International Journal of Fisheries and Aquatic Studies 2014; 1(6): 183-189

ISSN: 2347-5129
IJFAS 2014; 1(6): 183-189

www.fisheriesjournal.com
Received: 12-05-2014
Accepted: 10-06-2014

Gebremedhin S.
Department of Fisheries, Wetlands and Wildlife Management, College of Agriculture and Environmental Sciences, Bahir Dar University, P. O. Box 5501, Bahir, Ethiopia

Kebede B.
Department of Water Resources and Irrigation Management, College of Agriculture and Environmental Sciences, Bahir Dar University, P. O. Box 5501, Bahir Dar, Ethiopia

Mingist M.
Department of Fisheries, Wetlands and Wildlife Management, College of Agriculture and Environmental Sciences, Bahir Dar University, P. O. Box 5501, Bahir, Ethiopia

Correspondence:
Gebremedhin S.
Department of Fisheries, Wetlands and Wildlife Management, College of Agriculture and Environmental Sciences, Bahir Dar University, P. O. Box 5501, Bahir, Ethiopia

Effect of River Flow Variability on Spawning Migration of *Labeobarbus* Species In Infranz River, Lake Tana Sub-basin, Ethiopia

Gebremedhin S., Kebede B. and Mingist M.

Abstract
The study was conducted in 2011 at four sites of Infranz River selected based on the nature, velocity of the flowing river, human interference and, suitability for fish spawning. Fish samples were collected using gill nets of 6, 8, 10 and 14 cm and monofilament having 5-55 mm mesh size. The potential Evapo-transpiration of the river was estimated using the Thornthwaite method. Flow rate of the river was simulated from precipitation data using a 3- parameter monthly water balance model. The CV value for the mean monthly flow (CV= 0.96) was much larger than that of the annual flow (CV=0.19). The river showed an overall decreasing trend of flow rate. The number of adult fishes captured in the river was directly related to the flow. The number of Juveniles was less during the high flow seasons. The number of male and female was positively correlated with flow rate of the river. The decreased in river flow rate have an effect on migratory species; hence, management activities should be practiced in the catchment area of the river so as to increase its flow rate.

Keywords: Infranz River, *Labeobarbus*, Flow rate

1. Introduction

In aquatic ecosystem, the effects of abiotic influences on biological processes are usually complex and highly interactive. Stream discharge is one of the abiotic drivers that are characterized by strong spatial and temporal variability at a range of scales. Variation in stream flow has potentially major effects on all stream biota and is the primary abiotic driver of many ecosystem processes through its influence on in-stream hydraulics and one of the basic determinants of the amount of habitat space available in river systems for different species and life stages [14, 17].

Many hydro-ecological studies have provided evidence for the importance of extreme events, such as floods and droughts, in regulating stream community structure [15]. The importance of physical disturbance in maintaining biological diversity and ecological functioning in aquatic ecosystems is formally recognized by disturbance theory.

Disturbance theory has been incorporated in the natural flow paradigm, which postulates that the full range of natural intra and inter-annual variation of hydrological regimes are critical in sustaining the integrity of aquatic ecosystems. The paradigm is widely recognized as forming a basis for flow management in regulated rivers. Aquatic organisms are generally adapted to a wide range of variability in stream discharge and temperature [1]. However, it is often difficult to define what natural variability is, given the wide range of anthropogenic impacts on many river systems. Moreover, empirical studies that directly examine the influences of physical variability on aquatic organisms are still relatively scarce. Thus, there is a need to understand the habitat requirements of species and life-stages in terms of discharge and stream temperature, particularly in terms of variations and interplays in both. This knowledge is an essential prerequisite for the environmental assessment needed to underpin sustainable river management through Ecologically Acceptable Flow regimes (EAFs) [9].

In order to specify flow regimes that are ecologically meaningful, the variability of hydrological conditions needs to be characterized in terms of its implications for ecosystem functioning or productivity. In many hydro-ecological studies based on the natural flow paradigm, it is assumed that monthly or daily means, which are often readily available, are sufficient to characterize parameters such as discharge, in ways that allow meaningful correlations with ecological data. In addition, few studies have attempted to consider hydrological and thermal variability simultaneously and to explicitly link them to the ecological functioning or productivity of aquatic ecosystems [10]. Hence, analyses conducted for longer temporal scales, e.g. months or years, underplay the fact that the biological responses can occur much more rapidly. In extreme cases, responses can occur over the course of individual hydrological events. Short-term natural perturbations can cause temporary, but substantial, changes in physical habitat and affect ecological functioning. All the migratory movement of several fish species over summer season to streams occurred in response to a single hydrological cue lasting for only a few days [16]. Against this background, there is a need to develop analytical approaches that focus on the magnitude, duration, frequency and timing of physical events on fine temporal scales and that consider biological responses, particularly during ecologically sensitive periods.

For a migration to be successful it must be initiated at the appropriate time. Thus, migration cues play an essential role in tuning up the response of a species, allowing a coordinated breeding or feeding strategy among individuals that will maximize the chances of survival at the scale of a population. In this context, a better understanding of the factors that initiate migrations is important, so some of the important factors which initiate fish migrations are water discharge, water level and current.

Different studies conducted in some tributary rivers of Lake Tana such as Gelgel Abay, Gelda and Gumara [12, 13, 4], Ribb, Dirma and Megech Rivers [8, 2] and in Arno-Grano River [7] revealed the upstream and /or downstream migration of some *Labeobarbus* species.

From previous studies, at least eight *Labeobarbus* species (*L. acutirostris, L. brevicephalus, L. macrophtalmus, L. megastoma, L. platydorsus, L. truttiformis, L. tsanensis and L. intermedius)* of the 15 endemic *Labeobarbus* species of Lake Tana are reported as riverine spawners. The riverine spawners of *Labeobarbus* species aggregate in river mouths before they migrate upstream to spawn on gravel beds in clear, small and fast-flowing and well-oxygenated tributaries [12, 5, 3, 13, 2]. According to Fish Base and Mekong Fish Database there are a number of fish species triggered by thresholds or changes in water discharge, water level and current. For instance, fish species which are grouped under the family of Cyprinidae are highly triggered by those factors. From this point of view, the *Labeobarbus* species of Lake Tana which are grouped under the family Cyprinidae may be influenced by water discharges, water level and current during their migration to Infranz River for spawning. However, the effect of river variability on the spawning migration is not clearly known. Therefore, this study helps to know the effect of stream discharge variability and water level on *Labeobarbus* species migrating to Infranz River.

2. Materials and Methods

2.1. Area description

Infranz River which is the tributary of Lake Tana is situated north–west of Bahir Dar town, in the southern part of Lake Tana watershed in the district of Bahir Dar Zuria Woreda and western Gojam zone of the Amhara region (Fig. 1) The river is surrounded by three Kebeles, namely: Yibab from the South, Waramit from the North, and Chercher Wegelsa from the West and its source of water is ground water [6]. The mean monthly temperature of this River is 17.5 °C , mean annual rainfall of 1437 mm with heavy rains during July-September and dry season during December –April [6].

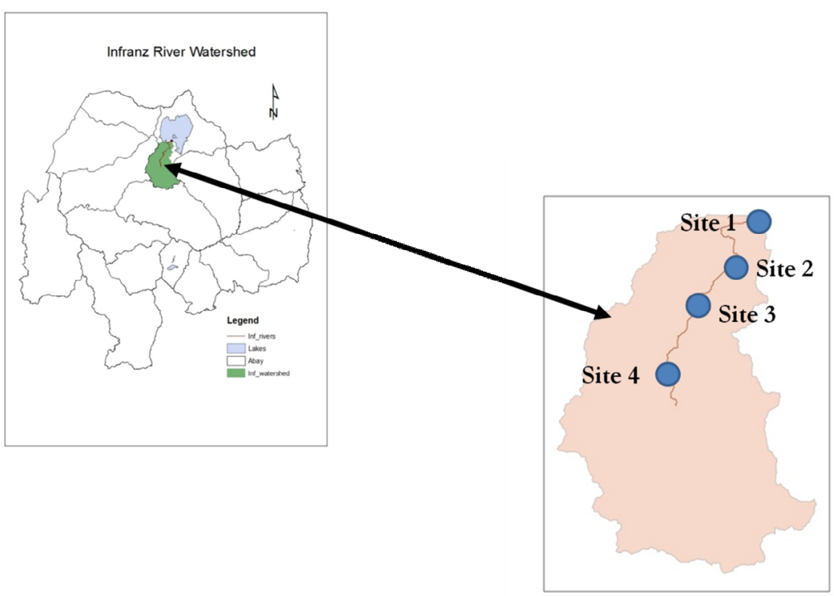

Fig 1: Map of the study areas and the selected sites for fish sampling

2.2. Data collection
2.2.1. Field sampling
Four sampling sites based on the nature, velocity of the flowing river, human interference, suitability for fish spawning, and availability of fishes were selected by preliminary survey and sampling sites were fixed using GPS. Fish samples were collected monthly in July, and November, and twice per month from August to October 2011 at all selected sites.

Gill nets of 6, 8, 10 and 14 cm stretched bar mesh, having a length of 25 m and depth of 1.5 m were used to sample fish. Gill nets were set in the river mouth at a depth of 2.5-3.5 m overnight. But in the upstream fish were sampled during day time since it was difficult to set gill nets overnight due to the usual heavy rainfall in the afternoon in the area. Monofilament having 5-55 mm mesh size was used to sample small sized fish and set for about 2 hours.

2.2.2. Hydrological Data Collection
Computation of Potential Evapo-transpiration

The mean monthly temperature from Bahir Dar meteorology station was used for estimation of potential Evapo-transpiration (PET) using the Thornthwait method. Thornthwaite method is a widely used temperature based method for estimating potential Evapo-transpiration. It was developed by Thornthwaite (1948) who correlated mean monthly temperature with Evapo-transpiration as determined from water balance for valleys where sufficient moisture water was available to maintain active transpiration. Steps followed for computation of potential Evapo-transpiration using Thornthwaite method are:

1. The annual value of the heat index I is calculated by summing monthly indices over a 12 month period.
   The monthly indices are obtained from the equations.

$$i = \left(\frac{T_a}{5}\right)^{1.51}$$

And

$$I = \sum_{j=1}^{12} i_j$$

While I is the annual heat index, i is the monthly heat index for the month i (which is zero when the mean monthly temperature is ^{o}C or less), Ta is the mean monthly air temperature (^{o}C) and j is the number of months (1 - 12).

2. The Thornthwaite general equations calculate unadjusted monthly values of potential Evapo-transpiration PET^1 (in mm). Based on a standards month of 30 days, 12 h of sunlight/days

$$ET^1 = C\left(\frac{10\ Ta}{I}\right)^a$$

In while c = 16 (a constant) and a = 67.5 x 10^{-8} I^3 - 77.1 x 10^{-6} I^2 + 0.0179 I + 0.492.

3. The unadjusted monthly Evapo-transpiration value ET^1 are adjusted depending on the number of days N in a month $(1 \le N \le 31)$ and the duration of average monthly or daily day light d (in hours), which is a function of season and latitude

$$ET = ET^1\left(\frac{d}{12}\right)\left(\frac{N}{30}\right)$$

In which ET is the adjusted monthly potential Evapo-transpiration (mm), d in the duration of average monthly daylight (hr), and N is the number of days in a given month, 1-31 (days). Thornthwaite equation was widely criticized for its empirical nature but is widely used.

Model Development

Infranz River has no flow data and was simulated from precipitation data using a 3- parameter monthly water balance model developed for Upper Blue Nile Basin which is modified from a two-parameter monthly water balance model, suggested by Xiong and Guo (1999) [11]. The model uses three parameters to divide precipitation into three parts, i.e. Evapo-transpiration, runoff and soil moisture (infiltration). The optimum values of the proposed three parameters of the model were obtained from previous research output. If the values of the model parameters are obtained, water balance of a catchment can be computed in more reasonable sense especially for un-gauged catchments in the basin. The three parameter monthly water balance model may have different structures based on the available data and the intended use. The structure of the model used in this study and the different components of the model are described as follows.

Actual Monthly Evapo-transpiration

The monthly actual Evapo-transpiration rate of a catchment was calculated using the following formula.

$$E(t) = c \times EP(t) \times \tanh\left(\frac{P(t) + ES(t)}{EP(t)}\right)$$

Where
C = the first model parameter
E (t) =actual evapotranspiration
Ep (t) = potential evapotranspiration
P (t) = rainfall
ES (t) = available soil moisture for evapotranspiration
And, Es (t) is also given as,

$$ES(t) = S(t-1) \times \left[1 - EXP\left\{-\frac{S(t-1)}{SC}\right\}\right]$$

Where
S (t-1) = previous soil moisture
SC = field capacity

Monthly Runoff

The monthly runoff generated by the model is given as below [11].

$$Q(t) = MAX\{0, AS(t) - SC\} + k \times MIN\{AS(t), SC\} \times \tanh\left(\frac{MIN\{AS(t), SC\}}{SC}\right)$$

And,

$$AS(t) = S(t-1) + P(t) - E(t)$$

Where, Q (t) is the monthly runoff
AS (t) initial available soil moisture for runoff generation,
S (t-1) the water content at the end of the (t-1)th month
k is slow runoff coefficient, and
SC is field capacity of catchments.

Runoff is usually the sum of surface runoff and interflow, whereas surface runoff is the part that does not enter the soil but directly moves over the land surface. In contrast, interflow is infiltrated water, which travels through the macro pores laterally within the vadose zone of the ground (above groundwater table and below soil surface) under saturated conditions. If there is no precipitation for a considerable length of time, the total river flow is only groundwater discharge.

2.2.3. Data analysis

SPSS version 16 software was used to analyze and manage the data. Multiple linear regression and correlation analyses were used to determine the relationship of river flow variability and spawning migration.

3. Results and Discussion

3.1. Rainfall

Assessing the rainfall distribution of a given area provides important information about the surface and ground water conditions in a given area. Rainfall data of the past 33 years (1980-2012) from Bahir Dar station shows a generally increasing trend of rainfall and higher inter-annual variability, (Figure-2).

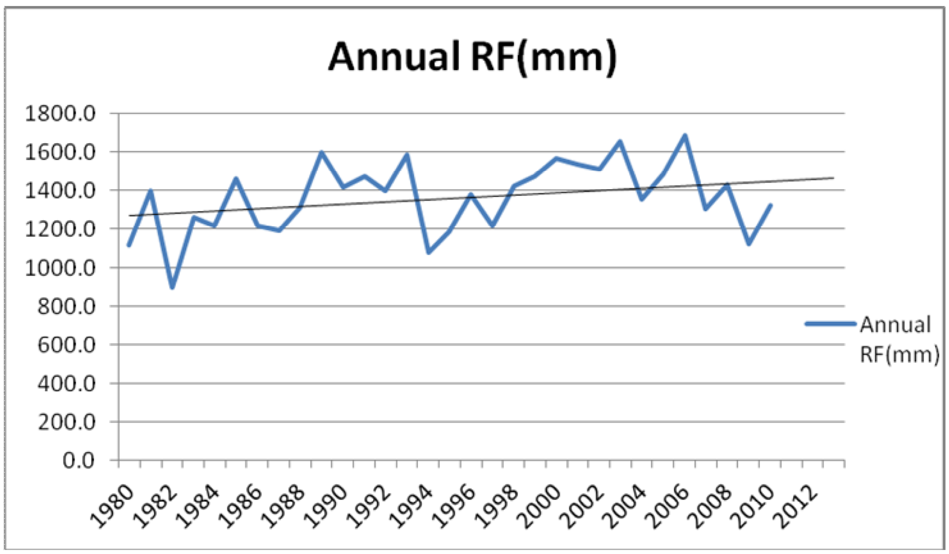

Fig 2: Mean annual rainfall in the study area

3.2. River Flow Variability

Though Infranz River has no recorded flow data, the simulated flow from rainfall data allows a good analysis of the annual and monthly river flow variability. The study used a 17 years rainfall data (1995–2011) to simulate the mean monthly and annual flow. Infranz River flow experiences two main periods of flow; the first dry period begins in November and ends in May, and the second rainy period begins in early June and tails off to late October as shown in Figure 4. The mean monthly hydrograph show the trend of all simulated flows in a channel at different months of the year. Because these statistics measure how far the data points are spread apart or lumped together, the emphasis is on the typical flow patterns rather than the extreme events. Although annual stream flow allows for general comparison of stream flow at a single site from year to year and from site to site throughout the river, the coefficient of variation (this coefficient is the ratio of the standard deviation of annual flows to the mean flow) of flow can also be used as overall flow variability. Since the flow data was simulated at one site, at the mouth of Lake Tana or outlet of the Infranz river catchment, the coefficient of variation (CV) was sufficient statistical parameter to characterize the temporal variability of flow rate.

For this study the annual and mean monthly flow were analyzed and the result shows that the CV value for the mean monthly flow (CV= 0.96) is much larger than that of the annual flow (CV=0.19) indicating that the monthly flow of Infranz River is much more variable than the annual flow. In addition, the annual hydrograph and mean monthly hydrograph in Figures 3 & 4 show the nature of the flow variability. The annual hydrograph in Figure 3 shows how the flow varies from year to year. Though the flow increases at some of the years (1996, 1998, and 2000) and decreases at another years (1996, 1998, 2000, 2003, and 2006), the graph generally shows an overall decreasing trend.

The decreasing trend may be caused by many factors from which land use changes as a result of increasing human interference in the watershed may be the major one. This land use change in turn decreases infiltration rate by increasing runoff and finally resulting in depletion of ground water which is the main source of the river flow. This decrease in river flow rate seems to have the largest effect on the biodiversity of the river unless some management activities are practiced.

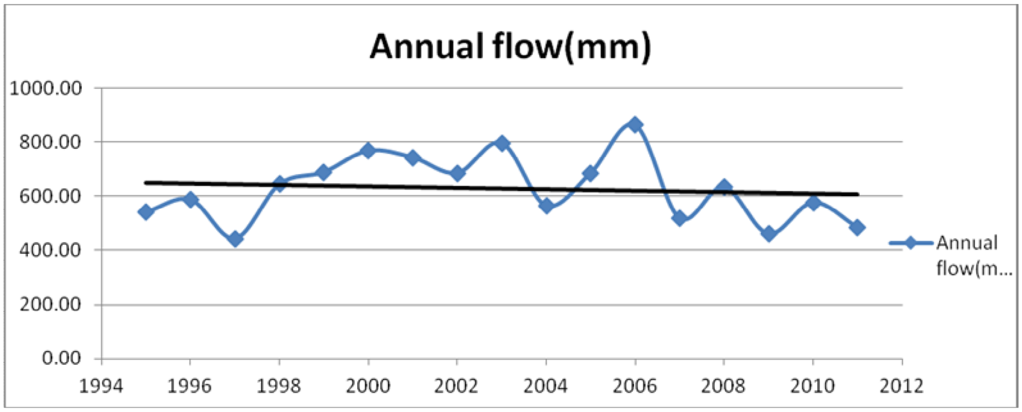

Fig 3: Infranz River Annual Flow.

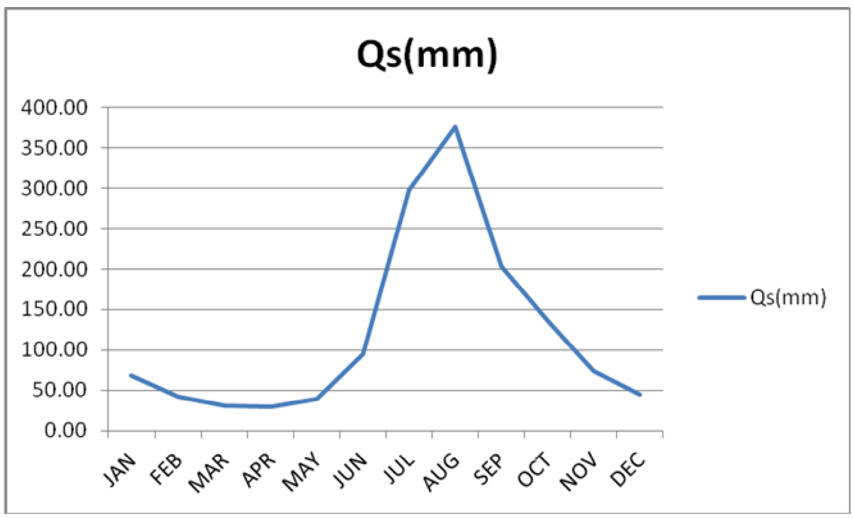

Fig 4: Simulated mean monthly flow

3.3. River flow variability and fish spawning migration

Studies to determine the effect of river flow variability on fish communities are not as common as those to determine the spatial variation of fish assemblages, as they require the repeated sampling of established stream sites over time, especially in case of Ethiopia where there is no infrastructure. This study has tried to provide preliminary information with limited data and its main focus is to see the effect of river flow variability in the spawning migration of *Labeobarbus* species. Fish biological data was collected during the high flow seasons (July-November, 2011) and the monthly flow was also simulated for the year 2011 as shown in Fig. 5, and was used to analyze its relationship with fish spawning migration. The river experiences two main periods of flow. The peak flow occurs in the months of July and August (the peak being in August) and the low flow in March and April. Figure 5 describes the flow condition of the river and fish spawning migration in the year 2011.

As can be shown in Figure 5, the number of adult fishes captured in the river was more or less directly related to the flow, i.e. as flow increased, the number of adult fish captured increased and *vice versa*. This implies that the adult fish migrate to the river for spawning during the high flow seasons (July-August). However, the number of Juveniles was less during the high flow seasons and this is because the fish migrate to the stream out of the lake to lay their eggs during high flow periods and turn back to the lake when the flow decreased. When the flow decreased and adult fish start to turn back to the lake, the eggs start to be hatched and increase the number of juveniles in the river, though the flow continues decreasing, showing negative correlation with the flow as shown in fig-5.

The number of male is less (41%) than the number of female (59%), but both having positive correlation with flow as shown in Fig-6. This is because the female adult fish are observed to initiate spawning entry into the Infranz River at or before ovulation and male fish generally follow the females in response, probably, to Phermonal as well as abiotic cues.

Generally the study has shown positive correlations between flow rate during spawning period and number of migrating adults, males and females, and negative correlation for Juveniles. This may emphasize the importance of regulating discharge variation for ecological integrity.

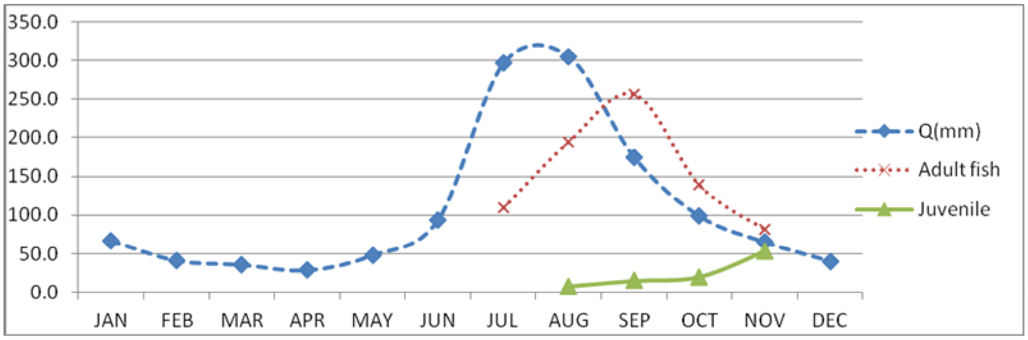

Fig 5: Relationship between monthly flow, adult fish and Juvenile

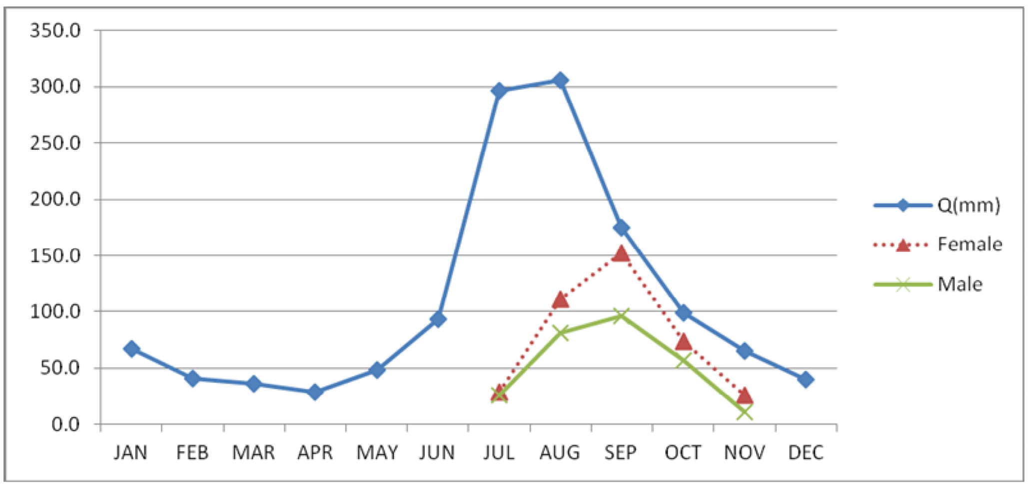

Fig 6: Relationship between monthly flow, female fish and male fish

4. Conclusion and Recommendation

4.1. Conclusion

The rainfall data of the past 33 years (1980-2012) from Bahir Dar station showed a generally increasing trend of rainfall and higher inter-annual variability in Infranz River. The river experiences two main periods of flow; the first dry period begins in March and ends in May, and the second rainy period begins in early June and tails off to late October. The annual and mean monthly flow was analyzed and the result showed that the CV value for the mean monthly flow (CV= 0.96) was much larger than that of the annual flow (CV=0.19) indicating that the monthly flow of Infranz River was much more variable than the annual flow. Considering the up and downs of the river flow variability, it showed an overall decreasing trend through time. The decreasing trend may be caused by many factors from which land use changes as a result of increasing human interference in the watershed may be the major one. This land use change in turn decreases infiltration rate by increasing runoff and finally resulting in depletion of ground water which is the main source of the river flow. This decrease in river flow rate seems to have the largest effect on the biodiversity of the river unless some management activities are practiced.

The number of adult fishes captured in the river was directly related to the flow rate, which means as flow increased, the number of adult fish captured increased and vice versa. This implies that the adult fish migrate to the river for spawning during the high flow seasons (July-August). However, the number of Juveniles was less during the high flow seasons. This may emphasize the importance of regulating discharge variation for ecological integrity.

4.2. Recommendation

- The flow rate of Infranz River showed a decreasing trend since the last of October, at the same time the migratory world unique *Labeobarbus* species starts to return back to the lake at the end of October. Hence, the late spawner might be suffering with getting a sufficient water flow which supports them to easily return back unless some intervention is not taken.

- The high variability of monthly flow rate of Infranz River is caused by watershed degradation and over exploitation of the river water for irrigation activities. Therefore, concerned bodies should take a measure to rehabilitate the degraded watershed by practicing soil-water conservation and sustainably using the water for irrigation
- This study was conducted with a limited data of fish that were harvested using the traditional gillnet and monofilament and the rainfall data was taken from Bahir Dar gauged station as it is un- gauged river. Therefore, further study should be conducted taking into account the limitations of this study by gauging the river and using modern fish harvesting or fisheries data recording mechanisms.

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