments		5	
Anaerobic detritus		1	
14) Macrobenthonic community			
Well structured and diversified, appropriate to the fluvial type		20	
Sufficiently diversified but with altered structure as compared to that expected		10	
Poorly balance and diversified with a prevalence of taxa tolerant of pollution		5	
Absence of a structured community, presence of a few taxa all relatively tolerant of pollution		1	
Total Score			
Fluvial Functioning Level			