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The Impact of Soil and Water Conservation Measures on Base Flow Modification in the Northeastern Highland of Ethiopia

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Abstract: Severe land degradation is the principal environmental problem in Ethiopian highlands in the form of soil erosion, and soil fertility loss, which is caused by human intervention for food, shelter, and energy demands. Soil erosion contributes to the loss of precious soil and water resources which are the basis of agricultural production and provide numerous other ecosystem services. The Ethiopian highlands are one of the most degraded regions in the world. To combat such problems, the government of Ethiopia has been implementing massive soil and water conservation works at the watershed scale since 2010 to conserve soil and water resources. Mount Yewel is one of the highlands in Northeastern Ethiopia where intensive soil and water conservation has been implemented. Despite the massive investment in soil and water conservation measures, most of the rivers in the highlands of Ethiopia carry huge amounts of sediment with high flood risks in the wet season and streams are dried up in the dry period. Nonetheless, the impact of soil and water conservation measures on flood reduction and dry season flow enhancement has not yet been quantified and evaluated. This research was then conducted on paired micro-catchments of Mount Yewel with the main objective of evaluating the impact of soil and water conservation measures on base flow modification. Stream flow and rainfall data were collected from 22/11/2020 to 8/11/2022 on paired micro-catchments of Mount Yewel at their outlets and centers respectively. Base flow separation was done from the stream hydrograph using Sp. Hydro base flow separation tool and SPSS Ver.21 statistical software were employed for data analysis. Flow duration curves (FDC) for both watersheds were developed to compare the stream flow patterns between treated and untreated micro-catchments of Mount Yewel. The FDC indicated that the base flow from treated micro-catchment is higher and sustained in the dry season while it is low and unsustained in untreated micro-catchment. From statistical analysis, there is a significant ($P<0.001$) difference in base flow enhancement between the treated and untreated micro-catchment. Hence, catchment treatment contributed to improving groundwater recharge and sustaining base flow in the dry season by reducing surface runoff during the rainy season and improved recharge. Implemented SWC measures (soil bunds, stone-faced soil bunds, check dams) positively affected the dry season base pattern and negatively influenced wet season base flow. Hence, it can be concluded that catchment treatment is a good strategy to convert rainfall to groundwater reserves and sustain dry season flow for further use in times of water shortage.

Keywords: soil and water conservation; micro-catchments; base flow

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1. Introduction

Severe land degradation is the principal environmental problem globally including in the most developed countries like USA and Chi [1–5] which is caused by human intervention for food, shelter, and energy demands [6,7,9]. Land degradation leads to the loss of fertile soil, water, and forest at an alarming rate [5,15–17] and has become one of the major constraints for future growth and development. Soil erosion contributes to the loss of precious soil resources [8–10] that are the basis of agricultural production and provide numerous other ecosystem services. Anthropogenic activities such as intensive and uncontrolled grazing, deforestation and burning of biomass, and intensive cultivation are the main factors that trigger soil erosion that limits rainfed crop production [2,20].

The Ethiopian highlands are one of the most degraded regions in the world [1,2,4,11–13,18,19]. Soil erosion is a major issue in most of the watersheds located in northern and Northeastern Ethiopia highlands due to its topographic complexity, insufficient land cover, inappropriate land uses, poor land management techniques, and high rainfall variability [22]. The erosion pattern in the watersheds is highly dependent on the land-cover dynamics [23]. Soil erosion by water is the most common type of soil erosion in Ethiopian highlands [9,20] which is more aggravated by slope steepness, climate change, mineral mining types of cultivation practice, and overgrazing [3,24,25] that make the soil less productive [20,24,26]. Today almost all rainfed farmlands are cultivated using old, traditional, and primitive soil, water, and crop management practices [21] that lead to severe land degradation. Hence, rainfed agriculture in the highlands of Ethiopia faced multidimensional problems. The most important problem of rainfed agriculture is moisture deficits and water availability [28].

Water deficit being the biggest limiting [29] and the greatest challenging [30] factor for sustainable agricultural development in Ethiopia, it is a crucial issue in areas prone to droughts. Recurrent drought occurring at about three three-year return intervals [27] associated with land degradation is the root cause for the drying up of stream base flows in the dry period. Such conditions are more common in the highlands of Northeastern Ethiopia where the annual rainfall amount is sufficient for crop production [6] but the distribution is spatially variable and unpredictable [31]. The Erratic nature of the Rainfall, its variability spatially and temporally, and extreme events such as drought and flood due to climate change affected the availability of water in the dry season [13]. Drought limits the dry period availability of water [32] in the vicinity making the highlands farmers travel long distances to fetch water for different purposes.

Irrigation is a major solution to reduce moisture deficit problems in Ethiopia. Irrigation expansion is seen as a significant leverage to food security, livelihoods, rural development, agricultural and broader economic development [33]. Nowadays, Ethiopia focuses on agriculture-led development using irrigation from multiple water sources, such as dry period stream flows, springs, deep and shallow wells from underground aquifers, rainwater harvesting, and surface reservoirs [34]. This is because the Ethiopian government intends to place a priority on water resource development as an essential strategy for the sustainable economic and social development of the country [13]. Groundwater provides an important buffer to climate variability and can supply dry period stream and spring flows in the form of subsurface flow or base flow that significantly support irrigated agriculture [33]. The groundwater from dry period streams and spring flows for agricultural development offers several advantages when compared with surface water harvesting through the construction of dams that demand huge investment. Though groundwater can be utilized from dry period stream flows and springs, high surface runoff and associated low recharge of groundwater in the wet season influenced the availability of water in the dry periods [32]. High surface runoff or flood in the wet season has less contribution to irrigation as there is no need for moisture at this time [32]

Different interventions were implemented in different parts of the country including the Northeastern highlands of Ethiopia to combat the water deficit problems [2]. Soil conservation measures are the most common techniques recommended for converting excess rainwater(runoff) into soil moisture and groundwater reserve to achieve sustained base flow in the dry season [32,35]. Converting runoff into groundwater reserves using different interventions is, therefore, an advisable approach in catchment-based water management [1,20]. Using a watershed-based approach to

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enhance soil and water conservation and increase the groundwater level in the valley bottoms for easily accessing the groundwater reserve for domestic water supply, livestock, and irrigated agriculture.

Noted moisture deficit problems at Mount Yewel, Wollo University supported by UNEP, started studies and development activities on some of the micro-catchments of this mountain to improve water conservation at the micro-catchment level. Interventions at the micro-catchment level, including Physical and biological Soil and water conservation measures, were implemented to reduce surface runoff and improve base flow in the study area. Degnu, one of the micro-catchments at Yewel Mountain, has been treated with soil and water conservation (physical and biological) measures since 2011. The local communities continued the interventions after the support from UNEP stopped. Amanuel is almost untreated micro-catchment, though a small touch on the right periphery, the treated part is not significant. The physical observation in the treated micro-catchment, and studies in Northern Ethiopia [32] depicted that the base flow in the treated micro-catchment has been increased and flood flow reduction was visible. In contrast to the treated micro-catchment, untreated micro-catchment shows high flood hazard in the wet season and minimal specific base flow in the dry period.

Despite the huge amount of implemented structures on the highlands, the hydrological responses to land management practices are not yet quantified [2,32] and are not well-documented [7,32]**.** This is because the main focus of SWC measures in Ethiopia was on reducing surface runoff and topsoil loss, and little attention was given to replenishing the groundwater reserve [36]. This implies that SWC measures are not constructed for groundwater recharges, except few sites in the Tigray region, Ethiopia where small dams and recharge shafts are built aiming at artificial groundwater recharge [36]**.** In spite of the large number of studies on individual SWC measures, impact studies on catchment management are rare [32], particularly in the Northeastern Ethiopian highlands. There are few studies conducted by different researchers in different locations of Ethiopian highlands to evaluate the effect of SWC measures at the watershed level. For example in the Northwestern highlands by [2,37], in the Northern highlands by [32], and in the Southern highlands by [38] but most of them focused on surface runoff and sediment yield reduction at the catchment outlets, and soil fertility. FAO33 [39] also evaluated the impact of catchment treatment on crop yield response without accounting for the impact of hydrologic responses to catchment treatment. As hydrologic responses depend on land use /cover, morphology [32], the scale of the watershed [40], location, catchment character, and rainfall pattern [13], a site-specific study is of utmost importance to be conducted in the Northeastern highlands of Ethiopia. The paired catchment approach is more preferred for the comparison of the impact of SWC measures than the single catchment approach [40]. This is because, in the latter case, the comparison is in different input descriptors such as climate and land descriptors whereas, in the paired approach, comparison is made with the same climate and other descriptors keeping the same for the catchment to be compared. Thus, paired micro-catchments were compared for their base flow in response to catchment treatment.

Similar to other parts of the highlands of Ethiopia, the level of improvement in base flow enhancement in the study area is not known. However, Comparison of the hydrological response to land management practice to enhance base flow is, therefore, imperative [32]. Thus, the amount of base flow enhancement in the dry season, due to catchment treatment, needs to be evaluated, quantified, and compared in the study area. Impact analyses of soil and water conservation measures on available base flow and groundwater recharge and linking it with irrigation schemes in moisture deficit and erratic rainfall areas are vital. Filling the knowledge gap on the impact of catchment treatment in base flow modification in the dry period of the study area makes catchment treatment a profitable investment [32].

This research was conducted to evaluate the catchment treatment responses of the paired micro-catchments with the specific objective of evaluating the impact of soil and water conservation measures on base flow enhancement.

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2. Materials and Methods

2.1. Description of the Study Areas

This study was conducted on two pared micro-catchments, Amanuel and Degnu that are part of Mount Yewel in the Northeastern highlands of Ethiopia. Degnu lays from 10⁰50′ 00″ to 10⁰52′10″ N, and 39⁰26′20″ to 39⁰27′23″ E with an altitude range of 2860 to 3160 m. a.m. l., and Amanuel micro-catchment extends from 10⁰50′ 23″ to 10⁰52′07″ N and 39⁰25′37″ to 39⁰26′30″ E with an altitude range of 2880 to 3260 m.a.s.l.

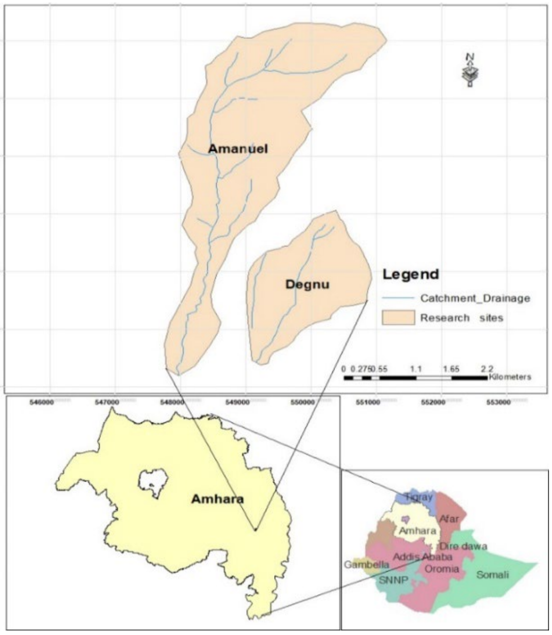

Figure 1. Location map of the study areas.

2.2. Approaches

The approach followed in the data collection and data analyses was based on the conceptual model developed for understanding the hydrologic/ water cycle (Figure 2).

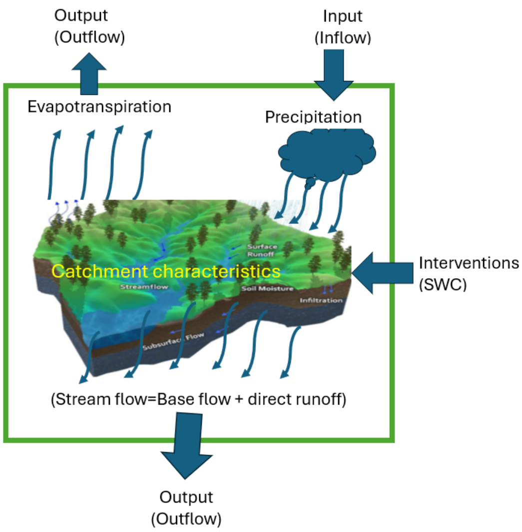

Figure 2. Schematic diagram of simplified water cycle.

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From the schematic diagram (Figure 2), there are two outputs/outflow and one input /inflow component with reference to the catchment boundaries. The input inflow component crossing the conceptual boundary is precipitation, and the output components are evapotranspiration and stream flow (base flow and surface runoff) leaving the catchment boundaries. The precipitations were measured at/near the center of the micro-catchments. The evapotranspiration for adjacent watersheds is assumed to be the same for paired micro-catchments. The components that were responsible for the base flow variation of the micro-catchments are catchment characteristics and catchment intervention (SWC). Thus, catchment characterization and intervention inventories were made for ease of comparison between the two micro-catchments. Catchment characterization helps to identify the existence of similarities or differences in the catchment parameters such as watershed morphologies, land use, and slope between the two micro-catchments in which hydrologic responses are dependent [37]. Hence, catchment characterization and comparisons should be carried out for both micro-catchments. Catchment interventions (SWC) are human-induced activities purposely done aiming at modifying the stream flow of the micro-catchments to create variation in wet and dry season stream flows. Hence, catchment treatment, which is the cause of variation in both dry and wet seasons, is the main concern of this study. Thus, detailed data collection and analyses were done based on the catchment intervention, particularly soil and water conservation measures (SWC). In relating the stream flow, which is the major outflow component, with catchment interventions, the base flow was separated from the stream flow hydrograph.

2.3. Catchment Characterization

When comparing hydrologic responses, watersheds located in the same or similar agrological zone, have closely related landscape descriptors and, may, therefore, have comparable hydrologic responses. The major descriptors are listed here to look at how much is the difference between the two micro-catchments in the study area. A list of the selected watershed parameters like drainage area and pattern, topography/slope, morphology, and other important parameters pertinent to hydrologic response are shown in Table 1.

Table 1. Morphologic characteristics of micro-catchments.

S/N	parameters	symbol	Unit	Formula	Result	
					Amanuel	Degnu
1	Area	A	km2	Calculated	7.42	2.73
2	Perimeter	Pb	km	Calculated	16.34	7.33
3	Axial length	Lb	km	measured	6.73	2.92
4	Basin width	W	km	measured	2.26	1.85
5	Total no. streams	N	no	counted	9.00	3
6	Total stream length	L	km	measured	12.96	4.47
7	Mainstream length	Lm	km	measured	6.77	2.73
8	Mainstream slope	S	%	Calculated	14.49	18.92
9	Stream order	Os	no	counted	2.00	2
10	Stream density	Sf	no/km2	N/A	0.27	0.73
11	Drainage density	D	km/km2	D=L/A	1.75	1.63
12	Overland flow length	Lo	m	Lo=1/2D	286.03	332.91
13	Shape factor	B	unit less	B=Lb2/A	6.10	3.11
14	Form factor	Rf	unit less	Rf=A/Lb2	0.16	0.35
15	Elongation ratio	E	unit less	E= Dc/ Lb	0.457	0.67
16	Circularity ratio	Rc	unit less	Rc=4A/Pc2	0.35	0.70

Drainage pattern: Drainage patterns and streamlines were generated from DEM_30 using GIS 10.5 with ground truthing. The drainage pattern of Mount Yewel is radial and dendritic drainage patterns with 3rd stream order. Mount Yewel is south-facing, with a convex slope, conical in shape draining towards Selgi River which is the main tributary of the upper Blue Nile. Amanuel and Degnu

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micro-catchments are part of the Yewel mount draining again to Megech River. Both study micro-catchments have similar dendritic drainage patterns with 2nd-level stream order in Strahler's system [42].

Topography: The landforms were also generated from DEM_30 using the GIS 10.5 computer program for both micro-catchments. The landform in both cases includes a rolling plain at the bottom and a hilly slope near the upper part. In the case of the Degnu micro-catchment, the upper part is a V-shaped valley steeper on the right side.

Catchment Morphology: The rate and volume of stream flows as well as associated sediment yield from the watersheds do have strong relations with shape, size, slope, and other parameter indices of the landscape [40,43]. The study of [44] found that there are some important relations between basin morphology and hydrologic responses. If the watershed and hydrologic characteristics are to be related, the watershed form must also be represented by quantitative indices. Morphological parameters are expressed by some indices. These indices for the study sites are generated from measured parameters. Some of the parameters were calculated from measured data extracted from the maps in both micro-catchments using GIS10.5 computer software. However, some parameters were found by simple measuring or counting from the maps. Brief descriptions of the most important watershed forms and relief parameters are presented the Table 1.

Land use/land cover: The land uses of both research sites are dominantly cultivated areas. The two micro-catchments had similar patterns in their land cover. The cultivated area covers about 66 % at Amanuel and 70% at Degnu (Table 2) with a slightly higher cropland proportion at Degnu but there is no significant difference (p=0.475) between them. Mixed agriculture, crop, and animal husbandry is the dominant economic base of the study area. Cultivated areas are on the upper steeper parts in both cases while grazing lands are in the lower flatter parts. Scattered trees, villages, and gullies also existed in both micro-catchments.

Table 2. Land use/cover and Slope classes distribution of the micro-catchments.

Land use (ha)	Amanuel		Degnu	
	ha	%	ha	%
Cropland	473.59	***66%***	190.8	***70%***
Forest	63.85	9%	36.46	13%
Grassland	15.98	2%	12.65	5%
Shrub land	87.86	12%	0	0
Degraded land	45.03	6%	13.79	5%
Road	0	0	5.55	2%
Settlement	29.82	4%	14.18	5%
Total	716.13	100%	273.43	100%
Slope class (%)				
0	3.72	0.52	1.42	0.57
0-3	18.19	2.54	6.95	3.93
3-8	63.66	8.89	24.31	11.11
8-15	140.79	19.66	53.76	21.5
15-30	312.30	***43.61***	119.24	***44.7***
30-50	156.47	21.85	59.74	16.37
>50	21.05	2.94	8.04	1.81
Total	716.13	100	273.43	100

Slope class: The dominant slope class falls in the range of 15 to 30 % (Table 2) in both micro-catchments (43.61% at Amanuel and 44.70% at Degnu micro-catchments). However, the difference is not significant (p=0.213) at 95% confidence interval.

Soil: The dominant textures identified by the hand feel method in both catchments are clay loam on the upper and clay on the lower parts. Soil depth in both the micro-catchments ranges from deep

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to very deep (>150cm) in the lower part and medium to shallow (<25 cm) soil in the upper part of the micro-catchments.

Climate: According to [45] 30-year climate data (1981-2012) obtained from the Ethiopian National Meteorology Authority recorded at Kabe metrological station (just a few kilometers downstream of the research sites) indicated that the mean annual rainfall of the area is about 866.5 mm. The maximum amount of rainfall is observed in July followed by August. In this research period, daily rainfall data were recorded on both the study sites for the whole research period using a simple/ manual rain gauge installed at/near the center of both the micro-catchments. Rainfall data were collected every Morning at 8:00 AM. Based on long-term average data (1992-2012), the mean minimum and maximum annual air temperatures of the area (Kabe Met. station) are 8.6 and 19.1^0 C respectively [45].

Area Coverage of SWC measures: Different physical soil and water interventions have been implemented at the Degnu micro-catchment since 2011. These include soil bunds, stone-faced soil bunds, and loose stone check dams. They are the most dominant conservation practices implemented at Degnu. when evaluated from Ethiopian standards points of view, like the vertical interval which was fixed to be 1m in most of the Amhara region, bund width, height, spacing, and size of the trench, it was by far below the recommended values or regional standards. In some parts of the micro-catchment, the vertical interval is 1m while in most of the watershed is less than 1m. In principle, the width of the bunds and trench sizes should have to be fixed based on the calculated surface runoff amount generated from the area between the bunds, but it was not done as per the calculated surface runoff amount. Moreover, the Trench sizes are affected by sediments deposited due to surface runoff between the bunds. Because of the lack of maintenance, trenches are silted up with eroded sediments from upstream of the bunds resulting in reduced trench size.

Grass strips were also established as biological measures at the Degnu micro-catchment for bund stabilization, and they are the most effective measure in arresting the sediment outflow from the catchment, reducing runoff, and improving infiltration. At Degnu, exotic and local grasses were planted on and below the bunds to assist the performance of the bund to trap the sediment, improve infiltration, and reduce surface runoff. However, currently, most of the grasses are grazed by cattle in the dry periods that have affected their primary functions.

Forage trees were another biological intervention implemented at Degnu that was designed to assist physical measures to control erosion hazards and to be used as fodder for animals. It is assumed to be the second-best measure, next to grass strips, to reduce surface runoff, trap sediment, and improve infiltration. At present, forage trees are becoming bush with less impact on ground cover to reduce surface runoff and sediment yield.

Terrace Density: Terrace density over both the micro-catchments was determined from the Google Earth Image of 2021 "on screen digitizing" method. Digitized lines were saved in KML file format and converted into layers to make them shape files and be compatible with the GIS interface. Physical soil and water conservation measures at Degnu cover about 47.21% of the total area and 53% of the total cultivated lands with few biological interventions on the bunds. Physical measures area coverage at Amanuel is about 6.91% of the total area which is about 9.23% of the total cultivated lands. Normalization (Conservation measure area coverage in percent) was made. After normalizing the data, a comparison was made to see the significant difference between the two micro-catchments. The area coverage of treatment, as shown in Figure 3, between the catchment is the difference($P<0.01$)

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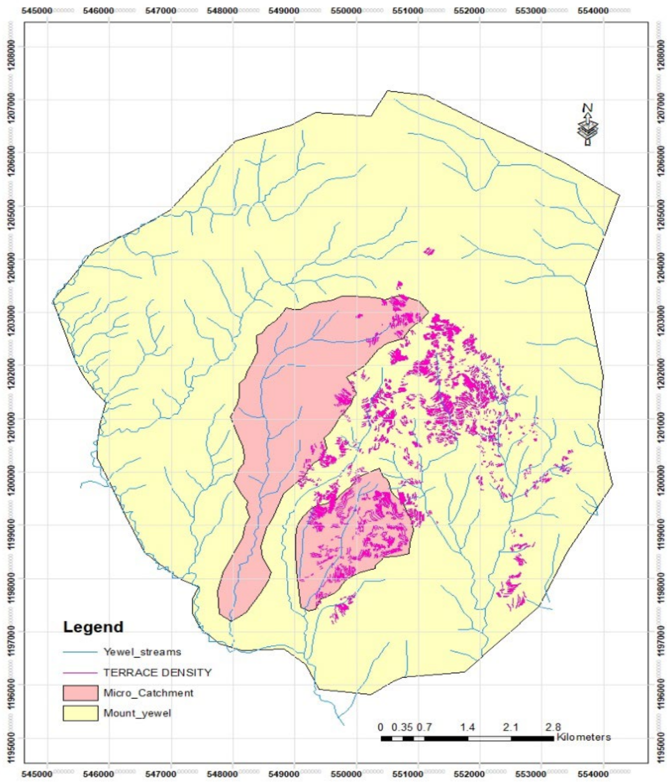

Figure 3. Terrace density of the study area.

2.4. Data Collection (Sampling) Methods

2.4.1. Flow Measurement

Stream gauging stations were established (Figure 4) at the outlet of both micro-catchments to measure stream discharges (surface runoff and base flow). Stream flow data were collected from 22/11/2020 to 8 /11/2022 with some interruption from 25/9/2021 to 4/01/2022 due to the prevailing civil war in the study area. Broad crest weirs made from masonry wall, as wide as the stream outlet, were constructed across the outlet of both streams in such a way that all the stream flow was guided to pass through it. The impermeable bedrock, close to the land surface at the catchment outlet, is assumed to prevent groundwater outflow below the weir. Thus, all the surface flow from the micro-catchments leaves the catchment boundary as a stream flow over the weir. Wooden staffs, on which the steel meter was fixed, were used to measure the depth of water over the weir vertically. The water depth over the weir was measured every morning at 8:00 A.M for the whole research period when there was no rainfall. During the rainfall events, measurement was delayed until the rain stopped.

Figure 4. Stream flow measuring weir at the outlet of the research sites.

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The depth of water in the driest periods was very small which made measurement over the weir difficult. Smaller weirs (0.4m width and 0.2m height) were constructed on both catchment outlets across the rivers just below the main weir sites to measure such a small flow. Moreover, in a few months, the mainstream flow at Degnu was so small, due to abstractions (night storages) upstream of the gauging site, that the depth of water even over the smaller weir (Figure 4) was very small to measure the depth of flow. In such cases, the volumetric method was used in such a way that the known volume of the plastic bucket was inserted below the weir and the time elapsed to fill this bucket was recorded. The volume was finally converted into discharges by dividing the volume bucket by the time taken to fill that bucket.

The depth of water over the weir was also converted to discharge based on the known weir formula [46] given by: $Q=CBd^{3/2}$, Where: Q = discharge (m^3/s), B= Width of the weir crest, length equal to the bottom width(m), d = upstream head (water depth) measured from the bottom(m), C=discharge coefficient(unitless). Some Authors recommend C to be 1.705 for broad-crested weirs. Some authors recommended using broad broad-crested weir calculator developed by Rahul Dhar and modified by Steven Wooding in 2023. But most researchers recommend using the calculated coefficient of discharge developed by Hager and Schwalt in1994, $C = 1.0929* [1-0.2221+[H1-\Delta ZL_{crest}]]$, where C = Coefficient of discharge, H1 = water height at the approach channel, ΔZ= Weir height, L_{crest} = Length of weir along the flow direction. In this study, the last option was adopted.

2.4.2. Abstractions

The major abstractions that made significant volume to affect the stream base flow one big spring at Degnu (Beshintie got) that is used for domestic water supply and livestock and Night storages along the Degnu mainstream for irrigation purposes. All abstractions were measured daily to calculate the volume of water withdrawn from the catchment by pumping or any form of water abstraction for domestic water supply or irrigation purposes.

***Spring flows*:** Beshitie spring is a developed spring with a protected tanker connected to the source/spring eye. Nobody has access to open or close this tanker as it is a sealed tanker. This spring serves more than 60 households at the Degnu micro- catchment which has a significant volume to affect the base flow patterns of the mainstream. The local communities and livestock are using the water from the overflow of this developed spring. The overflow was measured every morning at 8:00 A.M. in the volumetric method and checked whether there was a change in the noon time measurements. We found no significant change between noon time and morning measurement. However, there was a decline in the overflow as time went towards the dry period, as the other stream flow discharge changed. Spring discharge was measured by using the known volume of a bucket, inserted at the bottom of the spring, and recording the time taken to fill the bucket. Finally, the measured volume in liters per elapsed time in seconds gave us the discharge of the spring in liters per second.

***Night storages*:** Night storages are artificial storages made by the local farmers to stone water for 24 hours with regular shaped storages along the mainstream of Degnu. Night storages are other abstractions /water withdrawals from the mainstream flow at Degnu micro-catchments. Night storages are used to collect water at night because the stream flows in the daytime are not sufficient to irrigate the croplands by diverting only the daytime flows. Thus, collecting the night flow was common practice in the study areas. There are five-night storages at Degnu and one at Amanuel. The area of the night storages and average water depth were measured. The water depth multiplied by the average area gives the volume of water in the night storage. Because the night storages are used for 24 hours, the discharges were calculated by dividing the volume of night storage by the elapsed time in seconds (24 hours converted to seconds). Finally, the total base flow was calculated by summing up the mainstream flow, spring flow, and night storage volume converted to a discharge unit. There were of course few minutes elapsed until the stored water was evacuated to irrigate the land and the next storing process began which was neglected in the base flow calculation because of the minimal contribution to base flow from such types of losses.

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2.4.3. Base Flow Separation Method

The hydrograph is composed of two components, namely surface runoff (quick flow) and baseflow(low). Baseflow is the long-term discharge into a stream from natural storage, such as groundwater [47]. As discussed in [48,49]it is practically difficult to separate the two components of the stream flow. Different researchers have developed several methods to interpret the portion and contribution of baseflow to the stream flow of the river [50]. Base flow separation is a very complex process in large catchments due to different multitude of factors such as some catchments are dominated by topography, others by subsurface (soils and geologic) characteristics, and some others by spatial variations in rainfall inputs [49].

Chemical tracers and stable isotopes are cited in many literatures as the best method for base flow separations, but they all require extensive time and manpower resources for field measurements [41,49,51]. However, numerous non-tracer-based methods have been developed to estimate baseflow from streamflow without field measurements, such as graphical analysis methods, numerical simulation methods, and digital filter methods [41].

A study in [41] suggested that the baseflow separation method based on a digital filter is a simple method with appropriate filter parameters. However, there is no one best method universally accepted for all stream flows to precisely separate the base flow [50,52] because of the differences in input and filter parameters. But each has its own advantages and disadvantages [50].

Moreover, stream flow is governed by watershed parameters including size, slope land use /cover, etc. Taeuk, et al., [41] compared LH, Chapman, Eckhardt, CM, and EWMA methods for base flow separation and selected EWMA and LH because they need less number of parameters to separate the baseflow from the streamflow time series data with reasonable accuracy while fixed interval, sliding interval, local minimum, Baseflow Index(BFI) and Frequency Analysis were compared by [47] and the fixed interval was selected in this study as the best method for base flow separator of stream hydrograph.

In our study, having reviewed relevant literatures, base flow separation methods were compared and selected from the existing base flow separation domains. Controls were the driest period base flows where there were no flood discharges. In this research, filtering parameters are basin area, precipitation, and stream flow data, which are classified as a few numbers of filter parameters. Thus, we need to select method/s that uses a few numbers of filter parameters with reasonable accuracy [41]. Hence, selecting a base flow separation method that uses minimum parameters is appropriate for our case, and rejecting those methods that use a greater number of parameters and need more manpower with complex processes.

In this study, base flow separation methods were identified/selected in a stepwise approach i.e., in two steps. In the first step of base flow separation-method selection, twelve web-based (Fixed Interval, Sliding Interval, Local Minimum, Lyne & Hollick, Chapman, Eckhardt, TR-55, Szilagyi, Boughton (AWBM 1993), Furey & Gupta, Chapman & Maxwell (1996) and Chapman & Maxwell) base flow separation methods were compared in Sep Hydro- software from the existing domains compared to select the method that best fits our data (collected from the two micro-catchments). Stream flow data at the driest time was taken as an actual value(control) in the process of selecting the best method for base separation from the stream hydrograph and was used [42] for base flow separation method comparison. The 12 base flow separation methods, mentioned above, were evaluated against the control with the criteria of base flow index (BFI) given by:

$$\mathrm{BFI} = \frac{Total\ base\ flow}{Total\ Stream\ flow}.$$

Based on the base flow index (BFI), the first three methods (Fixed interval, sliding interval, and Local minimum) showed BFI greater than 92%.

In the second step of base flow separation method selection, the above three methods were compared (Figure 5). Among the methods compared in the second step, Fixed interval was better in the base flow separation in both micro-catchments in wet as well as dry seasons. When the mean base flow from both micro-catchments is taken, the Fixed Interval (95.5%) showed a better BFI ratio than the other two, followed by a Sliding interval (94.5%) and Local minimum (94.5%). Moreover, all of these methods use few numbers of filtering parameters and internally process the input data (precipitation and stream flow) using the known empirical formula for base flow separation given by $D=A^{0.2}$; where D= the number of days between the storm crest and the end of quick flow and, A= basin area(km^2). Fixed Interval is one of the best methods selected by [48] in the baseflow Separation of 8 Watersheds in East Java Regions. The Fixed interval method provides a good estimation of the rising limb of the hydrograph (Figure 5) while sliding interval and Local Minimum methods underestimate the baseflow [51].

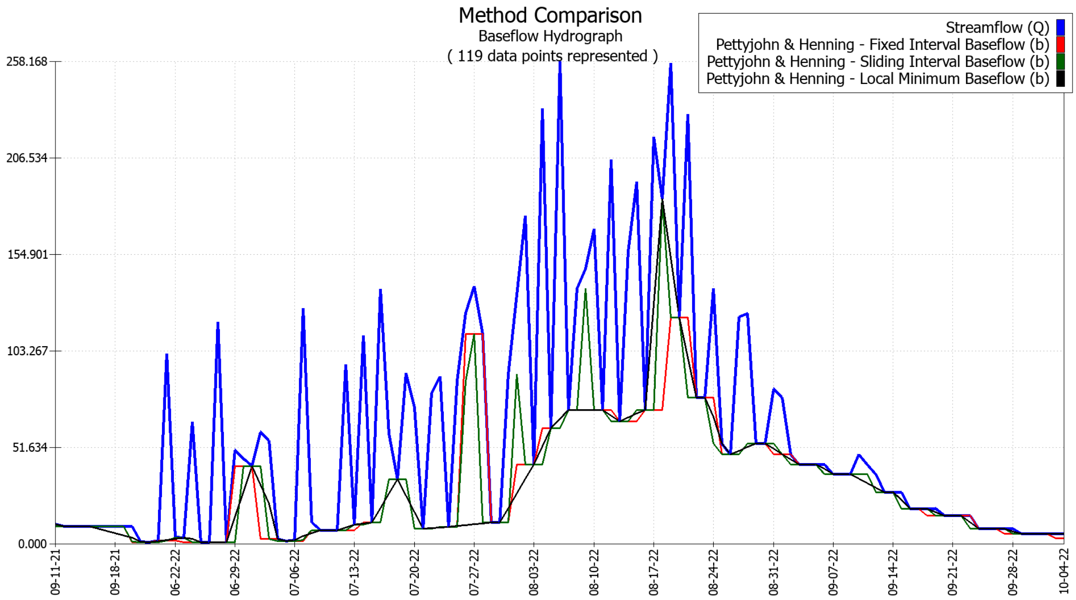


Figure 5. Base flow separation method comparison.

In this study, Fixed Interval, which is in agreement with [48,50] was selected as the best estimator method for base flow separation and adopted for base flow separation in both the micro-catchment (Degnu and Amanuel).

The fixed Interval method is one of the three methods developed by Pettyjohn and Henning in 1979. The method systematically draws connecting lines between the low points of the streamflow hydrograph to determine the baseflow hydrograph. The low points of the streamflow hydrograph are determined using a fixed window of specified width (i.e., equal to a set number of streamflow readings in the source dataset). All baseflow values in each interval or window are set to the minimum streamflow value in that respective interval [51]. The window width is the nearest integer between 3 and 11 that is equal to 2D, where D is empirically determined as: $D=A^{0.2}$, D - number of days after which runoff ceases; A – basin area [km^2]

2.4.4. Normalization

In comparing the hydrological response of paired micro-watersheds, variables should be in a similar context. Hydrological variables are separated base flows of the paired micro-catchments (Amanuel and Degnu). The spatial scale has a strong influence on watershed hydrology because the streamflow rate increases with an increase in drainage area [40]. When comparing watersheds with different drainage areas, it is necessary to eliminate the effect of spatial scale (drainage area) on streamflow by dividing the daily streamflow values by the drainage area of each watershed (normalization/specific discharge). After normalization, the normalized daily streamflow data (qkm^{-2}) was used to compare base flow and generate the flow duration curves.

However, comparing small catchments is better than comparing large catchments for they create more variability because of the differences in catchment parameters. Thus, unlike large watersheds, small watersheds show a high degree of homogeneity in landscape descriptors [40]. Because large watersheds experience uneven rainfall distribution that often leads to an uneven runoff distribution [54], this can be explained by the fact that small watersheds tend to receive a more evenly distributed rainfall, and thus their hydrologic response reflects that uniformity in rainfall distribution [40,55].

Hence, the hydrological variables (base flow discharges) of the two micro-catchments need to be normalized to compare the hydrologic responses. All the base flows from both micro-catchments were calculated (specific base flows in Ls^{-1}) and made available to be compared.

2.5. Data Analysis

The measured Base flows on both micro-catchments were analyzed using the SPSS version 21 computer program. Student T-test was done for paired mean comparisons to see the significant difference between the means of measured base flows and whether the catchment treatments could enhance the base flow or not. Data analyses on base flows were made after partitioning the specific base flows into wet and dry season base flows.

3. Results and Discussions

3.1. Results

3.1.1. Precipitation

The mean annual rainfall, recorded at the center of the micro catchments for this research period, were 904.70 and 926.20mm in the first year, 907.50 and 867.70mm in the second year at Amanuel and Degnu respectively. In the first year, Degnu received more rainfall than the Amanuel, the reverse was true in the second-year records. The long-term area rainfall is 8866.50mm [45], which indicates that the annual rainfall amounts for both micro-catchments are slightly higher than the long-term average rainfall of the area. The rainfall value slightly increased at Amanuel in the second year, but a slight decrease was observed at Degnu. As both micro-catchments are part of Yewel Mountain, the rainfall on the mountain is higher than the downstream records (Kabe station). The result shows that both micro-catchments have almost similar rainfall between the two micro-catchments which agrees with the work of [2] in comparing paired catchments that are near each other in Northern Ethiopia.

3.1.2. Base Flow

Base flow data from two micro-catchments were collected between 11/22/2020 and 11/8/2022. The first year of recorded data shows that the specific base flow at the Degnu micro-catchment was larger than Amanuel, and continued to be higher until it was intercepted by Belg (short rainy season) rainfall in May 2021. However, the base flow of both streams decreased and approached a minimum in the driest period which is in agreement with the result of [2,49]. During the intercepted rainfall events in the dry season, untreated micro-catchment (Amanuel) showed a quick response with abrupt rise and fall of the stage at the gauging station, though such changes are expected from treated (Degnu)micro-catchment in the wet(rainy) season due to the morphological parameters. After normalization, the statistical analysis result revealed that the specific base flow at Degnu is higher than at Amanuel in the driest season in both the first and second years (Table 3). But this phenomenon was reversed in all wet seasons. However, Degnu sustained the base flow, and the rise of stages was slower in the wet season despite the morphological indices, with gentle slope hydrograph showing sustainable base flow in the dry seasons after the Belg and main rainy seasons.

Table 3. Independent T-test Results of base flows.

Item	watershed	N	Mean	Std. Deviation	Std. Error Mean	df.	P (2- tail)	Confidence interval
Baseflow_y1 (Dry season)	Amanuel	213	0.52	0.36	0.025	242	0.001	95%
	Degnu	213	0.89	0.35	0.024			
Baseflow_y1	Amanuel	89	39.66	24.74	2.62	176	0.001	

(wet season)	Degnu	89	24.86	16.44	1.74		
Baseflow_y2	Amanuel	239	0.64	1.13	0.073	476	0.001
(Dry season)	Degnu	239	1.08	0.49	0.032		
Baseflow_y2	Amanuel	116	29.34	20.89	1.94	230	0.001
(wet season)	Degnu	116	15.78	16.15	1.50		

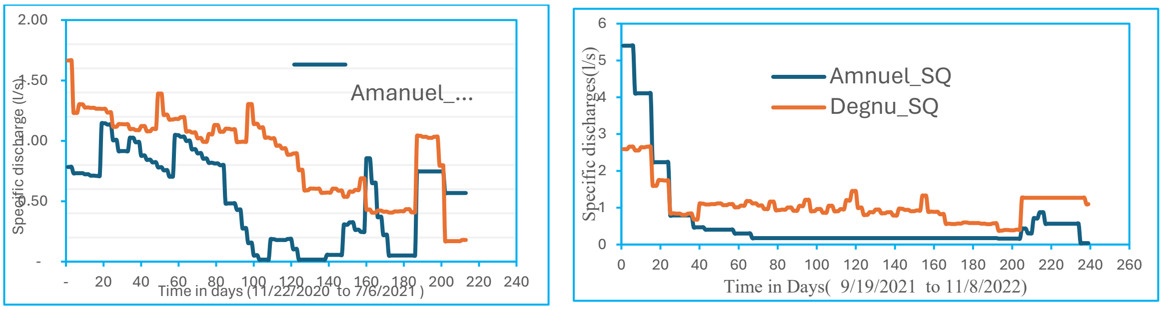
Y1=year one, y2=year two, N= number of records, df =degree of freedom, p= significant level.

Table 3 shows that the base flow of untreated micro-catchment (Amanuel) was higher in the wet season and for a few days after flood runoff (main rainy season) throughout the research period while the treated (Degnu) shows lower base flow in the wet season and higher and sustained base flow in the dry period. The responses of the study micro-catchments show high variation in the dry and wet seasons and the difference is highly significant($p<0.001$)

Partitioning the base flow into dry and wet base flows could clearly show the difference between the treated and untreated micro-catchment base flow responses. Thus, analyses were made based on the normalized (specific base flow or base flow per unit catchment area) of base flows after partitioning the flow into dry and wet base flow basis to look at the seasonal variation of the specific base flow. Daily mean streamflow data at the gauge stations were separated into surface runoff and base flow discharges using the selected method (fixed interval). Normalized (specific) discharges in the dry and wet periods were compared after the separation of the base flow from the stream flow hydrograph.

3.1.2.1. Dry Season Base Flow

In the first-year records, the specific base flow at Degnu was higher (Figure 6a) than at Amanuel in the dry period with a mean specific discharge of 0.89 Ls^{-1}at Degnu and 052 Ls^{-1}at Amanuel.



(a) (b)

Figure 6. Specific Base flow patterns in the dry season (a) first year and (b) second year.

The same pattern was observed for the second-year records with mean specific discharge values of 1.07 $Ls^{-1}$and 0.62 Ls^{-1} at Degnu and Amanuel respectively (Figure 6b). The analysis result of the dry period specific base flow shows that specific discharge at treated (Degnu) was significantly($p<0.001$) higher than untreated (Amanuel). The specific base flow at Degnu is not only significantly larger ($p<0.001$) than the Amanuel micro-catchment but also the base flow fluctuation was minimal. Thus, Degnu has a more specific base flow discharge in the dry season resulting in sustained base flow.

The total (cumulative) specific base flow (Figure 7) is also generally higher at Degnu than at Amanuel micro-catchment in both the first and second-year records which agrees with the result of [32]. Figure 7b shows that the base flow at Amanuel was recorded as high in the second year immediately after the rainy season. However, the flow declined when the dry season continued.

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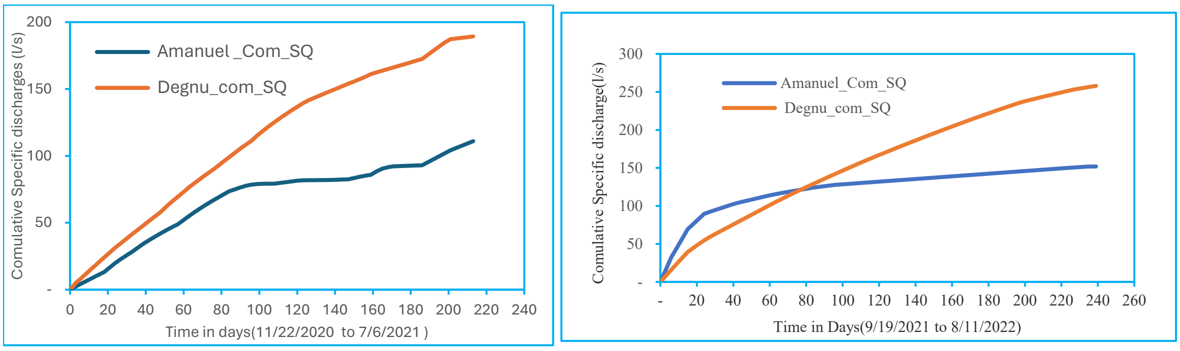


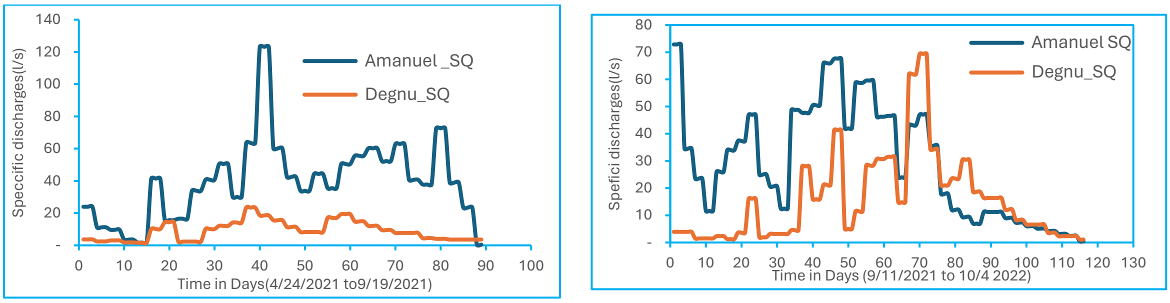
(a) (b)

Figure 7. Cumulative Specific discharge of the dry season(a) first year and(b) second year.

3.1.2.2. Wet Season Base Flow

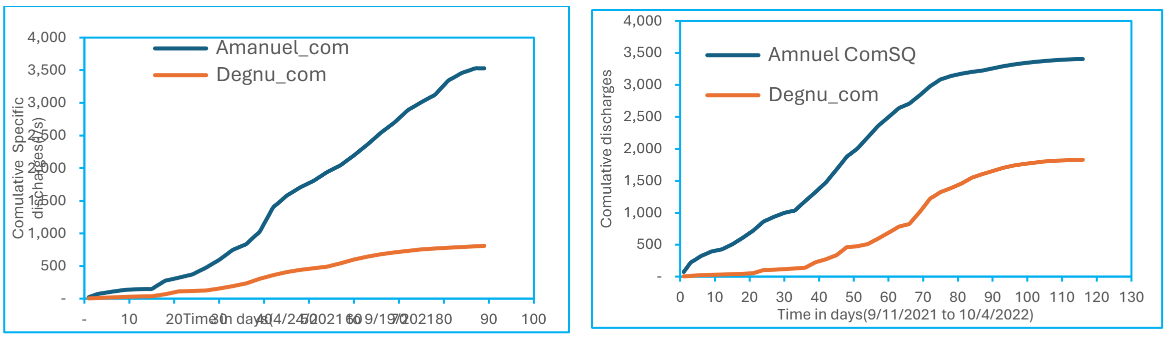
Base flow in the wet season was generally higher in untreated (Amanuel) than at treated (Degnu) micro-catchment in both first and second-year records. Similar results were reported in the work of [2,37] conducted in Northwestern Ethiopian highlands. The higher base flow was observed at Amanuel regardless of the morphological parameters such as elongation ratio, circularity index, shape, and other parameters that would have resulted in delayed flow at Amanuel and quick response at Degnu in the wet season. However, the recorded data showed the reverse responses, which might be due to catchment treatment. Higher base flow was observed at Amanuel in the wet season which lasted for a few days after the flood events, but lower base flow was seen for the longest dry periods in both the first and second years. The difference in wet season base flow discharge is clearly seen in the flow duration curve of the wet season (Figures 10b and 11b) which is the opposite of the dry season base flow.

The total specific base flow (Figure 8) was always higher at Amanuel than at Degnu throughout the research period of the wet season describing the quick response to each rainfall event. Hence, untreated micro-catchment could be characterized by high flood and low base flow discharges.



(a) (b)

Figure 8. Specific Base flow pattern of the Wet season (a)first year (b)second year.



(a) (b)

Figure 9. Specific Base flow pattern of the Wet season (a)first year (b)second year.

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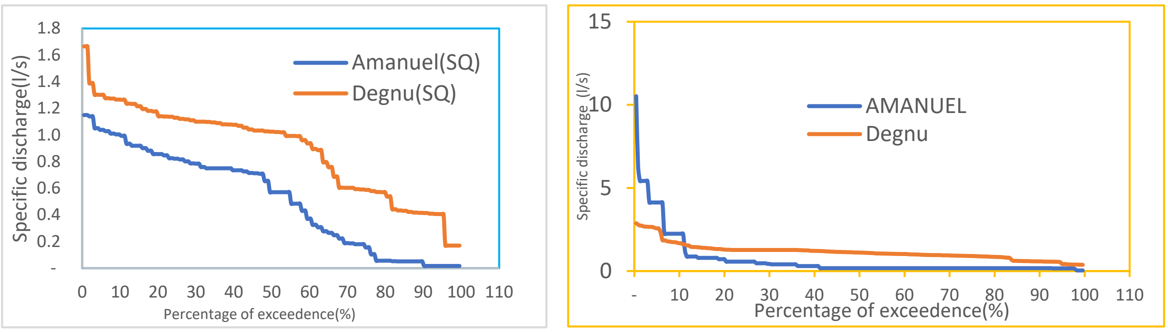
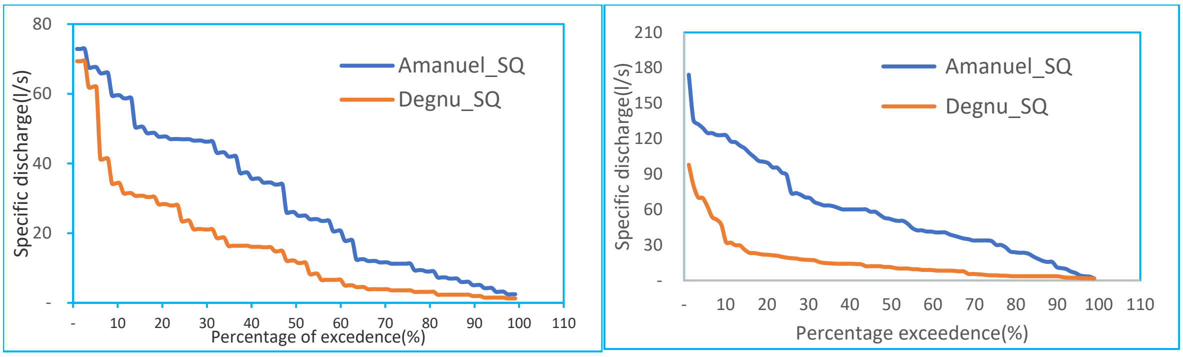


(**a**) (**b**)

Figure 10. Flow duration curve of dry season (a) first year (b) second year.



(**a**) (**b**)

Figure 11. Flow duration curve of wet season (a)first year and (b) second year.

3.1.3. Flow Duration

The flow duration curve is useful in appraising the catchment characteristics of drainage basins [55–57] and is used to describe the flow variability at two paired micro-catchments of the study area [4]. Figure 10 represents the FDCs' results of the two micro-catchments in the first- and second-year dry season. Flow duration indices (Q1, Q50, and Q95) which are most widely used in comparing hydrologic response at the watershed level [40] were used to represent the hydrologic responses of the study micro-catchments. It helps to Compare the hydrologic responses between the treated and untreated micro-catchments at high flow conditions, represented by the Q1 index, medium flow condition represented by the Q50 index, and low flow condition represented by the Q95 index [40].

The analysis result of FDC in the first year indicates that there was a higher Q1 index at Amanuel and lower at Degnu with index values of 135.73 and 80.54 LS^{-1}. However, higher Q50 and Q95 indices were found at Degnu with indices values of 1.14 and 0.42 respectively while it was 0.80 and 0.02 respectively at Amanuel.

In the second-year records, similar results were found that indicate Q1 was higher at Amanuel and lower at Degnu with the index value of 140.51 and 75.14 LS^{-1} specific discharges. Like the first year, the Q50 and Q95 indices were higher at Degnu and lower at Amanuel with the specific discharge value of 1.27 and 0.57 LS^{-1} at Degnu and 0.57 and 0.16 LS^{-1} at Amanuel. The FDC results showed that there was a higher Q1 that shows high flow conditions in both research periods which is an indication of flood risks whereas the higher medium(Q50) and low flow (Q95) conditions were exhibited at Degnu that show sustained flow in the dry season of both first and second year. FDC at the yearly time scale was not clearly seen because of the big variations in the dry and wet season flows. partitioning and plotting the FDC at dry and wet seasons with a daily time scale was preferred to see the difference between the seasonal variations of the stream flows.

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3.1.3.1. Flow Duration Curve of the Dry Season.

The dry season Flow Duration Curve (FDC) is plotted in Figure 10. For ease of comparison, base flows were normalized (specific base flow). The comparison results revealed that Degnu has the highest dry season flow in the first and second years indicating sustained flow. However, the Amanuel showed a lower dry season flow in both the first and the second years.

Figure 10 depicts that the FDC of Amanuel has a steep slope in both dry and wet seasons of the first year which indicates high runoff generation from smaller rainfall events in short periods and quick decline of the flow that is attributed to less catchment treatment. A similar result was found in [2,37] from the study conducted in the Northwestern highlands of Ethiopia in comparing the three adjacent micro-catchments.

Figure 10a) shows that 61.2 % of the flow exceeded the mean daily specific base flow in the dry season at Degnu but at Amanuel about 54.67% of the specific base flow is greater than the mean.

The flow duration curve in the second-year dry season (Figure 10b) shows that Degnu had higher medium and low flow conditions, but Amanuel had lower medium and low flow conditions. Higher medium flow was observed at Amanuel in the second-year dry season (Figure 10b) immediately after the main rainy season and extended for a few days. However, the FDC declined very quickly with a rough-steep slope showing unsustainable flow at Amanuel while the FDC at Degnu was a smooth, gentle slope which expresses sustained flow in the second-year dry season (Figure 10b). The Percentage of exceedance in the second-year dry season record shows about 40.83% of the flow at Degnu is greater than the mean while it was only17.4 % of the specific base flow is greater than the mean at Amanuel micro-catchment.

3.1.3.2. Flow Duration Curve of the Wet Season.

The wet season FDC of the first and second year are plotted in Figure 11. In contrast to the dry season, the first-year wet season records showed generally higher flow discharges at the Amanuel micro-catchment than at Degnu.

In the first-year wet season, the specific discharges at high(Q1), medium(Q50), and lowest (Q95) flow conditions of flow were greater at Amanuel than at Dengnu. The specific base flow in the first-year wet season at Amanuel is about 1.78 times greater than Degnu's at high, 4.59 times greater at medium, and 2.14 times greater at lowest flow conditions. The Percentage of exceedance in the first-year wet season record shows about 43.82% of the flow is greater than the mean specific base flow at the Amanuel micro-catchment, but the percentage of exceedance at the Degnu micro-catchment about 31.64 % of the specific base flow is greater than the mean. The FDC of the first-year wet shows that smooth and gentle curve at Degnu while a bit rough and steep at Amanuel (Figure 11a) depicting low fluctuation at Degnu.

Figure 11b shows that the second-year wet season FDC is a rough and steep slope at Amanuel which is the characteristic of streams with high flow fluctuation [40]. The Degnu micro-catchment, however, showed a smoother and gentler slope than Amanuel which is the behavior of streams with uniform and sustained flow. The percentage of exceedance at Amanuel in the second-year wet season indicates that about 46.96% of the flow is greater than the mean while it is 41.74% at Degnu.

FDC of the mean for first- and second-year dry season flow is worth mentioning here for water resource planning. Because the dry season flow is the local communities' concern in domestic water supply, livestock, and irrigated agriculture. Though the two data are not representative of long-term water resource planning, averaging the available data gives better information for the dry season flow of the study area. The mean base was similar to the second-year data (Figure 12). The FDC of the mean specific base flow at Degnu and Amanuel best fits the logarithmic function to express the shape of the curve [57–59] given by $Y= -0.375\ln(x)+2.418$, with $R^2 =0.90$ at Degnu and $y=-0.803\ln(x)+3.545$, with $R^2 =0.91$ at Amanuel.

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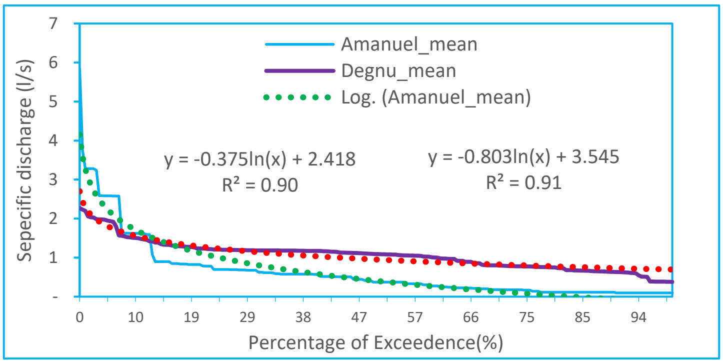

Figure 12. Mean Flow Duration Curve (FDC) for the first- and second-year dry season baseflow.

3.2. Discussions

3.2.1. Precipitation

The rainfall patterns in the study catchments are variable. In the first year of the research period, there was Belg rainfall in May 2021 that could intercept the long dry season but no Belg in the second year. A higher total amount of rainfall was recorded at Degnu in the first year, but it was reversed in the second year. A higher peak was also observed at Amanuel in the first year with a big variation between maximum and minimum rainfall. The maximum peak rainfall (at Amanuel) was 80 and Minimum 0.5mm d^{-1} while it was 75 and 2mm d^{-1} at Degnu. The second-year record shows that the total rainfall at Amanuel is greater than Degnu with maximum rainfall of 56 and Minimum of 2 mm d^{-1} while the maximum and minimum rainfall at Degnu was 65 and 2mm d^{-1}. Things were reversed, such as rainfall amount and peak values. The annual rainfall amount(926.5mm) at Degnu was higher with a minimum peak (75 mm d^{-1}) in the first year but the inverse was recorded at Amanuel (maximum amount and low peak) in the second year. Hence, the rainfall patterns in both micro-catchments are erratic and unpredictable in both amount and peak events. However, the difference in rainfall between the two micro-catchments is not significant. The third-year data (not indicated here) indicates there is Belg rainfall in the study area in February 2024.

3.2.2. Base Flow

All comparisons were made after the normalization of the base flow. Higher specific base flow was exhibited from Degnu in the dry season throughout the research periods. When this research started in October 2020, the specific base flow of Degnu was higher than Amanuel, as time went towards the dry period, the discharges in both micro-catchments declined until they were intercepted by Belg rainfall in May 2021. In this case, there was an abrupt rise of the stage at Amanuel responding to the precipitation quicker than Degnu but the discharge at Amanuel immediately fell below Degnu's (Figure 6a). Regardless of its morphological indices, Amanuel exhibited quick response in the rainfall events and low base flow in the dry season. Mostly, larger catchments are expected to have a larger base flow due to their larger recharge areas [40]. However, the statistical analysis in both research periods showed that the base flow from a larger catchment (Amanuel) was smaller than a small catchment (Degnu).

The second-year dry season showed, as seen in Belg rainfall of the first year that there was a high specific base at Amanuel immediately after the end main rainy season (September 2021) but reduced after a few days and became minimal when compared with Degnu specific base flow (Figure 6b), similar results were found in [2]. When we eliminate the data at the end of the rainy season of the second year, as an outlawyer, the same pattern was observed as the first-year dry season graph (Figure 6a).

In contrast to the dry seasons, the wet season records showed that there were generally higher specific base flows at Amanuel than at Degnu (Figure 8). Higher peak flows were also observed in the first year of the wet season at Amanuel describing quicker responses than Degnu micro-

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catchment. However, Degnu showed a smooth curve and low peaks in the same period (Figure 8a) which is an indication of sustained flow. A higher specific base flow was recorded at Degnu in August second year wet season. This is attributed to different factors such as high rainfall intensity, shape factor, and antecedent moisture content resulting from consecutive rainfall events [40]. This is due to the soil reached the maximum saturation before the rainfall, so it couldn't store more water. Such a trend was documented in [2,40].

The mean specific discharge at treated (Degnu) micro-catchment was by 71% and 67% more in the dry period of the first and second year respectively. However, the specific discharge in the wet season is higher at the untreated than at the treated micro-catchment showing a high risk of flood and quick response to rainfall events. During the wet season, the mean specific base flow discharge at the untreated micro-catchment is, however, 4.28 times greater than the base flow at treated micro-catchment in the first year and about 1.87 times greater in the second-year records. In contrast to untreated, the flood response at the treated micro catchment is lower and delayed in the wet season.

3.2.3. Flow Duration Curve

The flow duration curves (FDC) of the study catchments indicate that the specific base flow in the treated micro-catchment is significantly higher than the untreated in both first- and second-year dry season flow. The curve, with a rough and steep slope for the Amanuel micro-catchment in the first year dry season, indicates that the variability of the stream flow with flows that are largely from direct runoff; whereas a curve with a flatter slope at Degnu shows that baseflow is also substantial and sustainable (Figure 10). Figure 10b shows, that there is high variability of base flow at Amanuel at the beginning of the second year dry season (September 2021). However, the flat slope at Degnu (after September 2021) indicates a large amount of water storage and higher sustainability in dry season flow. This result also confirmed that the implemented SWC measures affected the dry base flow positively and the wet season negatively. Our study agrees with the result of [2,4,40] in that SWC measures enhanced dry season base flow and reduced wet season(flood) flows.

In the case of wet season flows, all the above discussed issues were reversed i.e., higher base at Amanuel and lower at Degnu. The curve at Amanuel in all cases (first and second year) was rough and steep slopes that indicate high flow variability which is characteristic of streams with high fluctuation [60–63], whereas the smooth curve and gentle slope at Degnu show sustainability and uniformity in the base flow.

In general, watersheds that have high Q1 indices have high surface flow runoff components and low subsurface runoff components. On the other hand, watersheds with high Q95 indices have sustained low flows and are, therefore, suitable sources for water supply and irrigation [40].

The mean FDC of the first- and second-year dry seasons best fits the logarithmic function (Figure 12). The low (dry season) flow at Degnu and Amanuel can be expressed by the equations, $y= -0.375\ln(x)+2.418$, and $y=-0.803\ln(x)+3.545$, where y= the specific base flow, x= percentage of exceedance, -0.375 and -0.803 are the slope of the trend lines, 2.418 and 3.545 are the y-intercepts. This model helps water resource planners to allocate the dry season flow conditions. If someone wants to plan the dry season flow for different purposes using this model, she/he can enter the value of the percentage of exceedance in the model and calculate the amount of discharge corresponding to it. For example, if someone wanted to know the specific discharge at Q50 (50%) of the low flow, She/He enters the 50% exceedance on the x-axis and can calculate the discharge on the y-axis using the formula given for Degnu or Amanuel; and do the same for other percentages. Generally, the allocation of water depends on the flow conditions. Low flow condition(Q95) is used to allocate water for ecosystem service, medium flow condition(Q50) for irrigation, and high flow condition(Q1) for flood risk management [40].

4. Conclusions

Watershed-based quantifying the base flow of streams provides useful information in the analyses of water quantity, quality, and other ecosystem services.

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The analysis result shows that the relation between catchment treatment and specific base flows was strong. The specific base flow was higher and sustained at Degnu micro-catchment in the dry season whereas it was lower at Amanuel which is attributed to catchment treatment. In contrast to the dry season, Amanuel exhibited higher base flow than Degnu in the wet seasons. FDC at Degnu showed higher medium and low flow conditions indices (Q50 and Q95) that indicate the dry season flow was higher in the treated micro-catchment in both the first and second. On the other hand, the FDC at Amanuel had higher highest high flow Q1 indices in the wet season in the untreated micro-catchment in both first- and second-year records that indicate higher flood risk.

In general, catchments that have high Q1 indices have high surface runoff components and low subsurface runoff components while catchments with high Q95 indices have sustained base flows and are, therefore, suitable sources for water supply and irrigation in the dry season. Therefore, Degnu has a better position than Amanuel for the allocation of water for irrigation and water supply because it has higher medium and low flow conditions (higher dry season flow). Had Degnu been fully (100%) treated catchment, the base flow at Degnu would have been more than this result.

The statistical analysis confirmed that catchment treatment could influence dry season base flow significantly($p<0.001$). Hence, implemented SWC measures (soil bunds, stone-faced soil bunds, check dams) positively affected the dry season base flow pattern and negatively influenced the wet season base flow. Hence, quantifying surface runoff reduction and enhanced base flow enhancement helps experts, policymakers, and local communities to develop good water management and utilization plans.

Finally, we can conclude that catchment treatment is a good strategy to convert rainfall to groundwater reserves and sustain dry season flow for further use in times of water shortage.

Automating the rainfall and stream flow data collection with long-term records, proper maintenance of SWC measure at the catchment level, and additional SWC measure implementation, will add knowledge of understanding of the stream flow conditions in the study micro-catchments; and therefore, be the issue of future research.

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