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Landscape Fragmentation, Ecosystem Services, and Local Knowledge in the Baroro River Watershed, Northern Philippines

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Abstract: Landscape fragmentation, the breaking up of land use type into smaller parcels, is damaging watersheds worldwide. Without addressing its causes, landscape fragmentation can permanently destroy habitats and compromise ecosystem services (ES) that a watershed provides. This paper aims to establish associations between watershed landscape fragmentation and ES by integrating science (satellite imageries and fragmentation analyses) and local geographic knowledge (key informant interviews and focus group discussions) at different time periods. Using the case of the Baroro River Watershed in Northern Philippines, this paper posits that local knowledge, when integrated with scientific knowledge, becomes a significant medium through which watershed landscape fragmentation and declining quality of ES can be better understood and addressed. Results also indicate that people's experiences and knowledge on ES coincide with watershed landscape fragmentation as evidenced by satellite images and fragmentation analyses done at different time periods. This implies that people's knowledge is well grounded on facts and complements scientific knowledge necessary in crafting more effective landscape policies that can tackle watershed fragmentation. Study results are also crucial in providing information to serve as inputs in the development of a more robust watershed management plan; particularly in implementing sustainable land uses without sacrificing the watershed's overall integrity.

Keywords: landscape fragmentation; watershed; ecosystem services; local knowledge; Philippines

1. Introduction

Tropical forests are known as the richest terrestrial ecosystems in the world in terms of flora and fauna as well as structural complexity [1,2]. These forests can be found inside watersheds, where both surface and groundwater emanate and drain into a common outlet. Watersheds are landscapes composed of a mix of local ecosystems and land uses covering a wide area. Currently, most watershed landscapes are being threatened by fragmentation, mainly caused by anthropogenic activities. As species are becoming extinct due to habitat destruction, the numerous ecosystem services (ES) being provided by these watersheds are being compromised at an alarming rate, which adversely affects both socio-ecological systems and human well-being. Ecosystems are indispensable sources of various goods and services needed by humans to survive, and keep natural processes intact [3,4].

To sustain the flow of ES, there is a need to address watershed fragmentation at the landscape level. Landscape fragmentation is defined as the breaking up of contiguous land use into several patches over time which affects the effective functioning of the ecosystem [5,6]. As deforestation happens, patches of original vegetation remain, modifying both biotic and abiotic elements of the environment [7]. This process has been aggravated by continued expansion and encroachment of agriculture, cattle ranching, and illegal logging, converting the last remnants of tropical watersheds into isolated patches [8–11].

Studies estimate that the tropics has around 50 million forest fragments and that when summed up together will produce nearly 50 million kilometers of forest edges [12]. Watershed landscape fragmentation is found to have substantially increased carbon emissions from tropical forests by 31%, and that Asia accounts for the second largest emission due to its topography and small-scale nature of fragments [12].

Within the tropics are watershed landscapes composed of diverse and mosaic natural and human-modified ecosystems. As the components of the watershed landscape are interconnected, a change in the flow of ES upstream will have direct or indirect impacts to midstream and downstream areas [13]. A change in land use due to human activities usually results to fragmentation of natural habitat that affects the capacity of the watershed to provide certain ES [4]. Thus, understanding historical land use patterns can explain current and future conditions of the ES in a given watershed [14].

While there has been an increase in the number of research studies investigating the link between fragmentation and ES in recent years [4], current studies that examine the role of historical land use in shaping the current condition of the watershed are limited in the ES literature [14]. Historical land use has an important role in influencing the current structure and function of the environment that affects its capacity to produce ES [14,15] and has a considerable effect in the way local people view and manage their resources.

Historical land use can characterize the relationship between populations and the ecosystem that they inhabit in a given time period [16,17], and can determine the driving forces of land cover change [3]. Thus, understanding the drivers of land cover change in the past can therefore explain the differences in land use practices of people, which can be established by using local and scientific knowledge.

This paper therefore assesses the link between watershed landscape fragmentation and ES by comparing scientific data and local knowledge of people interacting with their environment. Examining the case of the Baroro River Watershed in Northern Philippines, the paper argues that local knowledge is a powerful medium through which watershed landscape fragmentation and the declining quality of ES can be better explained and addressed. Currently, majority of the 143 watersheds supporting the national irrigation system in the Philippines are affected by declining forest cover [18]. Changes in the landscape are due to ballooning population, unsustainable land use practices, and lack of coordinated governance efforts resulting to loss of biodiversity and continuing poverty. Such conditions prompted the conduct of this timely and relevant study.

As knowledge of local people differ based on their cultural background, geographical location, life experiences and land practices, this study selected communities to represent the entire cross-section of the Baroro River Watershed (upstream, midstream, and downstream). This method of analysis aims to capture differences in levels of local knowledge and appreciation of ES.

Aside from the standard historical land use/land cover (LULC) change analysis, this study is the first scientific attempt to quantify the extent of watershed landscape fragmentation using established landscape ecology metrics at different time periods. Official LULC maps were used, except for the 1940s as satellite images were not yet available at that time. In addition, this is the only fragmentation study done in the Philippines, both at national or local levels, which relates to ES. Results of this study are expected to contribute to the buildup of knowledge relevant in designing future plans and interventions on watershed and habitat management.

2. Landscape Fragmentation in the Philippines: A Historical Perspective

In the 1600s, Philippine forests constituted around 90% of the total land area of the country [19]. At that time, lands were traditionally owned and managed by the indigenous people who practiced swidden farming for survival. Under the Spanish regime in the 1880s, trees were cut and used in the construction of ships for the galleon trade. This practice reduced the forest cover to around 70% at the beginning of the 20th century [20]. Table 1 shows data on land use changes in the Philippines from 1880 to 1980.

Table 1. Land use change in the Philippines in a century (1880–1980).

All Totals in 1000 km^2	1880	1920	1950	1970	1980	2010
Total land area	300	300	300	300	300	300
Total forest area	210	193	163	138	103	77 *
Total net cultivated area	20	35	47	64	97	121 **
Population per square kilometer	20	36	68	122	160	308 ***
% forest area	70%	64%	54%	46%	34%	26%
% net cultivated area	7%	12%	16%	21%	32%	40%

Sources: Goldewijk, et al., 2004 [21], * Mangobay.com, 2016 [22], ** World Bank, 2106 [23] *** PSA, 2012 [24].

During the Post-World War II era, Philippine forests were given importance due to the value and contribution of its timber to economic development [25]. Large-scale logging peaked in the 1970s that resulted in high deforestation rate, said to be among the fastest in the world [26]. With the opening up of a significant portion of the forests in the watershed areas, migrants started to come in and occupied the logged-over areas. Migration in the country was mainly driven by landlessness and lack of employment opportunities in the lowland. As a result, more mid- and upland watershed areas were planted with agricultural crops such as rice, leading to increased fragmentation [19]. Up till now, people are living in the uplands and contribute to changes in the watershed landscape.

Given its history of large-scale timber extraction, the forest cover in the Philippines is now at about 26% of its original state [27]. This is a clear indication that forests and watersheds are the main casualties of economic development and population growth throughout the centuries. What remains of the natural tree vegetation in the country is confined in the upper elevation of the watershed landscape, with scattered distribution in the mid- and lowlands. This historical perspective on land use change from the early 17th century to the present is significant in the study of watershed landscape fragmentation in the Philippines as it explains why the conversion of watersheds into different land uses led to the breaking up of watershed landscape into numerous patches.

3. Watershed Landscape Fragmentation and Ecosystem Services

Changes in the watershed landscape are brought about by natural disturbances and human activities. As the world population grows over time, supporting people's needs is critical for survival. This eventually led to the opening up of tropical forests for extractive industries, food production, and settlements resulting to watershed landscape fragmentation. A study of Gibbs et al. [9] revealed that more than half of the new agricultural lands in the tropics encroached on intact forests, while an additional 28% are estimated to open up secondary forests [11]. Hence, fragmentation and land-use intensification are integrally intertwined [28].

Combined with climate change, landscape fragmentation may have deleterious consequences to a wide range of ES [29]. It weakens the health of the ecosystem by increasing the edge to interior ratio and reducing the core of the forests to the point of endangering the survival of species. A recent study estimates that more than 70% of the world's forests are now within one kilometer of an edge usually in close proximity to human modified areas [30].

The disruption caused by fragmentation can have devastating effects to flora and fauna that cannot adjust to the level of sunlight, rain, noise, and pollution at the edge of these fragments [31].

Some species that require large contiguous area for habitat can be permanently lost as fragmentation reduces the ability of these species to move across landscapes, interrupting its foraging and breeding activities [32]. Large predators are usually absent in fragmented landscape that can result in food-web cascades. In this case, species at the lower level of the food chain multiply out of control, contributing to pests and diseases [33]. Thus, only those species that can thrive in the edges of the fragments can adapt to the harsh conditions, eventually replacing the original species composition [34].

Watershed landscape fragmentation will also likely lead to local warming due to creation of non-vegetative surfaces that absorb more solar radiation, affecting the microclimate of the watershed and exacerbating the impacts of global warming [34]. This increases evapotranspiration that alters the local water cycle, with rivers and streams becoming more prone to either floods or droughts at any month of the year [35]. This also affects soil dwelling organisms sensitive to increasing temperature and are critical in ecosystem processes such as nutrient cycling [34]. As there is less vegetation to hold the soil during peak flows in a fragmented landscape, soil deposition or erosion is evident when observing the quality of water in the rivers and streams. Soil erosion encompasses water pollution and siltation, loss of organic matter, and reduction of water storage capacity of the watershed [36].

Particularly interesting in ES studies and fragmentation is the time lags between land-use change and ecosystem responses. These time lags delay the effects of fragmentation on the provision of ES supply, which means that some effects of fragmentation can be manifested not at present but can be felt in the future [14]. Such delayed effects are more pronounced for biodiversity-based services as re-colonization and establishing connectivity are slow processes [37] as well as to hydrological services where groundwater turnover times are typically very slow, thereby reversing water quality degradation is difficult [14].

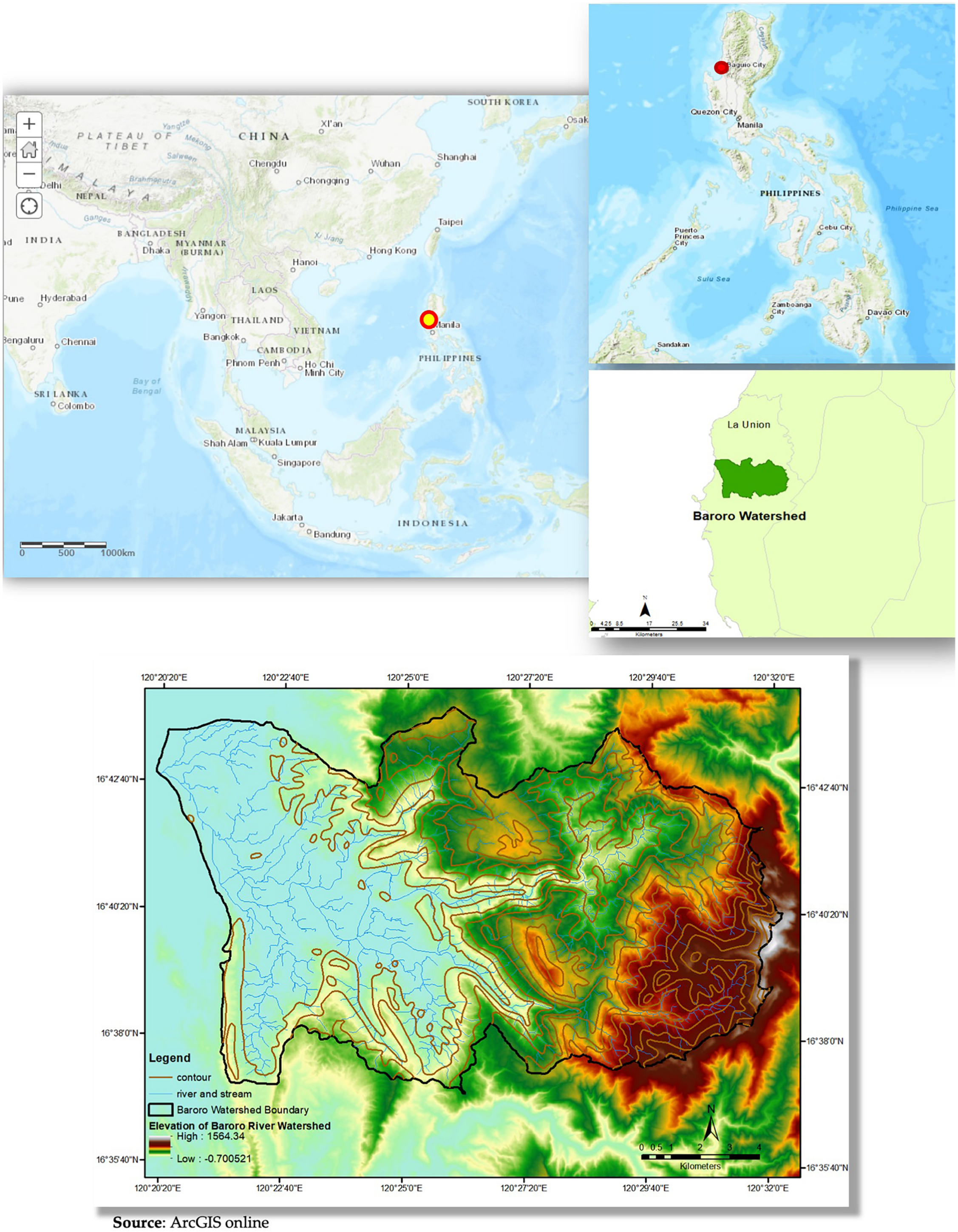
4. Methods

4.1. Study Area

The Baroro River Watershed is located in the province of La Union (Northern Luzon, Philippines, see Figure 1). It is composed of the municipalities of San Gabriel, Bagulin, San Juan, San Fernando, Bacnotan, and Santol. The watershed has a total land area of 19,063 hectares, which is the main source of water for both irrigation and domestic purposes in all municipalities except for Bagulin and Santol. The Baroro River Watershed represents the case of majority of watersheds in the Philippines in terms of anthropogenic pressures and changes in land use—from a contiguous forest in the early 1900s to numerous patches of mini-forests concentrated at the upper portion of the watershed at present. Agricultural areas, production forests, and protection forests constitute the present land uses in the watershed. The study further focused on three villages, which are representatives of the cross-section of the watershed namely, (1) Barangay Lon-oy in San Gabriel for the upstream; (2) Barangay Cabaroan in San Juan for the midstream; and (3) Barangay Baroro in Bacnotan for the downstream area.

Forest vegetation can still be seen in the upper and middle portions of the watershed while its downstream portion is dominated by an urban sprawl. San Juan is one of the municipalities at the receiving end of the watershed. It is also a popular tourist destination primarily because of its famous beaches for surfing. Some communities in this side of the watershed are into fishing and farming, but agricultural lands are now slowly being converted into subdivisions and business establishments due to improving economic opportunities and outcomes. Agriculture dominates the middle portion of the watershed, particularly of rice and corn varieties, interspersed with permanent and semi-permanent dwellings.

Communities that inhabit the upper watershed are composed of Kankanaeys, an indigenous people and original settlers in the area. The Kankanaeys are still practicing rice terracing, particularly in sloping areas, but commercial agriculture as compared to swidden farming is the dominant practice for the rest of the watershed. The middle and lower watersheds are occupied by migrants of Ilocano and Tagalog descents. From 55,697 individuals recorded in 1990, the population in the watershed increased to 77,166 in 2015, with an annual growth rate of 2.76 % and is expected to put more pressures on the remaining natural resources.



Source: ArcGIS online

Figure 1. Location and elevation maps of the Baroro River Watershed, La Union, Philippines.

4.2. Research Design

The study was conducted using a two-stage research design. First, satellite images were sourced from the official land use and land cover (LULC) maps of the National Mapping and Resource Information Authority (NAMRIA). This government facility is responsible for providing mapmaking services and related information to the general public. The LULC maps represent the different land use classes of Baroro River Watershed, and correspond to the years 1988, 2003, 2010, and 2015. These four time series were the same time when NAMRIA produced the official land use cover maps of the country. The maps were then cross-referenced using available sheets from Google Earth Pro (Open Geospatial Consortium, Inc., Wayland, MA, USA). The processing and analysis of reclassification of land types were done using an ArcGIS software (ESRI, New York Street, Redlands, CA, USA). Selected landscape metrics were computed using FRAGSTATS 4.2.1 due to its accuracy in calculating fragmentation metrics and straightforwardness on raster datasets [38,39]. FRAGSTATS is a spatial pattern analysis program that offers a comprehensive choice of landscape metrics and have been used to quantify landscape structure. It is used to analyze fragmentation and describe the characteristics and components of landscapes [38]. These statistics facilitate the comparison of landscapes and the evaluation of processes. The advantage of FRAGSTATS is that the calculations are applied in a fully integrated approach in a GIS platform, which can generate a patch map. The raster datasets were then processed in ArcGIS software.

For the second stage of the research design, site visits to the three selected villages were done to validate the maps and obtain additional relevant data. Land use and environmental changes in the villages were traced based on recollection of oldest inhabitants in the areas through focus group discussions (FGDs). Prior to the FGDs, key informant interviews (KIIs) with village officials were done to gather crucial information needed to craft questions for the FGDs. Information focused on reconstruction of the changes that happened at different time periods (1988, 2003, 2010, and 2015). Specifically, the timeline presented to the participants were divided into four decades to coincide with the produced maps: 1940s (pre-mapping period), 1980s (coinciding with 1988), 2000s (coinciding with 2003), and 2010s (coinciding with 2010 and 2015). This was also done to confirm whether the two types of data have overlaps. Key questions were formulated to gain a more comprehensive understanding of how local people used watershed resources, how these practices affect watershed landscape fragmentation, the ES delivery of the Baroro River Watershed, and how people in the watershed adapt to existing conditions and projected scenarios. Also, before the start of the FGDs, an introduction about the study and its objectives, definition of watershed landscape fragmentation, and presentation of fragmentation maps based on LULC were given to the participants.

In terms of ES, emphasis was placed on freshwater production, soil productivity, preservation of biodiversity, provision of food, fiber and raw materials, cultural services, and maintenance of microclimate. These were the ES that the FGD participants were most familiar with and were defined in the Millennium Ecosystem Assessment (MA). An average of eight carefully selected participants joined the FGDs, with ages that range from 35 to 83 years old representing the different age groups and gender and knowledgeable of the history of their barangays. The FGDs were conducted following the protocols set by the Overseas Development Institute (ODI) to ensure that reliable information will be generated [40]. The older participants can recall what transpired in the 1940s through oral history and life experience, which became the study's base year. After the FRAGSTAT results, KIIs, and FGDs, interpretations regarding the impacts of watershed landscape fragmentation to ES were made.

4.3. Satellite Imagery Classification and Accuracy Assessment

Geospatial and remote-sensing data are reliable sources for understanding and determining the drivers of LULC changes at any landscape [41]. In this study, satellite images used for LULC maps from NAMRIA that represent land use classes of Baroro River Watershed from 1988 to 2015 were obtained. The land cover maps were generated based on a classification scheme consistent with international standards for global reporting and integration [42]. For 1988 land cover data, Landsat TM data from 1982 to 1985 were processed and supported by ground measurement conducted by the then Bureau of Forest Development (BFD) with the assistance from German Technical Cooperation Agency (GTZ), and Food and Agriculture Organization (FAO). The 2010 land cover map was sourced from Landsat 7 ETM+ data from 2010 with 30-m resolution and classified based on FAO-FRA Project Field Inventory Manual with NAMRIA and Forest Management Bureau (FMB) collaboration; ALOS AVNIR-2 (10 m resolution), SPOT 5 (10 m resolution) and Landsat 7 ETM+ (30 m resolution). Data were validated on the ground with accuracy assessment (calculated by province through overlaying the ground validated sample data over the preliminary map and presented the success or failure of the matches in Confusion matrix with overall accuracy of 89%). Landsat operational land imager (OLI) data from 2015 was used, with 30 m resolution with reference data from Google Earth Pro, topographic maps, ground truth data and Interferometric Synthetic Aperture Radar (IFSAR) data for coastline using OBIA eCognition software for digital classification with ground validation and accuracy assessment of 93.92% [42]. The land cover maps were validated and presented to the Department of Environmental and Natural Resources (DENR) regional and provincial offices, with local government units (LGUs), and selected stakeholders for comments, suggestions, and approval. The 1988, 2003, 2010, and 2015 LULC maps are the officially recognized maps by the Philippine Government that can be used by the national government offices, academe and other organizations/institutions.

4.4. Image Reclassification

A reclassification scheme of five classes (from 12 aggregated categories) was developed based on physiographical knowledge of the study area, supporting ancillary data, researchers' prior local knowledge, and visual interpretation using historical function of Google Earth Pro. The five LULC classes were categorized as water bodies, grassland/barren land, mixed agriculture, forest, and built-up areas (Table 2).

Table 2. Reclassified land use/land cover classes for Baroro River Watershed based on NAMRIA LULC data.

LULC Class	Description
Water	River and reservoirs
Grassland/Barren land	70% grassland, open areas
Mixed agriculture	Annual crop, perennial crop, cereals and sugar, cropland, cultivated land
Forest	with brush land, wooded land/wooded grassland, forest plantation, shrubs, open forest/broadleaved
Built-up area	Area with residential, infrastructure development

4.5. Landscape Metrics

Spatial metrics were analyzed at both class and landscape levels. This means that each patch type in the landscape mosaic of the watershed was analyzed as a whole. At the class level, eight landscape metrics were selected including class area, number of patches, edge density, total edge, median patch size, area-weighted mean shape index, mean shape index, and mean perimeter-area ratio. At the landscape level, nine indices were selected, namely: (1) number of patches; (2) mean patch size; (3) edge density; (4) area-weighted means shape index; (5) perimeter-area fractal dimension; (6) contagion; (7) aggregation index; (8) largest patch index; and (9) mean shape index. These landscape metrics were chosen because it can show changes in land use activity, as demonstrated in past studies [43,44] and as described in Table 3.

Table 3. Landscape metrics used in the Baroro River Watershed.

Acronym	Metric Name (Units)	Description	Levels of Application	Reference
CA	Class area (ha)	Total area of all patches per class	Class level	[45,46]
TE	Total Edge (m)	Total edge is an absolute measure of total edge length for a particular patch type (class level) or for all patch types (landscape level)	Class level	[45]
NP	Number of patches	Total number of patches	Class and landscape level	[45–47]
MPS	Mean patch size (ha)	Average patch size	Class and landscape level	[48]
ED	Edge density (m/ha)	Total length of edge of a certain LULC class per unit area (m/ha)	Class level	[46,49]
AWMSI	Area-weighted Mean Shape Index	It measures the complexity of patch shape of a particular LULC class covered to a standard shape (square), by weight patches according to their size. It equals 1 when all patches are square and increases with complexity of patch shapes	Class and landscape level	[46,47]
MSI	Mean shape index	MSI is equal to 1 when all patches are circular (for polygons) or square for raster (grids) and it increases with increasing patch shape irregularity	Class level	[45,50]
PAFRAC	Perimeter- area Fractal Dimension	It indicates the relationship between the area and perimeter of the patches	Landscape level	[45,51]
CONTAG	Contagion (%)	CONTAG is widely used in landscape ecology, it measures both patch type interspersion (e.g., the intermixing of units of different patch types) as well as patch dispersion (e.g., the spatial distribution of a patch type) at the landscape level. It indicates the aggregation of patches.	Landscape level	[48,52,53]
AI	Aggregation Index	Calculates the like adjacencies of different pairs of patch types involving the focal class	Landscape level	[47,54]
LPI	Largest Patch Index (%)	Percentage of the landscape comprised by the largest patch of the corresponding LULC class	Landscape level	[55]
MSI	Mean Shape Index	MSI equals the sum of the patch perimeter (m) divided by the square root of patch area (m^2) for each patch of the corresponding patch type, adjusted by a constant to adjust for a circular standard (vector) or square standard (raster), divided by the number of patches of the same type; in other words, MSI equals the average shape index (SHAPE) of patches of the corresponding patch type	Landscape level	[45,51]

5. Results

5.1. Land Use and Land Cover Change Dynamics

The LULC classification from the five classes across four time periods indicate the conversion of forest and grassland/barren lands to mixed agriculture and built-up areas (Table 4 and Figure 2). The dominant land use/land cover that increased progressively over the study period was mixed agricultural land and built-up areas. For example, cultivated land increased by 14% from 2003 to 2010, while built-up areas increased by 100% in the same period. On the contrary, forest cover decreased by 8% from 2003 to 2010 and 5% from 2010 to 2015. Grassland/barren lands were also reduced by 94% from 1988 to 2015. In addition, grassland/barren land and forest lands were mainly converted to cultivated, built-up areas.

Table 4. LULC changes in the Baroro River Watershed from 1988 to 2015.

LULC Class	1988		2003		2010		2015		Cover Change between Periods (%)			
	Area (ha)	Shares	Area (ha)	Shares	Area (ha)	Shares	Area (ha)	Shares	(1988–2003)	(2003–2010)	(2010–2015)	(1988–2015)
Grassland/Barren land	117.93	0.01	0.00	0.00	3.32	0.00	7.27	0.00	−100	+100	+54	−94
Built-up area	0.00	0.00	0.00	0.00	279.26	0.01	502.03	0.03	0	+100	+44	+100
Forest area	13,596.88	0.71	14,137.35	0.74	13,034.50	0.68	12,454.41	0.65	+4	−8	−5	−8
Inland water	166.27	0.01	166.27	0.01	166.27	0.01	166.27	0.01	0	0	0	0
Mixed agriculture	5302.04	0.28	4879.50	0.25	5699.77	0.30	6053.14	0.32	−8	+14	+6	+14

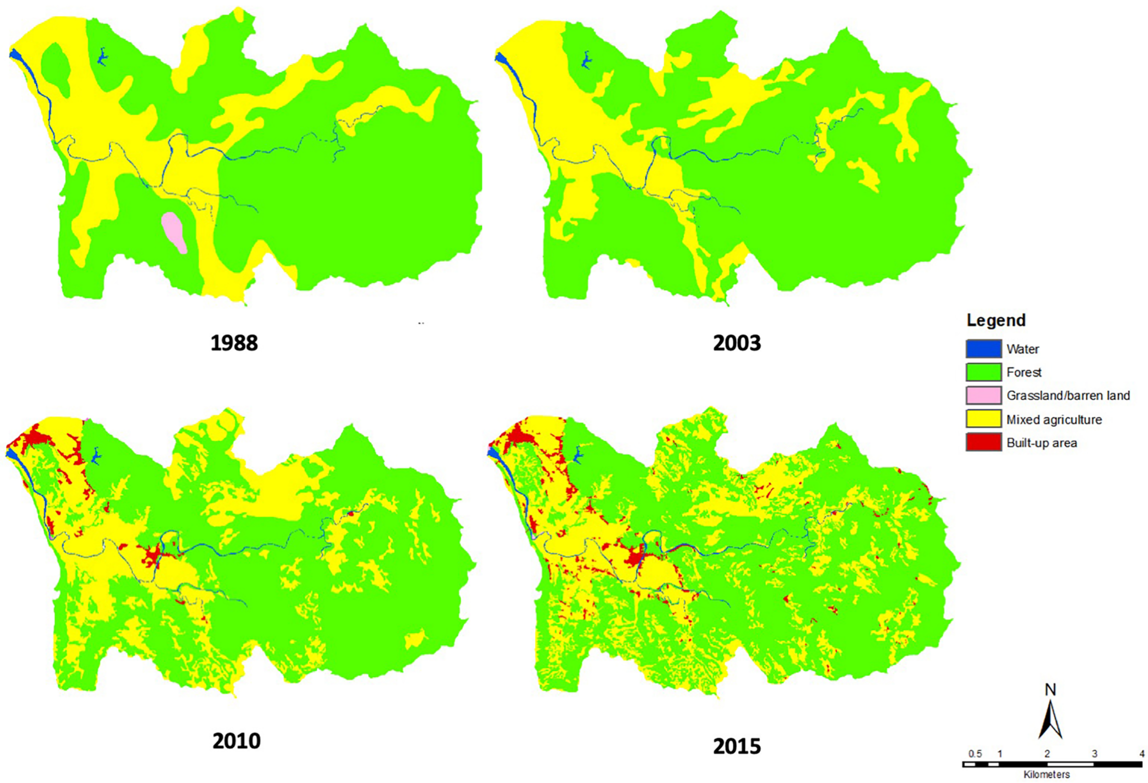


Figure 2. LULC maps for 1988, 2003, 2010 and 2015 in Baroro River Watershed, Northern Philippines (Source: NAMRIA).

Land use change detection is an important process in monitoring and managing land resources because it provides quantitative analysis of spatial variation of land use pattern [49]. As shown in Table 4, there has been a considerable change in land use during the 17-year period. In the upper part of Baroro River Watershed, forest was the dominant land use. However, results show that dense forest cover decreased by 8% during the study period, while mixed agriculture increased by 14%. Forest areas have been converted to cultivated and built-up areas with a remarkable increase of 100% (Figure 3).

Note that the official LULC 1998 and 2003 maps from NAMRIA did not include a category of built up areas. However, this particular category was included by NAMRIA in the 2010 and 2015 maps. Secondary documents and local interviews revealed that human activities such as increasing population and proliferation of farms in the study area occurred from 1998 to 2003.

From 1998 to 2003, forest cover registered a significant increase, which government and other sectors attribute to regrowth vegetation, plantations established through reforestation projects, and spontaneous tree growing activities on public and private lands [56]. Correspondingly, the area for mixed agriculture also decreased as a direct effect of these efforts.

5.2. Landscape Fragmentation: Spatial Metrics at Landscape Level

Landscape metrics are used to determine structure and quantify changes in the configuration of a landscape [57]. Also, landscape metrics are discrete and static quantitative indicators of landscape [54]. Spatial metrics applied at landscape level were used in this study to measure the graininess of the landscape (e.g., the tendency of the landscape to exhibit fine versus coarse-grain texture). Metrics in Table 5 help determine the structure and fragmentation of land use/land cover of the Baroro River Watershed landscape, and all mosaic structures and related information were obtained in conjunction with GIS and FRAGSTATS.

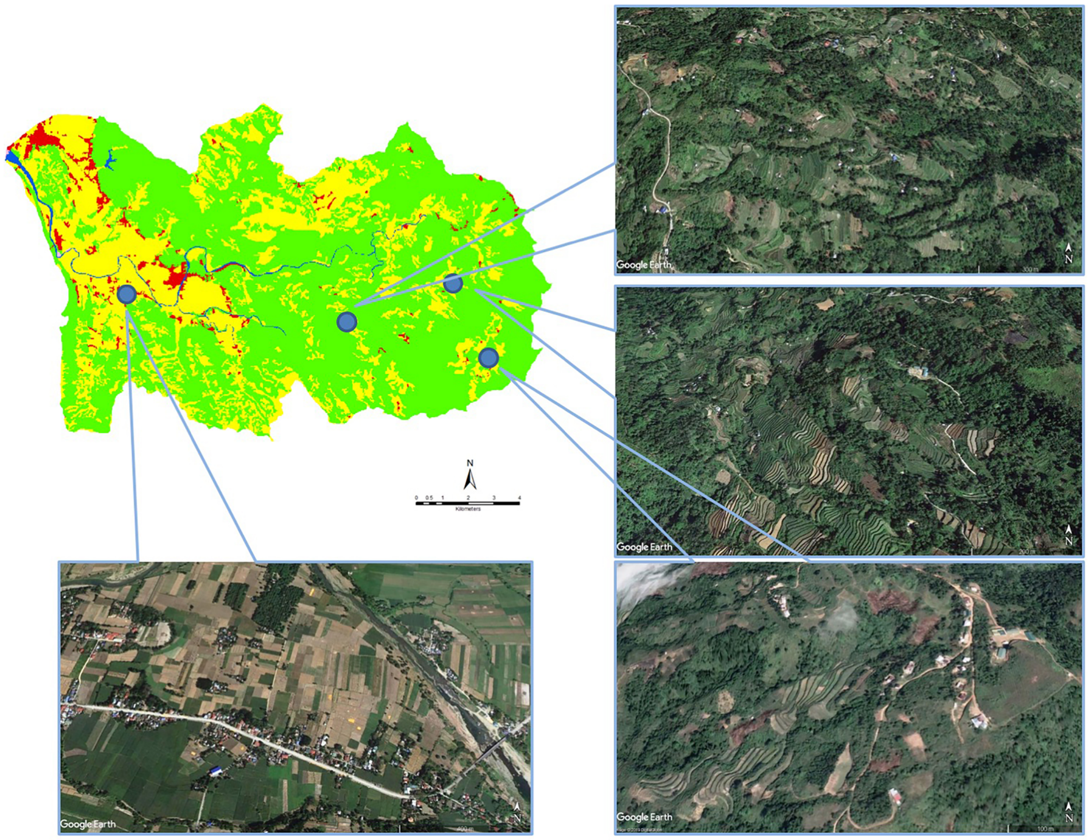


Figure 3. Cultivated and built-up areas in the upper, middle and lower part of Baroro Watershed, La Union (Source: Google Earth Pro).

Table 5. Spatial metrics change at landscape level in Baroro River Watershed. Between four time periods.

Metrics	1988	2003	2010	2015
Number of patches (NP)	101	120	384	786
Mean patch size (MPS; ha)	189.93	159.86	49.96	24.41
Edge density (ED; (m/ha)	11.58	15.34	50.68	75.96
Area-weighted Mean Shape Index (AWMSI)	3.46	4.95	6.96	9.85
Perimeter-area Fractal Dimension (PARFAC)	1.31	1.33	1.39	1.45
Contagion (CONTAG)	74.72	70.44	63.41	61.36
Aggregation Index (AI)	98.22	97.70	92.42	88.64
Largest Patch Index (LPI)	46.90	64.95	17.82	23.44
Mean Shape Index (MSI)	1.85	1.89	1.97	1.87

The spatial metrics at landscape level showed significant changes between four time periods (Table 5 and Figure 4). The number of patches increased from 101 in 1988 to 786 in 2015, and the mean patch size declined from 189.93 to 24.41, indicating that the landscape is dominated by small patches. This is supported by the area weighted mean shape index (AWMSI), where the value increased from 1988 to 2015, indicating an augmentation of the non-regularity of patches in the watershed. The ED increased significantly from 2003 to 2010 and may be a result of the rapid increase of NP during this period. The PAFRAC value continued to increase during the period and approached the critical status of 1.5, suggesting a decrease in the stability of the land use/land cover structure of the Baroro River Watershed landscape. The CONTAG analysis showed a series of decreasing values.

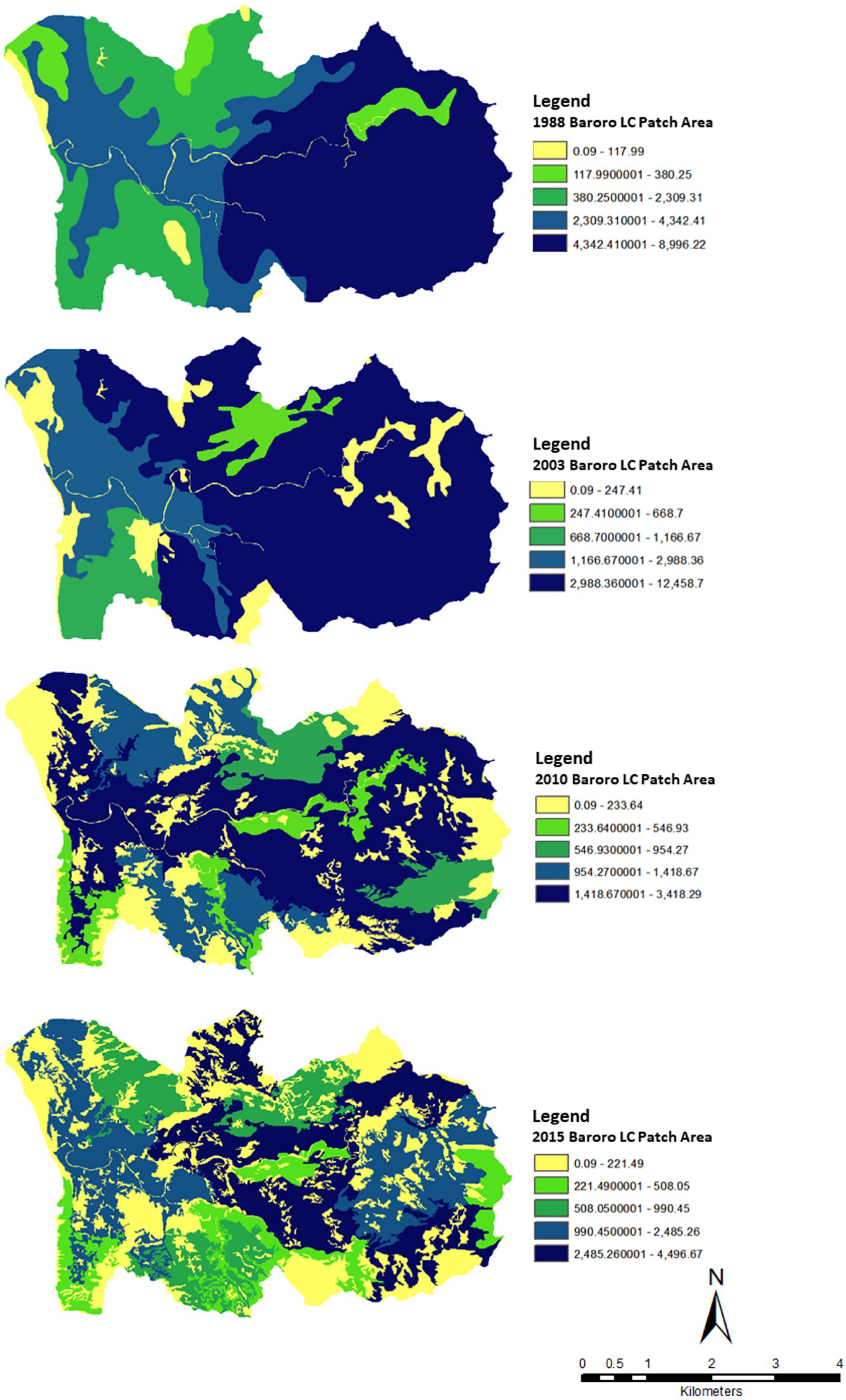


Figure 4. Patch maps of Baroro River Watershed in 1988, 2003, 2010, and 2015.

The results of landscape metrics show that several small forests were removed between 1988 and 2015 resulting in reduced patches and sizes. The agricultural expansion in Baroro River Watershed and conversion of forestland into different land uses during the last two decades led to fragmentation of contiguous forests affecting the watershed landscape.

5.3. Landscape Fragmentation: Spatial Metrics at Class Level

Changes in landscape metrics at class level between four time periods are presented in Table 6. There have been changes in the size, number, and spatial distribution of fragments, with different patterns for different land uses at class level. Landscape fragmentation in the upper portion of the Baroro River Watershed increased and encroached in the natural forest cover through agricultural expansion and deforestation. The forest cover is highly dynamic in patch type. Forest area is the patch type with the largest class area (CA). The total landscape area decreased from 71% (13,595.49 ha) to 65% (12,453.48 ha), while the patch number increased from 9 to 214. The mean patch size (MPS) also drastically decreased from 1510 in 1988 to 55 in 2015 for the dense forest. The increase in number of forest patches as well as decrease in mean patch size indicate that forest cover in the watershed has been fragmented. Several forest patches have also been converted into numerous small patches and isolated in recent years. AWMSI showed changes for forest type class, indicating an increase in the shape complexity and fragmentation.

Table 6. Spatial metrics change at the class level in the Baroro River Watershed between four time periods.

Year	CA (ha)	NP	ED (m/ha)	TE (m)	MPS (ha)	AWMSI	MSI	MPAR
1988								
Grassland/Barren	117.99	1	0.31	6000	117.99	1.37	1.37	50.85
Built-up area	0.00	0	0.00	0	0.00	0.00	0.00	0.00
Forest	13,595.49	9	8.04	154,230	1510.61	2.79	1.91	260.71
Mixed agriculture	5305.23	10	9.99	191,730	452.50	3.88	2.10	500.04
Water	164.25	81	4.82	92,520	2.03	4.41	1.82	997.61
2003								
Grassland/Barren	0.00	0	0.00	0	0.00	0.00	0.00	0.00
Built-up area	0.00	0	0.00	0	0.00	0.00	0.00	0.00
Forest	14,138.01	16	13.14	252,060	1139.11	3.34	2.09	509.53
Mixed agriculture	4880.70	23	12.71	243,840	158.68	3.43	2.05	412.96
Water	164.25	81	4.82	92,520	2.03	4.41	1.82	997.61
2010								
Grassland/Barren	3.51	3	0.07	1,320	1.17	1.28	1.27	569.72
Built-up area	280.62	24	3.17	60,840	11.69	2.82	1.89	370.03
Forest	13,031.10	170	61.17	1,173,390	52.45	4.81	1.89	2290.48
Mixed agriculture	5703.48	106	32.13	616,290	28.62	3.98	1.94	970.68
Water	164.25	81	4.82	92,520	2.03	4.41	1.82	997.61
2015								
Grassland/Barren	7.29	4	0.13	2580	1.82	1.52	1.44	545.82
Built-up area	500.31	192	9.36	179,640	2.61	2.38	1.51	663.23
Forest	12453.48	214	78.54	1,506,750	55.34	5.26	2.00	463.17
Mixed agriculture	6059.34	295	59.02	1,132,260	12.09	5.69	1.76	456.43
Water	164.25	81	4.86	93,270	2.03	4.41	1.82	997.61

Agricultural land is one of the important land use classes in the watershed and plays an important role in fragmentation of the natural forest. During the study period, agricultural land increased from 5305.23 ha (28%) in 1988 to 6059.34 ha (32%) in 2015. The number of patches (NP), edge density (ED), total edge (TE), and area-weighted mean shape index (AWMSI) increased progressively over time with the exception of the mean patch size, which showed the reverse pattern. This suggests that mixed agriculture patches have become more complex and been broken into small sizes.

5.4. Ecosystem Services at Spatial and Temporal Scales

Examining the land use history of the Baroro River Watershed requires going back to past events that led to its current condition. These events may explain why watershed landscape fragmentation occurred and what ES were affected by changes in the land use and forest cover. To do this, three villages were selected to represent the cross-section of the watershed and accurately describe the connectivity of each section in the context of a watershed landscape. Barangay Lon-Oy depicts past and current situation in the upstream watershed section, Barangay Cabaroan for the midstream section, and Barangay Baroro for the downstream section. A timeline was established and divided according to decades corresponding to fragmentation maps. These were then used to gather temporal knowledge from the local people about the history and uses of the Baroro River Watershed.

5.4.1. Upstream Section or Headwater in Barangay Lon-Oy, San Gabriel

The earliest inhabitant arrived in Barangay Lon-Oy from the neighboring province of Benguet in the early 1920s to search for areas suitable for *kaingin* or swidden farming. Stories passed orally to the next generation of Kankanaeys describe the watershed area as being covered with lush green forest, with around 90% forest cover until the 1940s. Inside the watershed were river and streams with clear water used by Kankanaeys for drinking and cooking. The FGD participants shared that the clean and steady flow of water came from the thick forest where wildlife of numerous species still existed, with some being hunted for food such as wild boars (*Sus philippensis*) and wild deer (*Rusa marianna*); see Table 7). Different kinds of fish abounded in the rivers such as eel (*Anguilla marmorata*), crabs (*Brachyura spp*.) and *ipon* or largesnout goby (*Awaous melanocephalus*), an endemic species in the Baroro River Watershed. Houses were made from bamboo (*Bambusa vulgaris*) and other grasses sourced from the forest and nearby areas, and there was no need to cut trees for timber. Settlers used to survive by eating root crops such as taro (*Dioscorea alata*) and cassava (*Manihot esculenta*) harvested from *kaingin* farms, and rice from paddies. The soil back then was described as very productive since there were limited number of farms for few families and crops were only for household consumption. Kankanaeys used caves as burial grounds based on their belief system. The microclimate was generally cool throughout the year.

The forest cover started to decline in the 1980s, from the 90% in the 1940s to an estimate of 60% in the 1980s. This was attributed to the increasing number of families living inside the village. Water became polluted at this time, particularly due to use of chemical fertilizers and pesticides up to a point that it was not safe for drinking. Some farmers began to use a 60/40 ratio of organic to chemical fertilizer as the soil was not that productive. Still, food was sufficient and rice terraces were a familiar sight in the area. As population increased, so did the houses constructed using wood as primary material. Timber became for sale and trees from the forest such as narra (*Pterocarpus indicus*), red lauan (*Shorea negrosensis*), and yakal (*Shorea astylosa*) were cut moderately. There was an increase in hunting activities to support the growing number of families, thus the number of wildlife species began to go down. Caves were replaced by cemeteries as permanent burial place. The weather became hotter and drought was experienced by the people for the first time.

In the 2000s, people in Lon-Oy observed that the forest cover in the watershed started to increase, but this was not due to a natural occurrence. The government led reforestation activities using exotic species such as gmelina (*Gmelina arborea*), narra (*Pterocarpus indicus*), and mahogany (*Swietenia macrophylla*). Despite this effort, the volume of water flowing from the river was declining, especially during summer. The ratio of organic to chemical fertilizer used by farmers was recorded at 50/50 based on the estimates of the FGD respondents. Village officials also prohibited the cutting of dipterocarps during this period and encouraged families to plant fruit trees such as marang (*Artocarpus odoratissimus*), jackfruit (*Artocarpus heterophyllus*), guyabano (*Anona muricate*), and rambutan (*Nephelium lappaceum*). The number of wild animals waned as wild boar (*Sus philippensis*) and deer (*Rusa marianna*) were not sighted anymore. According to the respondents, the microclimate was hotter preventing them from using their beddings at night. Typhoons became stronger with increased gustiness that damaged roads and the mini-hydro plant in the village.

Table 7. Status of ecosystem services through time in Barangay Lon-Oy, San Gabriel, La Union (Upstream/Headwaters).

Ecosystem Services	1940s	1980s	2000s	2010s
Freshwater production	• 90% forest cover • Water was crystal clean • Strong but steady flow in rivers and streams • Safe and potable	• 60% forest cover • Increased number of *kaingin* farms • Water flowing from the river was not potable due to pollution • Cases of poisoned animals from drinking water in the river	• Increasing forest cover due to reforestation activities of the government and individual efforts to plant gmelina (*Gmelina arborea*), Mahogany (*Swietenia macrophylla*), and narra (*Pterocarpus indicus*) • Number of farms still increasing • Declining water quantity flowing from the river;	• Increasing forest cover due to reforestation through the National Greening Program (NGP) and other private initiatives (i.e., Holcim) • Through NGP, fruit trees were planted inside the forest using coffee (*Coffea arabica*), rambutan (*Nephelium lappaceum*), guyabano (*Anona muricate*), and lanzones (*Lansium domesticum*) • Decreasing volume of water in the river • Decreasing water quality (i.e., brownish in color) • Presence of algae in the river
Food, fiber, and raw materials	• People hunt and forage for food • Bamboo (*Bambusa vulgaris*) and giant ferns (*Diplazium esculentum*) abound and used for house construction • Root crops as food sources such as ube (*Dioscorea alata*), carrot (*Daucus carota*), and cassava (*Manihot esculenta*) • Timber harvesting was limited	• Naturally growing trees for house construction, *i.e.*, narra (*Pterocarpus indicus*), red lauan (*Shorea negrosensis*), and yakal (*Shorea astylosa*) • Harvesting of timber for sale • Depleting food sources (i.e., wild animals) forcing increased hunting activities • Declining number of bamboos, giant ferns, and timber • Food remained sufficient	• Timber harvesting was prohibited • Naturally growing trees was confined to upper slopes • Pioneer tree species such as marang (*Artocarpus odoratissimus*), langka (*Artocarpus heterophyllus*), guyabano (*Anona muricat*), and rambutan (*Nephelium lappaceum*) occupied the forest	• Houses were made of concrete, hence, limited use of timber/trees • Increase number of farmers into livestock raising • Bamboo (*Bambusa vulgaris*) and rattan (*Calamus manan canes*) started to decline in numbers

Table 7. *Cont.*

Ecosystem Services	1940s	1980s	2000s	2010s
Maintenance of biodiversity	• Many species of fish were abundant in rivers, i.e., *ipon* (*Awaous melanocephalus* juvenile stage), *bunog* (*Awaous melanocephalus* adult stage), eel (*Anguilla marmorata*), lobster (*Nephropidae spp.*), and crab (*Brachyura spp.*) • Wild boars (*Sus philippensis*), deer (*Rusa marianna*), monitor lizard (*Varanus indicus*), monkey (*Macaca fascicularis*), and wild cat (*Felis silvestris*) to name a few were abundant in the forest with presence of a wild range of birds	• Wild deer (*Rusa marianna*) was already non-existent • There were monitor lizards (*Varanus indicus*) sighted • Exotic species of trees not yet planted in the forest • Declining number of birds were observed • Harvest of *ipon* (*Awaous melanocephalus* juvenile stage) started to decline	• Practice of planting exotic tree species • No more sightings of deer (*Rusa marianna*), wild boar (*Sus philippensis*) in the forest • Number of monitor lizard (*Varanus indicus*) and birds started to decline • Increased number of sighting of heron (*Nycticorax nycticorax*)	• No more sightings of deer (*Rusa marianna*), wild boar (*Sus philippensis*) in the forest suggesting that they are now extinct • Continuous practice of planting exotic species and fruit trees
Cultural services	• Caves used by local people as burial sites • With traditional system of naming typhoons	• Cemetery replaced caves as burial ground • Increased number of farmers practicing terracing of rice and other crops • Flowering of bamboo as signal that there is an impending drought	• Increasing number of farmers practicing terracing	• Farmers started to go back to *tabas* system of composting
Microclimate	• Microclimate remained cool even in summertime • Intensity of rain was not heavy	• Temperature started to rise • Case of moderate drought observed every 10 years	• Temperature even during dawn started to get hot; (people were not using beddings and jackets at night) • Experienced strong typhoons and winds as compared in the past (i.e., Typhoon Ondoy, Pepeng, Perya) that damaged the community's mini-hydro plants and roads	• Erratic weather is the new normal

The situation worsened during the decade following 2010. While forest cover was described by local people as improving due to additional reforestation efforts by the government and the private sector such as Holcim, a cement manufacturing company in the Philippines, water volume continued to decline and its quality worsened as algal bloom was observed in some portions of the river. Diet of the people was completely replaced by livestock as boar and other wild animals cannot be found in the forest. Weather continued to be erratic and temperature soared.

5.4.2. Midstream Section in Barangay Cabaroan, San Juan

The same as with Lon-Oy, the forest cover in Barangay Cabaroan was estimated to be at 90–95% in the 1940s (see Table 8). Water in the river was used for drinking and irrigation purposes; while different species of fish thrived due to high quality and volume. Rice farming was still limited and that the soil was described as very productive. If needed, farmers used carabao manure as fertilizer. Diet was composed of fish, vegetables, and meat—some coming from animals in the wild such as frogs (*Fejervarya limnocharis*) and wild chicken (*Gallus gallus domesticus*). Houses were made of bamboos and only branches of trees were cut for fuel wood. Several varieties of timber and fruit trees abound in the area such as duhat (*Syzygium cumini*), guava (*Psidium guajava*), mabolo (*Diospyros blancoi*), and guyabano (*Anona muricate*) to name a few. People used to have a picnic near the river and freshwater can easily be dug from the soil. Climate was generally colder during this period.

Reduction in the forest cover from 95% to 70% in the 1980s was observed by the participants. The river was described as in good condition and can be used for drinking, though some portions were already contaminated from the use of chemicals upstream, which coincides with what happened in Barangay Lon-Oy during this period. Farmers started to build deep wells at a depth of 10 feet. As agriculture intensified, so did the use of chemical fertilizers, especially by wealthy farmers. It was also during the later years of this period when farmers were forced to use chemical pesticides as stem borers and grasshoppers attacked crops. People were increasingly relying on the market for food as commercial livestock were available and accessible. Decreasing number of fish and absence of wild animals for food explained the shift to other food sources in the village. While some benefits were not derived from the watershed, people still go to the river for recreation. This was also the period when the climate began to become hotter.

The next period saw a steep decline in forest or tree cover, as recalled by the respondents. Data showed a decline to 30% in 2000s from the previous 70% in the 1980s due to the increasing number of farms devoted to commercial agriculture. As all farmers were completely relying on chemical fertilizers and pesticides, water quality in the river further declined. In 2009, people started to buy bottled water for drinking. The period also saw an increase in output of charcoal making to support the tourism industry in the coastal areas of San Juan, resulting to more cutting of trees. There were lesser fish in the rivers and native trees were replaced by fruit trees. Picnic was not viable along the river as the quality of the surrounding areas became degraded. People started to use air-conditioning system to get them through summer.

There was no change in the forest/tree cover in 2010 and the succeeding years from the previous period. However, 90% of the population relied on bottled water for drinking, costing the household more money to survive. Some farmers began shifting to organic agriculture, however, majority of the farmers were not convinced that the soil can support crop production naturally. Demand for charcoal still exists but authorities regulated its sale to prevent further cutting of trees. This decade also saw extreme typhoons passing the area with stronger wind and rains such as typhoons Ondoy, Pepeng, Yolanda, and Egay.

Table 8. Status of ecosystem services through time in Barangay Cabaroan, San Juan, La Union (Midstream).

Ecosystem Services	1940s	1980s	2000s	2010s
Freshwater production	• 90–95% forest cover • Water from the river used for drinking • Clear and high water level in the river (average of 15 feet in depth) • Plenty of fish in the river and its tributaries	• 70% forest cover • Water in the river was already contaminated due to brownish cover, which people attributed to upstream activities • Water was potable • Construction of deep-wells for irrigation started (depth at 10 feet)	• 30% forest/tree cover • Some forests were converted into houses and agricultural farms • Water from the river was not potable • Frequent flooding • Increased number of households in the area • Some households constructed septic tanks to prevent river pollution • Application of chlorine in deep wells to make the water potable; • In 2009, people started to buy drinking water; • Deep wells remained at a depth of 20 feet	• 30% forest cover (no change from previous decade) • Increasing number of people in the village, 90% of which drink mineral water • Low surface water level
Soil productivity	• Soil was productive without the need for inputs • Carabao manure as fertilizer • Limited number of *kaingin*	• Farmers who had enough capital already used chemical fertilizers as the soil cannot support production • Pests were a natural occurrence such as stem borer (*Scirpophaga incertulas*), grasshopper (*Caelifera spp*) • Two-cropping seasons rice (*Oryza sativa*) and corn (*Zea mays*), peanut (*Arachis hypogaea*); due to chemical inputs • Increasing number of farm lands	• Started to use chemical fertilizer in the 1990s • All farmers in the barangay already used chemical fertilizers • Three cropping cycles for rice (*Oryza sativa*) and corn (*Zea mays*) can be supported by chemical fertilizers	• Some farmers practiced organic farming due to high price of produce in the market • Continuous use of chemical fertilizers

Table 8. *Cont.*

Ecosystem Services	1940s	1980s	2000s	2010s
Food, fiber, and raw materials	• People were dependent on fish and wild animals for food • No cutting of trees as bamboos (*Bambusa vulgaris*) and grasses were used for house construction • Vegetables were plenty such as sitaw (*Vigna unguiculata ssp. sesquipedalis*), talong (*Solanum melongena*), upo (*Lagenaria siceraria*), and kangkong (*Ipomoea aquatica*) • Presence of wild frogs (*Fejervarya limnocharis*), snakes (*Boiga cynodont*), and chicken (*Gallus gallus domesticus);*	• Food from wild animals and fish declined • Forest vegetation thick with bamboos (*Bambusa vulgaris*)	• Cutting of trees for charcoal making • No more wild animals and fish	• Charcoal making regulated by the local government • No more wild animals and fish
Maintenance of biodiversity	• Fish and other water species were abundant, i.e., dalag (Channa striata), hito (Clarias batrachus), carpa (Cyprinus carpio), ipon (Awaous melanocephalus juvenile stage), eel (Anguilla marmorata), tilapia (Oreochromis niloticus), sugpo (Penaeus monodon), talangka (Synchiropus spp.), bunog (Awaous melanocephalus adult stage), kampa (Rhiyacichthys aspro), shells (bukkukao), and suso (Lymnaeidae and Ampullariidae spp.) • Wild fauna: carabao (Bubalus bubalis carabanesis), sheep (Ovis aries), chicken (Gallus domesticus), wild pig (Sus philippensis), monkey (Macaca fascicularis), usa (Rusa marianna), bayawak (Varanus indicus), bird, and snake (Boiga cynodon) • Horses were used for transportation via karitela • Fruit trees abound: guava (Psidium guajava), duhat (Syzygium cumini), narra (Pterocarpus indicus), molawin (Vitex parviflora), mabolo (Diospyros blancoi), sineguelas (Spondias purpurea), guyabano (Anona muricate), anonas (Annona reticulata), atis (Annona squamosa), kamachile (Pithecellobium dulce), and aratilis (Muntingia calabura)	• Declining number of fish in the river such as hito (*Clarias batrachus*), eel (*Anguilla marmorata*), and ipon (*Awaous melanocephalus* juvenile stage) • No more carps in the river • Wild animals such as wild boar (*Sus philippensis*), deer (*Rusa marianna*), and monkeys (*Macaca fascicularis*) were already non-existent • Monitor lizard (*Varanus indicus*) became lesser in numbers • Mabolo (*Diospyros blancoi*), kaimito (*Chrysophyllum caimito*), and atis (*Annona squamosa*) were lesser in number	• Much lesser in number and kinds of fish caught in the river (composition and distribution of macroinvertebrate communities • Same situation in for vegetation, specifically forest trees: narra (*Pterocarpus indicus*) and fruit bearing trees such as guava (*Psidium guajava*)	• Same condition during the previous decade

Table 8. *Cont.*

Ecosystem Services	1940s	1980s	2000s	2010s
Cultural services	• People used to go to the river for family gatherings/picnics • They just dig the soil to get freshwater	• People regularly schedule picnics near the river; • People used "tambuli" or carabao horn to warn people of danger such as floods	• Lesser number of people doing picnics by the river due to pollution	• Recreation by the river was not an option due to pollution
Microclimate	• Fresh air was colder due to abundant trees • Flooding was observed near the Barangay Hall due to extraordinary intense rain	• Weather was hot • Flooding was experienced in 1976	• Much hotter climate than before • Some houses started to use air conditioning system • Experienced severe drought in 2009.	• Extreme typhoons were experienced, with stronger winds and more intense rains (*i.e.*, Typhoon Ondoy, Pepeng, Yolanda, Lando) • Hotter climate

5.4.3. Downstream Section in Barangay Baroro, Bacnotan

The present physical characteristic of Barangay Baroro at the downstream section of the watershed is completely different from its situation in the 1940s (see Table 9). Eighty percent (80%) of the area was said to be covered with trees as only 50 families were living in the village back then. Water quality in the river was clean and the volume was steady; making it ideal for different fish species to thrive. Open-dug wells were already existent during this period, but had shallow depths as compared now. While farmers used chemical fertilizers for rice (*Oryza sativa*), corn (*Zea mays*), tobacco (*Nicotiana tabacum L.*), and other crops, this was still at the 50/50 ratio. With the village near the ocean, presence of sea grass (*Enhalus spp*), seashells, and healthy coral reef abounded as households depended on the ocean for sustenance. Houses were made of natural materials such as bamboo (*Babusa vulgaris*) and *pawid (Nypa fruticans*). There were also several varieties of fruit-bearing trees as well as wild animals for hunting. *Ipon* (*Awaous melanocephalus*) was abundant during September to October. Respondents described the temperature to be cold and starts in the afternoon.

In the 1980s, tree cover started to decline due to increasing number of houses for 200 to 300 migrants coming from different parts of Ilocos Region. Water in the river was described as clean, but quality started to decline. The river's reach was getting wider and the depth became shallower. On the other hand, deep wells depths were recorded at 20 feet, indicating over abstraction of groundwater. Farmers were heavily relying on chemical fertilizers. As soil productivity worsened, the number of farmers in the village dropped to 14. Food was sourced from farms and market and not from the watershed. Enterprising individuals began putting fish pens in the river. The number of wildlife species for both flora and fauna, including fish, continued to decrease at an alarming rate. As a sign of declining supply, the price of *ipon* increased during this period. The weather started to become hotter. Storm surge was experienced in 1987.

Except for some patches of trees, forest cover was almost non-existent by 2000s. Houses increased to around 400 to 500, resulting in the establishment of subdivisions. The depth of deep wells remained at 20 feet, but there was absence of groundwater during summer. This convinced the local government to put up a communal potable water supply. Drinking water was sourced through refilling stations. River reach became wider, which was particularly dangerous to people living along the riverside especially during typhoon season due to flooding. With respect to occupation, some farmers shifted to other jobs in nearby municipalities. This period also saw an increase in the number of fish pens to 16. Unregulated harvesting resulted to decreasing number of fish species in the river and ocean, particular *ipon*. There were limited sightings of green viper (*Trimeresurus flavomaculatus*), monitor lizard (*Varanus indicus*), dolphin (*Orcaella brevirostris*), and tortoise *(Eretmochelys imbricata).*

Beginning in 2010, salt water intrusion was experienced due to overabstraction of water. This was brought about by pressure from a burgeoning population, which increased to 500–600 households composed mostly of foreigners. Due to this, water refilling stations proliferated. The water quality in the river worsened and became brownish in color. People were experiencing extreme weather events. A fish kill was recorded in 2017.

Table 9. Status of ecosystem services through time in Barangay Baroro, Bacnotan, La Union (Downstream).

Ecosystem Services	1940s	1980s	2000s	2010s
Freshwater production	• 80% forest/tree cover • Community was established in the 1920s • Original 50 households in the area • Water in the river and streams was crystal clean • Presence of open-dug wells • River reach was narrow	• Increasing number of houses due to the establishment of subdivisions • Increased number of households to around 200–300; composed of mostly migrants • Deep wells were 20 feet deep to abstract water; • River reach became wider and depth became shallower	• Households increasing to about 400 to 500 • Foreigners started to live in the area, drawn by its beaches • Communal Baroro Potable Water Supply was established to provide safe drinking water to households • Deep wells were 20 feet deep to abstract water; but no water during summer • River reach continued to become wider and depth became shallower	• Households now at 500–600 • Saltwater intrusion has been observed • Increasing number of water refilling stations • Water from the river becomes brown during rainy season
Soil productivity	• Limited number of farmers who planted corn (*Zea mays*), tobacco (*Nicotiana tabacum L.*), rice (*Oryza sativa*), and peanut (*Arachis spp*) • Some wealthy farmers using chemical fertilizers in the 1960s	• Heavy reliance on chemical fertilizers (100%) • Decreasing number of farmers due to land conversion	• Farmers shifted to other jobs as harvests continued to decline	
Food, fiber and raw materials	• Fish were plenty in rivers and ocean, *i.e.*, ipon (*Awaous melanocephalus* juvenile stage), tilapia (*Oreochromis niloticus*), and talaba (*Crassostrea iredalei*) • Presence of native spinach (*Talinum fruticosum*) • Availability of bamboo (*Bambusa vulgaris*) and pawid (*Nypa fruticans*) for house construction	• People became dependent on livestock. • Presence of fish pens with milkfish (*Chanos chanos*) and tilapia (*Oreochromis niloticus*) • Decrease in the number of fishes in the river • Houses were made of concrete • Ipon (*Awaous melanocephalus* juvenile stage) present in the river • Sea grass can be seen in coastal areas	• Fish were caught farther than before. • Fish pens increased in number • Sea grass started to disappear • Fish species same as the previous decade but numbers declined	• Same as the previous decade.

Table 9. *Cont.*

Ecosystem Services	1940s	1980s	2000s	2010s
Maintenance of biodiversity	• Healthy coral reefs • Presence of sea grass in coastal areas • Fora: lanete (*Wrightia pubescens*), anahaw (*Saribus rotundifolius*) camachile (*Pithecellobium dulce*), niyog (*Cocos nucifera*), acacia (*Samanea saman*), balete (*Ficus benjamina*), sampalok (*Tamarindus indica*), duhat (*Syzygium cumini*), mushroom, madre cacao (*Gliricidia sepium*), ipil (*Intsia bijuga*), yakal (*Shorea astylosa*), and narra (*Pterocarpus indicus*), • Fish species: hipon (*Fenneropenaeus chinensis*), ipon (*Awaous melanocephalus* juvenile stage), bongo (*Awaous melanocephalus* adult stage), padaw (*Perna viridis*), Prawn (*Penaeus semisulcatus*), aguas (*Planiliza macrolepis*), umok (shell), stringray (*Taeniura lymma*), imkadit (coral fish), octopus (*Octupos vulgaris*), dugong (*Dugong dugon*), and dolphin (*Orcaella brevirostris*) • Wild fauna: labuyo (*Gallus domesticus*), wild cat (*Felis silvestris*), bayawak (*Varanus indicus*), sawa (Phyton reticulatus), frog (*Fejervarya limnocharis*), and monkeys (*Macaca fascicularis*) • Abundance of ipon from September to December	• Declining number of wild animal/marine species, *i.e.*, monitor lizard (*Varanus indicus*), wild cat (*Felis silvestris*), snakes (*Boiga cynodon*), monkeys (*Macaca fascicularis*), dolphin (*Orcaella brevirostris*), and tortoise (*Eretmochelys imbricate*) • Declining catch from the ocean, i.e., octopus (*Octupos vulgaris*) • Stingray (*Taeniura lymma*) became low in number	• Dolphin (Orcaella brevirostris) and tortoise (Eretmochelys imbricate) disappeared • Declining number of monitor lizard (Varanus indicus), and green viper (Trimeresurus flavomaculatus) • Declining number of fish catch	• Decline in fish harvest and number of wildlife • Local government-initiated program to bring back the pawikan (*Eretmochelys imbricate*)
Cultural services	• None identified	• None identified	• None identified	• Floating restaurant was established in Baroro River Watershed
Microclimate	• Cold weather	• Local climate started to get warmer • Storm surge was experienced in 1987	• Strong typhoons and flooding in 1992	• Increasing number of storm surges • 2017 fish kill • Stronger typhoons

6. Discussion

Results of this study show the connection between local knowledge and land use metrics. The increasing number of patches (NP), decreasing mean patch size (MPS) as well as increasing edge density (ED) at the landscape level corresponded to the declining quality of ES. This includes loss of biodiversity, declining soil productivity, and deteriorating water supply as experienced by people living inside the watershed over four time periods being studied. Conversion of previously vegetated land use to agriculture and built up areas continues up to the present, which contributed to the near critical status of the watershed; specifically approaching the PARFAC of 1.5 and stood at 1.45 in 2015. This implies that the stability of the land use/land cover of the Baroro River Watershed is continuously declining.

In addition, the number of agricultural patches increased and the mean patch size decreased over time. This indicates that more farms have encroached in the watershed and affected the general flow of ES. Changes in the landscape metrics over time can also be explained by the economic growth within the watershed, particularly in the middle and lower portions as it became urbanized.

The relationship between local knowledge and scientific data was distinctly manifested in the upstream section of the Baroro River Watershed. The communities within are more proximate to the forest and the people benefit from the various ES that the watershed provides on a daily basis. On the other hand. people from the middle and lower portions of the watershed benefit from specific ES such as water for irrigation and soil fertility for crop production; as these are the most visible services valued [2,58]. They do not recognize other ES such as maintenance of biodiversity and regulation of microclimate unlike those living in the upstream section. This is due to the fact that the people in both midstream and downstream areas have more opportunities at their disposal. They can easily get food from the market unlike those living in the upstream who rely on forests and wildlife for sustenance. Thus, knowledge about a certain ES also depends on the location, access to resources, and socioeconomic status [17]. Historically, the conversion of forests to agricultural farms far outweighed the benefits that the watershed can provide since the value of ES coming from the watershed are less obvious and did not readily translate into monetary terms. This became the primary driver of land use conversion in the Baroro River Watershed.

Moreover, the loss of forest or tree cover in the middle section of the watershed as well as in the downstream communities coincides with the loss of knowledge about the ES from the watershed. An exception to this case are flooding and other natural disasters as people can easily relate to these adverse conditions, particularly in the upper watershed. When people experience the benefits or impacts of certain ES, they tend to put more value to a particular ES.

Tapping into this inherent knowledge may translate local knowledge into actions necessary to rehabilitate the Baroro River Watershed. Particularly, interventions to reconnect the different landscape fragments to regain what was lost in terms of species richness and other indicators of watershed health can be planned. As majority of the present generation has no recollection of what transpired in the past in terms of forest cover and landscape, which led to the current condition of the watershed, providing orientation or guidance on the benefits that one can derive from the watershed is of primary importance. In this manner, the communities can learn the importance of nature and value of the ES that it provides.

Nevertheless, the landscape fragmentation in the Baroro River Watershed did not only result from the breaking down of the watershed into patches, but also from a confluence of other factors such as fragmented governance, piecemeal policies, and unsustainable land management in the past. Lack of coordination, particularly among LGUs and community members on appropriate land uses in the watershed, has led to its current state. There was also lack of communication between national government agencies responsible for forestry and agriculture on how to manage the watershed landscape due to its varying and often overlapping mandates; as well as policies that were dysfunctional and not appropriate on the ground. This was evidenced by the increasing area of agriculture over time, particularly on inorganic farming and resulting to encroachment on forestlands. Also, as majority of the population in the watershed are migrants, land practices of indigenous groups are slowly becoming obsolete.

In addition, local knowledge about the ES in the watershed was evident from the results of the study's FGDs, KIIs, and fragmentation analyses. Due to increased awareness based on the study's results, there was a collective effort from the three LGUs to halt landscape fragmentation by initiating action to declare the Baroro River Watershed as a protected area. At this point, reconnection of fragments will start at the institutional level.

Lastly, this study showed that local knowledge on the history of land use in the watershed and the use of land use metrics provide complementary information in understanding the causes of fragmentation and its impacts to certain ES. Local people identified not only changes in the environment but also the time frame when these changes happened and its effect on livelihood. Land use metrics are therefore important inputs that can be used by decision makers to justify initiatives or plans, while local knowledge on ES can provide entry points for various initiatives on both watershed landscape rehabilitation and biodiversity conservation.

7. Conclusions

The current research is a preliminary attempt to establish a link between watershed landscape fragmentation and ES by integrating science and local knowledge as methods of analysis. Results provide scientific basis that the increasing fragmentation of the Baroro River Watershed highly compromised the condition of certain ES due to loss of ecosystem functions. This adds to the understanding of the relationship between watershed landscape fragmentation and its effects on the delivery of ES in the watershed, particularly in the tropics where similar studies are scant.

From 1940s to 2015, the forests of the Baroro River Watershed were lost to the expansion of agriculture and built up areas, and mostly evident in the middle and lower sections of the watershed based on land use metrics. Local knowledge from people living within the watershed confirmed this finding as they experienced the adverse impacts of land use conversion and watershed fragmentation through declining water supply, loss of biodiversity, incidence of pests and diseases, cases of floods and droughts, and worsening micro-climate. Reversing these conditions, however, requires more detailed studies on ecosystem functions as time delays govern the changes in ES [14].

Given the increasing number of fragments in the watershed landscape, it is seemingly a daunting task to attain a contiguous and intact forest of 50,000 hectares in the near future; which is said to be the minimum requirement to ensure that watershed landscape and ecosystems are properly functioning [59,60]. For one, this will entail the rehabilitation of the entire Baroro River Watershed and adjacent watersheds to satisfy the area requirement. Understanding the dynamics of small patches is therefore of critical importance as it provides ES such as water quality regulation and carbon storage.

At the watershed level, "reconnecting" these fragments would allow for an increase in area where biodiversity can thrive and re-populate, creating biodiversity corridors. While local governments, farmers, and the private sector have already initiated reforestation initiatives in Baroro River Watershed, these efforts should be deliberately targeted to connect fragments and reduce edge effects. One possible solution is to have an integrated watershed landscape management plan anchored on the management of these fragments and with primary focus on sustainable land uses that address both the environment and social requirements towards a healthy watershed. To this end, the study proponents suggest the use of landscape metrics and historical land use analysis as framework for watershed management planning to help adequately explain the historical land use pattern and anticipate future impacts brought about by time lags in ES supply.

Fragmentation does not only happen at the biophysical level but also at the governance, policy, and management levels. It is not only a result of increasing population but rather of other factors such as uncoordinated watershed management between local governments and national government agencies, unsustainable land use policies and lack of awareness of stakeholders vis-à-vis the situation of the Baroro River Watershed that happened in the past. Similar with other watersheds in the country, the governance in the study area started when problems on increasing fragmentation and deforestation manifested itself through decreasing flow of ES readily felt by people. While actions had been taken by the national government, particularly the local DENR office and the communities upstream to plant trees, efforts to manage the development of midstream and downstream areas were neglected due to lack of coordinated planning. In most cases and not just in the Philippines but also in other tropical countries, forests are the main casualties of development. The challenge now is how to avert the further fragmentation of the watershed to ensure that ES will remain intact for future generations.

Results from this study posit that reconnection can happen by first addressing these institutional issues in the watershed. This is beginning to take shape in the Baroro River Watershed as different actors have realized that past actions contributed to the fragmentation of the watershed, and that they can manage their natural resources to arrest the declining levels of ES.

In addition, this proposed framework would also create social and institutional corridors that will tap existing resources coming from the different stakeholders in the watershed landscape. In this context, local knowledge on watershed resources and ES can be used as entry points for the process as well as in effectively crafting incentives and disincentives through policies at the local level. Determining the current appreciation of the various stakeholders of the watershed functions would help in crafting effective education campaign, especially among the younger generation, especially those who are seemingly detached from the natural environment.

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