The hydromorphological characteristics of the Bonan Dolok Watershed as a basis for ikan batak (Tor spp. and Neolissochilus spp.) conservation

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Abstract. Lake Toba Caldera is one of the most extraordinary volcanic features formed during the Quaternary geological time. Currently, Lake Toba is a multi-functional lake, which is not only used as a source of water for the Sigura-gura power plant but also a tourist destination with a high level of visits. Lake Toba catchment area is part of the landscape of the Bukit Barisan Mountain Range extending northwest–southeast with irregular ridges and valleys, which have peaks with altitudes between 2000–3000 m above sea level, dominated by slope class (3–8%). Lake Toba is also a place for Indonesian native fishes having high values such as ikan batak (Tor spp. and Neolissochilus spp.). At present, however, the fishes are difficult to find. Generally, ikan batak prefers to live in a habitat with rocky bottoms, sand substrates, clear water, slow to heavy water flow, and the river environment is mostly in the form of primary forest. Description of physical characteristics of water bodies is needed to maintain an ecological system and to be used as a basis for determining fisheries protection zones. Bonan Dolok River is one of the rivers in Samosir Regency-North Sumatra where ikan batak can be relatively found. The river flows throughout the year and its morphology, which consists of a pool, riffle, and run and flow patterns such as laminar and turbulent are favored by ikan batak. Furthermore, the upstream area which is still covered by natural forest makes this area suitable as a conservation area for ikan batak itself.

Keywords: ikan batak, watershed, hydromorphology, conservation

1. Introduction
Lake Toba Caldera in Indonesia is one of the most extraordinary volcanic features formed during the Quaternary geological time. During the past 1.3 million years, the Toba region erupted an
intermediate lava composition, followed by a medium pyroclastic, three quartz-bearing silicate tuffs, and most recently, a medium for silicate lava. This pattern is an additional assembly and periodic eruption of the body of the magma crust from batholithic proportions [1, 2]. Currently, Lake Toba is a multi-functional lake, which is not only used as a source of water for the Sigura-gura power plant but also a tourist destination with a high level of visits. However, unorganized plan among the stakeholders to the use of Lake Toba can create a conflict of interest.

Tourism in Lake Toba has good prospects for development because it can generate high income and create jobs for local people. Government of the Republic of Indonesia through Presidential Regulation No. 81 in 2014 established Lake Toba as one of the world-class tourist destinations. Therefore, the tourism sector needs to be assessed by involving various aspects, so that its output is expected to be a guide in estimating the potential of disturbed areas and the appropriate types of tourism. One of the concerns is the existence of fish that have become an icon in the Toba community, the ikan batak or commonly named ihan (Tor spp. and Neolissochilus spp.). Ecotourism is an alternative to tourism development in Lake Toba, because it can bridge the preservation of nature and community tourism.

Indonesia has a high diversity of fish species and some of them are native and endemic fishes, but only a few species have been known for their value. One type of fish with socio-cultural and economic value is ikan batak. In Indonesia, these fishes have different local names and they are popular as Mahseer in the world. In Batak tribe community, ihan has a prestige value because only certain circles can enjoy the delicacy of the meat or can use it in traditional events. However, its population is rarely found in the Lake Toba ecosystem. This is due to the anthropogenic pressure like land use change in a watershed area of ikan batak habitat.

Lake Toba River Basin is part of the Bukit Barisan Mountain Range that extends northwest-southeast with irregular ridges and valleys, which have peaks with elevations between 2000–3000 m above sea level. The Toba River Basin area is dominated by the slope class (3–8%). Land use is one of the factors affecting the quality and quantity of lake water. Also, many farmers use fertilizers and pesticides on their farms which will flow into the lake [5, 6]. Hydromorphological characteristics will be related to fishery habitat. Lake Toba which was formed due to volcanic eruptions has a steep morphology in the rivers that enter, so it has a swift flow which is favored by ikan batak [7].

Generally, ikan batak habitats can be described as follows: the river bed is generally formed by boulders, gravels, and sand substrates; clear water; slow to strong water flow; and the river environment is mostly in the form of primary forest. This condition is a characteristic of the upstream area. In recent years, several large scale studies have identified the modification and the loss of aquatic habitats as a major factor threatening the conservation of freshwater fish populations [8]. Bonan Dolok River is one of the rivers that flow from the main plain of Sumatra Island to the Lake Toba with morphological characteristics of the habitat favored by ikan batak species. Other than that, the laminar and turbulence flows pattern is interspersed by the pool, riffle and running areas [9]. This research aimed to study the hydromorphological characteristics on Bonan Dolok River as a main basis for the ikan batak habitat conservation. This study used an analysis of Geographic Information Systems (GIS), remote sensing, and field observations to analyze habitat types that exist in Bonan Dolok River. The term hydromorphology was introduced to describe the characteristics and physical processes of rivers when they determine the condition of river ecosystems. Hydrological regimes, river continuity, and morphological conditions are indicated in the water framework directive as the three key elements of the river hydromorphological quality [10].
The high cultural value of ikan batak and their habitat degradation need some conservation actions, and one of them is by determination of conservation areas. Zoning of aquatic conservation areas is an engineering form of spatial engineering in the waters conservation areas through the establishment of functional boundaries in accordance with the potential of resources and carrying capacity and ecological processes that take place as an ecosystem unit [11]. Hydromorphological integrity is a center of conservation because it provides a template on which all other ecological structures and functions are developing [12].

2. Materials and Methods

2.1. Study area

The Bonan Dolok River Basin is part of the Lake Toba River. It is located on the island of Sumatra, administratively placed in Bonan Dolok Village, Sianjur Mulamula sub-district, Samosir Regency, North Sumatra Province, Indonesia. Geographically, it is coordinated at 98° 33' 44.5" – 98° 36' 54.2" East and 2° 36' 47.7" – 2° 40' 3.3" North. Bonan Dolok village is about 20 km from Pangururan city, which 0.5 hour by boat through Lake Toba. Figure 1 shows study area of Bonan Dolok Watershed.

![Figure 1. Study area of Bonan Dolok watershed.](image)

2.2. Data collection

This study not only use primary and secondary data but also supported by field observations. Primary data were obtained from field observations in 2019 (March and August). Table 1 shows the data used in the Bonan Dolok River hydromorphological analysis.
Table 1. Summary of data requirements.

| No | Margin | Data format           | Source                                              |
|----|--------|-----------------------|-----------------------------------------------------|
| 1  | Digital elevation model | Grid (cell size 8 x 8 m) | DEMNAS, Indonesian Geospatial Agency                 |
| 2  | Soil types scale 1:250.000 | Vector (shapefile) | Land and Agro-climate Research Center, Ministry of Agriculture |
| 3  | Meteorological data (daily and 15 minute), CHIRPs | Table (.dbf and text) | RC for Limnology                                    |
| 4  | SPOT satellite image 2017 | Satellite image | USGS, ground check                                  |
| 5  | Soil properties for SWAT database | Numeric | Field sampling and laboratory analysis (RC for Limnology) |
| 6  | Vegetation riparian | Image | Drone and field survey                              |
| 7  | River flow patterns | - | Drone and field survey                              |

2.3. Hydromorphology analysis for fish conservation

Hydromorphology is the study of the physical characteristics of water bodies on the surface of the earth, including river basins, canals, rivers, and lakes. Water quality, pollution levels, and biological components needed for the maintenance of ecological systems are some parameters that are assessed when classifying the water systems. This study examined the hydromorphological aspects of the Bonan Dolok River such as biophysical watersheds including area, shape, slope, and land use, river characteristic are obtained by measuring at; discharge, flow regime, river slope, and observing the river bed. The methods used to analyze the habitat types in Bonan Dolok River are Geographic Information System (GIS) analysis and remote sensing which are supported by field observations. Figure 2 shows the research flowchart.

Figure 2. Flow chart of habitat conservation based on hydromorphology characteristic study.

Observations were conducted at four locations that illustrate the biophysical condition of the Bonan Dolok River. Site 1 was located in the Sitapigagan waterfall which was the most upstream station because it was assumed that the ikan batak can no longer rise to the upper reaches due to the
steep waterfall. Site 2 was located ± 300 m downstream from site 1, which was the transition of the start of agricultural activities. Site 3 was located next to the church and represented the domestic activities of residents such as washing clothes and bathing in the river. The last location, site 4, was at the estuary from the Bonan Dolok River to the Lake Toba waters. Figure 3 shows sampling sites in Bonan Dolok River.

![Sampling site in Bonan Dolok River.](image)

The characteristics of the watershed and Bonan Dolok River was firstly identified by creating boundaries using the Automatic Watershed Delineation (AWD) method from hydrology Soil and Water Assessment Tools (SWAT) and Digital Elevation Model (DEM) data. The image was obtained from SPOT 7 satellite and Unmanned Aerial Vehicle (UAV). DEM data with a resolution of 8 x 8 meters were downloaded from http://tides.big.go.id/DEMNAS/. By using the AWD procedure from ArcSWAT Tools in the ArcGIS application to make the Bonan Dolok Watershed boundary, this data was also used to make the watershed slope and river network. The land use of the Bonan Dolok River Basin was obtained from the interpretation of SPOT 7 satellite images in 2017 which have been corrected by radiometric and atmospheric. Land use was classified using visual methods (digit on the screen) with the ArcGIS 10.3 application. The SWAT hydrological model has been widely used in Indonesia since the results of validation have a range from good-satisfying [13].

Hydromorphological observations included observations of the momentary discharge as measured by mean area methods, where the cross section of the river was divided into ten segments, and the velocity was measured in each segment. Flow velocity measurements used was the Tamaya current meter (UC-20). Daily discharge data were obtained both by measuring the instantaneous flow of the river and from the results of SWAT hydrology model simulation. Model input was obtained from the Climate Hazard Group InfraRed Precipitation with Station (CHIRPS) data which could be downloaded at https://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/.v2p0/.daily-improved/global/0p05/. The hydrological condition observed in this study was discharged and flow velocity of the rivers segment selected in the conservation areas. Discharge volume influences the thermal and the hydrologic stability of habitat characteristics [14].
Fishery habitat is a composition of the availability of food and comfort of each fish. In addition to the physical condition of food availability, it also becomes a support in the selection of conservation areas. Recent developments in the capability and availability of UAV, a combination of UAV and photogrammetry have been heralded as a route to democratization of data acquisition in geoscience and this capacity may enable quantification physical river habitat parameters in mesoscale [15]. Remote sensing technology can now be used to identify riparian vegetation that supports fisheries conservation, as conducted by Kosut et al [16] in Normandy, and Dofour et al [17] which identified vegetation plants in two small river systems located in the northwest of France using UAV and Lidar images. Observation of river topography and vegetation is very effective using UAV, not only is fast, but the accuracy is also high [18].

3. Results and Discussion
3.1. Characteristics of the Bonan Dolok Watershed
With DEM input, the boundary of the Bonan Dolok Watershed is 2,890 ha. Figure 4 shows the slope of the Bonan Dolok River Basin and downstream until the river mouth is flat again. Meanwhile, figure 5 shows the profile extending from the Bonan Dolok main river.

![Figure 4. Land slope (%) and 3-Dimensional view of Bonan Dolok Watershed.](image)
3.2. Land use and human activities

Land use is one of the dynamic parameters in the characteristics of a watershed. Land use changes due to human activities have become one of the considering factors in managing the river habitat conservation area. Land use in the Bonan Dolok Watershed was obtained from the results of the SPOT 7 satellite image classification in 2017. The classification results are shown in figure 5. Generally, this watershed is still dominated by forest cover which reaches 83%, mainly in the upstream, but in the middle of the bush and pasture cover the land with slopes >45% with a percentage of 15.8%, even though the border of the river is still overgrown with higher plants. The cultivated land in the downstream is mainly used for rice fields and settlements with a percentage of up to 1%. Table 1 shows the extent of each land use class in the Bonan Dolok Watershed, while figure 6 shows the distribution of land use.

| Landuse            | Area (ha) | %    |
|--------------------|-----------|------|
| Bush               | 4.0       | 0.14 |
| Dry Agriculture    | 0.5       | 0.02 |
| Forest             | 2405.4    | 83.21|
| Paddy filed        | 26.4      | 0.91 |
| Pasture            | 452.2     | 15.64|
| Plantation         | 0.5       | 0.02 |
| Settlement         | 1.9       | 0.07 |
| **Total**          | **2890.9**| 100.0|
3.3. Discharge and river morphology

One of the major challenges in river ecology and management is identifying river reaches where hydrological and geomorphological characteristics are similar and maintained by comparable river processes, so that proper hypothesis testing and management units can be established [19, 20]. Hydrology becomes an important part in studying aquatic habitats, measurement of discharge, and flow patterns in a river system become an indicator of the connectivity between upstream and downstream of the river. Rivers that flow throughout the year into fish can move foraging along river corridors unless there are geomorphological conditions.

River flow discharge is affected by rainfall, evapotranspiration, groundwater storage, shape and size of watersheds, water withdrawals, vegetation, and land use in watersheds [21]. Water discharge directly affects aquatic communities by water quality, food sources, biotic interactions, and creations as well as the availability of physical habitats. River discharge needed for fish conservation should flow throughout the year so that fish habitat is not disturbed, especially in drought conditions. While the flow discharge has varied conditions, some parts are fast flowing and others are calm. Hydrological conditions were observed with momentary observations and previous studies. The hydrological model simulation results are shown in figure 7. The simulation results also show that Bonan Dolok river still flows throughout the year with a minimum discharge reaching 0.28 m$^3$/sec which was occurred in August 2018, while the maximum discharge reaching 1.7 m$^3$/sec was occurred in January 20, 2018. The simulation results have not been validated due to...
the absence of a river observation station, but the flow value of the simulation results is still in a reasonable value.

![Simulation result of Bonan Dolok River discharge.](image)

**Figure 7.** Simulation result of Bonan Dolok River discharge.

Stream ecosystems provide natural habitats or environments for a variety of aquatic organisms and plants. A more in-depth analysis shows that each stream has different anatomy because each of them consists of a series of ponds, riffles, and runs (figure 8). The results of the photoshoot using Unmanned Aerial Vehicle (UAV) showed that there were many series of riffle pools and run in Bonan Dolok River. This condition is most preferred by ikan batak. However, this fish can only roam the river up to one kilometer from the lake because it is limited by the Sitapigagan Waterfall which is so steep that this type of fish can no longer swim upriver.

![River corridor analysis from UAV images.](image)

**Figure 8.** River corridor analysis from UAV images.
The observations at four stations along the Bonan Bolok river segment began after the Sitapigagan Waterfall. This is due to the assumption that the ikan batak can no longer rise upstream because the waterfall is too steep. The results of instantaneous discharge measurements do not show a significant difference between stations 1 and station 3, flow discharges range from 0.6 to 0.7 m³/sec. While the current velocity is different because each site has a different river slope, the highest current velocity values are found at station 2 (0.12 m/sec) with a river slope gradient reaching 18.5%. Bonan Dolok River discharge, current velocity, width, and the average depth of each station are shown in table 2.

| No | Parameters                  | Site 1  | Site 2  | Site 3  | Site 4  |
|----|-----------------------------|---------|---------|---------|---------|
| 1  | Width of river (m)          | 10      | 9       | 8.5     | 10      |
| 2  | Average of Depth (m)        | 0.5     | 0.4     | 0.3     | 0.3     |
| 3  | Gradient of river (%)       | 11.9    | 18.5    | 15.3    | 14.1    |
| 4  | Discharge (m³/second)       | 0.6     | 0.7     | 0.6     | -       |
| 5  | Flow velocity (m/sec)       | 0.17    | 0.12    | 0.9     | 0.3     |
| 6  | Riverbed                    | Boulder and gravel | Boulder and gravel | Boulder and Sand | Gravel and sand |
| 7  | Predominate morphology      | Water fall, pool, riffle | Riffle, run, pool | Riffle, run and pool | pool |
| 8  | Type of water flow          | Turbulent | Turbulent | Turbulent | Laminar |
| 10 | Distance to settlement (Km) | 0.4     | 0.14    | 0       | 0.1     |
| 11 | Riparian vegetation         | Forest, Bush | Paddy, Bush | Settlement and paddy | Settlement and paddy |
| 12 | Distance from Lake Toba (Km)| 0.95    | 0.66    | 0.36    | 0       |

The shape and size of the river bed are determined by the balance of four basic factors namely the energy of the water flow (slope and velocity of the water) and the resistance of the substratum (the size of sediment particles and their runoff). Any decrease in water energy will result in smaller sediment particles and river bed widening [22, 14]. Bonan Dolok river bed from site 1 to site 3 has a similar type, with gravel-boulder-sized rock bottom even at site 1 based on the andesite igneous rocks. The large grain composition is also interspersed with sand found at site 3. The large grain pattern underlying the river shows the high discharge and the slope of the river and once the flow reaches the estuary, the speed of the current decreases so that the sand is deposited. The recapitulation of the flow patterns and composition of large rock grains at each station is shown in table 2.

3.4. Conservation of ikan batak in Bonan Dolok River

This model of determining conservation areas is based on physical conditions. At the same time, other factor such as local wisdom is also used because they relate to people's perceptions of the importance of preserving the valuable fish. Hydro-morphological analysis showed that site 1 is considered suitable to be used as a conservation area for the ikan batak. The hydro-morphological condition and location of site 1 are suitable as a habitat for the protection of the fish. Site 1 is the
most upstream location, precisely under the Sitapigagan waterfall. This location has not been polluted by agricultural wastes because of the upstream forest and bush and grass area. The distance from the nearest settlement is 0.4 km, so it does not always directly interact with humans but can still be reached for monitoring. The river morphology is complete; under the waterfall, there is a deep pool (maximum 2 m), and after that, there is a riffle and run where ikan batak find food.

In the arrangement of conservation areas, space for buffer and utilization zones must be provided, based on the spatial analysis conducted at 4 locations. Site 2 will be a buffer zone because this zone must be placed in the main protection zone (zone 1). Hydromorphologically, this zone is also in accordance with the habitat preferred by ikan batak; where the flow regime, rocky bottom waters, and sand are found. Site 3 is not far from the settlement which is located right next to the church. Some activities such as bathing and washing are seen in site 3. This location has water flowing out of paddy and vegetable fields so that even though the river flow is heavy, there is still interference from human activities. Site 4 is a meeting point between the waters of the Bonan Dolok River and the waters of Lake Toba where at this location also a place to anchor several community motorboats so that the level of pollution is higher than others. Based on the conditions above site 3 and 4 are not suitable to be used as a location for fish protection but it is necessary to maintain the connectivity between the flow of Bonan Dolok River and the waters of Lake Toba.

Management of fish protection areas in Bonan Dolok River needs to be applied together with all stakeholders concerned not only involve the local government of Samosir District but the surrounding community and researchers. Community participation is needed in the application, especially in determining the detailed boundaries of the core zone and buffer zone. The community is also placed in guarding, currently through the local waters of the Bonan Dolok River area still awake, not just anyone can catch fish in this river, especially around the Sitapigagan waterfall. Furthermore, to get better results, it is necessary to conduct a more integrated research between ecology, hydrology, and geomorphology or known as eco-hydromorphology; which can be determined as the interaction of biological entities and river ecological processes with the shape and dynamics of hydrology and geomorphology [12].

4. Conclusion

The hydromorphological characteristics of the Bonan Dolok River are very suitable for ikan batak conservation area indicated by the heavy flow of water with a complete flow regime composition and rocky riverbed which is interspersed with sand. It is necessary to formally define the area around the Sitapigagan Waterfall (site 1) as the core zone of the ikan batak conservation and site 2 as the buffer zone in the downstream area. Forest cover in the upstream region of Bonan Dolok River needs to be conserved to maintain the quality and quantity of water. Also, determination of conservation area requires approval from various stakeholders which includes the Regional Government through the tourism department and the Department of fisheries and the communities around the Bonan Dolok River.

5. References

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Acknowledgments

This study supported by Field Priority Research Program of Research center for Limnology, Indonesian Institute of Sciences (LIPI), entitled "Teknopark Pengelolaan Perairan dan Sumber Daya Perikanan di Kabupaten Samosir", funded by LIPI through the fiscal year of 2018-2019.