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Impacts of small-scale irrigation water use on environmental flow of ungauged rivers in Africa

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Abstract
Failure in Environmental flow in quantity, timing, and quality leads to failure to support ecosystems, human livelihoods, and well-being. Irrigation water use is one of the main actors in impacting the water flow of rivers in quantity and time but was not well investigated in many ungauged catchments under smallholder irrigation systems. This study examined the impact of irrigation water use on environmental flow in Arata's small ungauged catchment. The study estimated the flow in sub-catchment using the area ratio method, the crop irrigation water requirement using F.A.O. cropwat 8.0, and the water balance in the Water Evaluation and Planning System tool and the environmental flow in Tennants, Q95, asnd local area thumb rule. The result showed that the minimum environmental flow of the Arata catchment is 290, 310, and 60 li/sec in the Tennant, Q95, and the local thumb rule. Irrigation consumes only 9% of the water resources of the catchment while 91% is contributed to downstream lake Ziway via Ketar river. January and February have unmet water demand and zero environmental flow. In December Tennant's 10% and Q95 recommended environmental flow had 19% and 24% deficit while the thumb rule environmental flow is 291% more than the minimum requirement. The rest of the months are by far more than the minimum environmental flow requirement. Given the result, meeting the environmental flow of the system throughout the year needs the installation of a water storage facility from upstream to downstream, the introduction of different water-saving irrigation technologies, farmers' capacity building in irrigation water management, and a standardized environmental flow estimation mechanism.

Keywords Irrigation, Ungauged catchment, Water balance, Environmental flow

Introduction

The world's rapid population growth over the last century, urbanization, economic development, and improved living standards have been significant factors in increasing global water withdrawals (F.A.O. 2021; Huitema et al. 2009; OECD. 2022; Pahl-Wostl et al. 2013; Wu et al. 2022). Irrigation is one of the major sectors that compete for water and plays a significant role in water abstraction. While food production is estimated to increase by 70% in 2050 compared to 2000 for a rapidly growing world population, the water to produce this much food will exponentially increase from the current 70% freshwater consumption (FAO 2011; WB 2016). In this context, the water demand for irrigation and to meet environmental flow becomes a key issue in sustainable ecological service (Pang et al. 2013).

Environmental flow is the flow of fresh water in a river necessary to preserve ecosystem service and is expressed in quantity, timing, and quality (The Brisbane Declaration 2018). The International Union for Conservation of

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Nature and Natural Resources(IUCN) demarcated environmental flow as “the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated” (Megan Dyson 2008). These thoughts lead environmental flows to consist the floods and medium and low flows, which are important for the ecosystem(Piniewski et al. 2014; Poff et al. 2010, 2007). These definitions infer river flow components management for competing water uses. Environmental flow management considers three key principles equity, efficiency, and sustainability at the basin level (Wang et al. 2008). It is censoriously important in the era of climate change and sustainable development at a country and small catchment level.

The theory of environmental flow management evolved to challenge and transform the traditional management rationale to the holistic ecosystem consideration. The traditional rationale was using the water resource only for human needs (particularly economic needs), exclusive of other ecosystem services like regulating, support, and cultural services (Acreman et al. 2014; PETTS 1996; Smakhtin 2008). The current environmental flow concept considers human beings, the water body, and its’ ecosystem as beneficial (Acreman 2016; Bunn and Arthington 2002; Poff et al. 2017a; Poff and Matthews 2013). According to Davis and Hirji (2003), the ecosystem is elaborated as not ’just in river fauna and flora, but also the floodplains and wetlands watered by floods, groundwater dependent ecosystems replenished through river seepage, and estuaries. The current governing theory among scientists underlying environmental flow is balancing the utilization and protection of water resources among social, economic, and ecological needs, which are determined by quality, quantity, and time considering the ecosystem as a stakeholder (Chen et al. 2019; Poff et al. 2017b).

According to Gessner et al. (2010), 65% of the global river system suffers water shortages for healthy ecosystem service. The quality, quantity, and timing issues of environmental flow failures are measured in different indicators like fish disasters (Kim 2019; Palmer et al. 2009), scarcity of water supply(Das Gupta 2008), food shortage (Stein et al. 2018), cultural failure (Dissanayake and Smakhtin 2007), loss of native species and increased spread of exotic species(Poff et al. 2007), conflict within the sub-basin among different water users(Legesse and Ayenew 2006) and others.

As the main water consumer, irrigation disrupts rivers in quantity and timing commencing from an abstraction point (Dyson et al. 2008). Though it needs more refining study on the estimate, a study by Jägermeyr et al. (2017) indicated that 41% of current global irrigation water use is at the expense of environmental flow. Other studies also showed that economic water uses mostly get the upper hand in tradeoffs over environmental flow (Crespo et al. 2019; Yeakley et al. 2016). Besides, several researchers are depicting the challenge of reconciling irrigation development and the environmental flow thresholds (Maliehe and Mulungu 2017; McClain et al. 2013; NBI 2020; Overton et al. 2014; Suresh Babu, Malavika Chauhan, Brij Gopal, Nitin Kaushal and Prakash Nautiyal 2013).

As part of the world water system, the Ethiopian water policy demands and urges the ensuring of the basic minimum required water for environmental reserves as the highest priority in water allocation planning (MOWR 1999). However, it didn’t set the minimum water to be reserved in a river system. The experience in small-scale irrigation development shows arbitrary downstream flow release that range from 0–24% of the dry time flow (ABOA 2020; AZILDO 2017). The global recommendation by some scholars is in the range of 20% and 40% Annual Average Flow (AAF) for dry and other periods respectively (Smakhtin et al. 2004; Tennant 1976).

Studies conducted on Ethiopia’s irrigation tried to figure out the role of irrigation water use in environmental flow management (Gebremariam and Sohail 2011; Nile Basin Initiative 2016; Shiferraw and Mccartney 2008). These studies showed that in most of the small-scale irrigation water sources rivers downstream flows reach near zero which resulted in a scarcity of water for livestock, sanitation, and ecosystem services in dry months of the year. This becomes one triggering cause for conflict between upstream and downstream users (Amede 2015; Derib et al. 2011; Gebremariam and Sohail 2011; Jembere 2009).

Irrigation water management and uncontrolled irrigation expansions are claimed as the cause of downstream water stress in dry months of the year in the rift valley catchment of Ethiopia (Desta and Lemma 2017; Eresso 2010; Fekadu 2016; Musie et al. 2021; Shumet and Mengistu 2016). Arata catchment, which is part of the Rift valley catchment through the Ketar catchment, is prone to a similar problem (Ayenew 2007; Fufa 2017; MOWR 2009; Pascual-Ferrer and Candela 2015). Irrigation water use is assumed as one of the responsible determinates for downstream environmental flow stress. This study was designed to examine the impact of irrigation water use on ungauged Arata catchment environmental flow. It aimed at examining the downstream flow, particularly the environmental flow of the Arata catchment considering irrigation and livestock as the key water demand determinates.

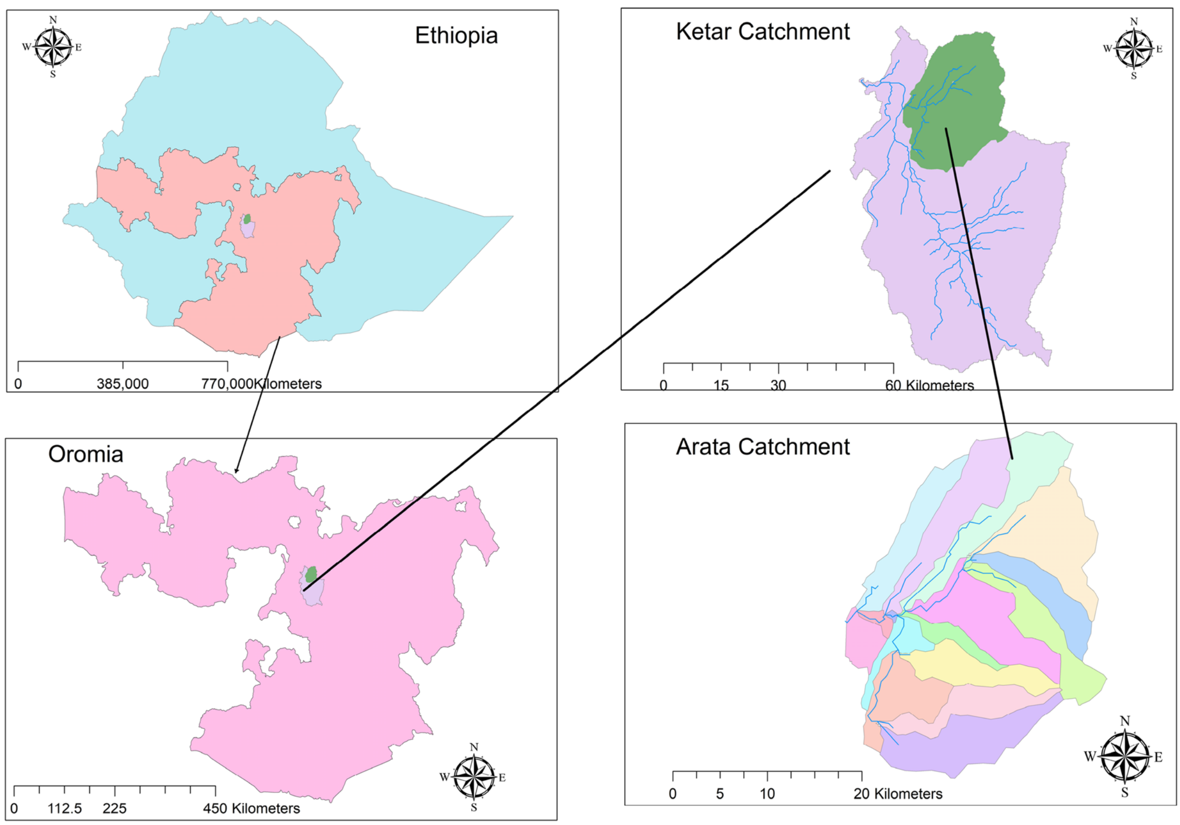

Fig. 1 Arata catchment location map

Materials and methods

Location

Arata catchment is located in the central rift valley basin, Oromia region of Ethiopia (Fig. 1). The catchment is built up by Kulums, Chefa, Bosha, and other sub-catchments in which Arata river is the primary watercourse in the Arata catchment system.

The main river, Arata is not gauged. However, the Ketar river which the Arata feeds is gauged at two points; Ketar at Fite 505512.9 E 859977 N and Ketar at Abura 505509 E, 892036.8 N (Fig. 1). Arata river catchment benefits 1960 irrigation user households (HH) with more than seven gravity small-scale irrigations (Table 1 and Fig. 2) and 31,010 different types of livestock, excluding poultry, dogs, and other wildlife, and birds. All the irrigation schemes use furrow irrigation.

The primary and secondary data of the Arata catchment were collected directly from the field and the Oromia region, Arsi zone, Tiyo and Ziway Dugda woreda irrigation, agriculture, environment, and livestock government offices and Arata Kebele administration. Irrigation area, crops, and irrigation period for the year 2015/16–2020/21 and livestock data were collected from the woreda irrigation and agricultural offices, respectively. River flow data for 27 years for Ketar at Abura and Fite was collected from the Ethiopian Ministry of Water and Energy (MoWE). Irrigation crop data, livestock watering points, and Ketar river gauge station points were collected during field observation. The flow of Ketar at Abur is used to estimate the Arata catchment rivers flow due to the proximity and similar characteristics of the catchments. The Arata catchment outlet is only 6 km far from Ketar at Abura gauge, while Ketar at Fite gauge is 26 km. The Arata catchment and rivers were

Table 1 List of irrigation schemes in Arata catchment

Irrigation schemes	Area (ha)
Arata	100
Balwelde	20
Bosha I & II	151
Chefa	50
Sheled	75
Kulumsa	70
Others (summed up)	24
Total	490

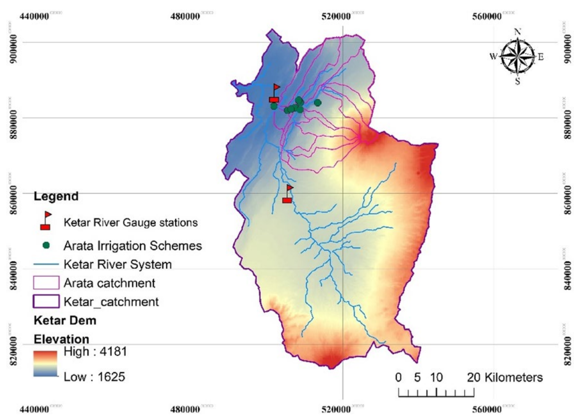

Fig. 2 Arata _ Ketar catchment, irrigation schemes, and river gauge stations

synthesized from 20 m X 20 m D.E.M. data. The collected data quality was checked, adjusted, and synthesized to analyze Arata's water balance and environmental flow.

Water balance and environmental flow analysis

The catchment delineation and irrigation land use were analyzed using Arc GIS while the water balance was analyzed by WEAP. Cropwat 8.0 is used for irrigation crop water requirement estimation. The environmental flow was analyzed using the Tennant, Q95, and a local thumb rule. Each sub-catchment water balance was estimated considering the irrigation and livestock water demand against the flow of each river. The aggregate water balance followed the same approach taking the Arata river as the main water course.

The main determinants for the water balance in the Arata catchment are the available water resource and the water consumption/demand (Fig. 3). The water resource for the Arata catchment and sub-catchments were estimated in the catchment area ratio method. The irrigation water abstraction was assumed to be nearly equal to with estimated CropWat value. Measuring the irrigation abstracted water on all irrigation schemes for one irrigation season was not done due to the absence of water measuring structures in all schemes. However, Arata river water abstraction was measured five different times using the float method for simple comparison. The livestock consumption value is referred from the International Livestock Research Institute study result (Sileshi et al. 2003). Though environmental flow is one demand, the field visit and discussion with the woreda office revealed that environmental flow at a local level is the leftover after every economic use abstraction. Hence, in the analysis model environmental flow was not added to the demand side. However, the flow that remains after economic use is checked against the Tennant, Q95, and local thumb rule recommendations as environmental flow. The year 2020/21 is used as reference year input for WEAP.

The result was checked at the end of January and the beginning of February 2021 at the field level and additional discussions with irrigation farmers and Ziway Dugda woreda irrigation offices were conducted. During field-level check, downstream flow status was observed physically whether it is aligning with the study result or not. Besides, the checking was based on the existing irrigation farmers' experience like justifying the water

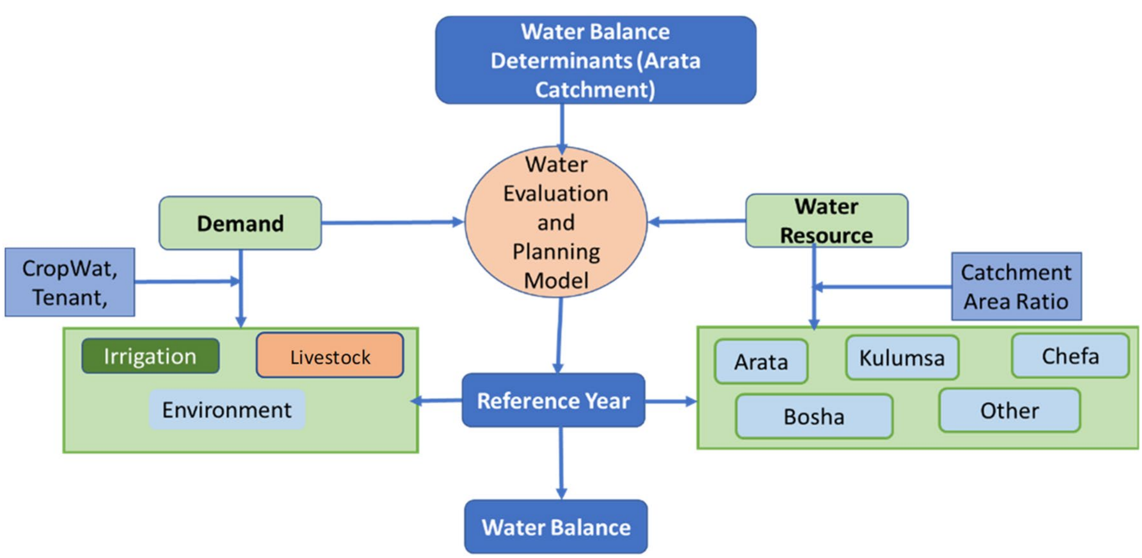

Fig. 3 Arata catchment water balance analysis framework

conflict period between upriver and downstream users and the irrigation area management practice of the woreda.

Water evaluation and planning system (WEAP)

WEAP tool was selected to analyze the water balance and environmental flow of the Arata catchment. The tool was developed by the Stockholm Environment Institute (SEI). The tool places the demand side on equal footing with the supply side. It is comprehensive, clear, and easy to use. WEAP simulates different scenarios between demand and supply, considering different development options and environments (Sieber and Purkey 2015).

Irrigation areas and livestock services were configured as demand-side water uses. The Arata catchment rivers; Arata, Kulumsa, Bosha, Chefa, and other small rivers, were configured as the water supply sources (Fig. 3). The water balance results were analyzed by subtracting the demand/abstracted from the water resources at the sub-catchment and catchment levels. The result was checked with the existing ground-level situation and discussed with the irrigation water user association of the Arata irrigation scheme. Both irrigation and livestock demands were given priority one as the experience of the farmers showed equal priority for both in their past allocation unless a critical water shortage happened. The irrigation demand sites and Livestock's water consumption rate were assumed as 95% which means 5% of the inflow return to the supply side (Roberto Arranz and McCartney 2007). The return flow from the irrigation is very small due to the loose control of the irrigation water user associations, canal breaches in the farm, and the absence of a drainage system. The monthly water demand for irrigation is decided based on the monthly crop water requirements, while a constant amount is assumed for livestock throughout the year.

Environmental flow assessments methods

Environmental flow assessments vary across a wide range of complexity and depth, as dictated by the level of funding, availability of data, technical capacity, time frame, the priority of the site, or expected level of controversy (Jacobson et al. 2016; Karakoyun et al. 2018). Most environmental flow assessment methodologies are categorized into hydrological, hydraulic rating, habitat simulation (or rating), and holistic methodologies (King et al. 2003; Poff et al. 2017a; Reitberger and Mccartney 2011; Tharme 2003). Each methodology can be used as a decision tool to identify failure in environmental flow in quantity, timing, and quality that leads to failure to support estuarine ecosystems and human livelihoods and well-being (The Brisbane Declaration 2007). In this study, the Tennant method, flow duration curve, and the thumb rule of Ethiopian downstream release which is 15% of the dry month flow is used for the environmental flow.

The Tennant method uses historical flow data to set a fixed percentage annual average flow (AAF) as environmental flow. Accordingly, 10% of AAF is recommended as a minimum environmental flow. Here, the historical daily river flow transferred from Ketar river is used to estimate the Arta Catchment environmental flow. The Q95 is estimated as environmental flow (Acreman et al. 2008; Hart and Chan 2011) using Flow duration curves (FDC). The FDC was plotted arranging the statistical flow data in descending order against the percentage of exceedance. To determine the Ethiopian thumb rule in the ungauged small catchments the dry month flow is estimated by direct measurement in the driest part of a year using the float method. However, in this study, the flow is estimated using the catchment area ratio method, and the January flow is used as the driest month flow of the year. The 15% flow of January is taken as the environmental flow. The results of the three methods were compared to the existing ground truth.

Arata catchment rivers flow estimation

The catchment area ratio method, which is suitable to estimate the flow of ungauged catchments where there is a gauged similar catchment nearby, is used to estimate the monthly stream flow where enough determinant variables are not available. The method responds to limited variables—catchment area and flow amount of another catchment. It can be used where no regional and local area correction factors and models are not developed (Douglas G. Emerson, Aldo V. Vecchia 2005; Li et al. 2019). According to Gianfagna et al. (2015), the area ratio method can produce an acceptable result than most complicated models.

The Arata catchment is part of the main Ketar catchment, which is gauged downstream of Arata in a place called Abura and Fite. The characteristics of Ketar and Arata catchments in terms of rainfall and soil are similar (Fig. 3). Both catchment's land use and land cover consisted of more than 50% cultivated land and less than 1% woodland (AZILDO 2017; Gurmu et al. 2021; Sime and Abebe 2022). Both catchments have similar drainage classes and fine to medium soil texture.

The catchment area ratio method is mathematically expressed as:

$$Q_{sd} = {}^{A_{sd}}/_{A_g} X Q_g \tag{1}$$

where Q_{sd}—the Discharge of the ungauged river; A_{sd}—the catchment area of the ungauged river, A_g is the catchment area of the gauged river (Ketar), and Q_g the discharge of the gauged river.

The ratio for Arata to Ketar at the Abura catchment area was used to transfer the Ketar at Abura 90% dependable flow to the Arata catchment rivers. The flow data of Ketar river gauges from the year 1987–2016 were collected from MoWE. Ketar at Abura gauge is located 6.0 km downstream from the Arata irrigation scheme. These data were checked for quality, missed, and outliers. To ensure the data quality, the installed measuring staff gauges straightness and readability were checked at the field level. Out of 13393 collected data, only 8.5% of data were missed. The missed data were filled with the arithmetic mean of similar months and date recorded data.

Crop and livestock water demand

Crop selection

According to the woreda irrigation office, the area's dominant crops used for this analysis were Tomato (*Solanum Lycopersicum*), Potato (*Solanum Tubesum)*, Onion (*Allium Cepa*), and Wheat (*Triticum aestivum L.*). The area coverage of these crops in the catchment varies yearly based on crop rotation, market, seed, and other inputs availability. The year 2020/21 was considered the base year due to the introduction of wheat which is set as the base year. Wheat is considered a strategic crop for food security and import substitution by the Ethiopian government.

The irrigation crop area data for the past 3 years (2018/19–2020/21) is considered for the water balance analysis. The 3-year average data shows 50% area for wheat, 25% of potato, 10% of tomato, and 15% onion were taken for the analysis. According to the study made by the Ethiopian Ministry of Agriculture, the overall irrigation efficiency of Arata is 55% which is similar to other research results in the area and literature recommendations (Doorenbos and Pruitt 1977; MOA 2018; Van Halsema et al. 2011).

Crop water requirement

All the irrigation schemes in the catchment have no water-measuring structures. Irrigation farmers divert water from their respective river courses without quantifying. Hence, the irrigation Crop demand analysis was conducted with FAO CropWat 8.0, taking the climate data from the nearby Ogolcho metrological station located 8 km downstream of the Arata.[1] The Arata scheme and the Ogolcho metrology stations are 1750 m and 1700 m altitude above sea level respectively.

[1] The CropWat result was checked with five times measured abstracted flow of the Arata irrigation. The water measurement was conducted using float method. The comparison of the CropWat and the average water abstracted indicated that the abstracted water is 10% less than the CrpoWat value.

The Soil data for the cropwat was referred from the Oromia Irrigation Potential Assessment study (OIPA) (OWWDSE 2019). The OIPA soil study for the central rift valley of Ethiopia was conducted in 2018 based on the F.A.O (2015) soil survey guideline for soil classification and F.A.O (2006) field description guideline. Hence, the catchment soil is classified as clay loam in texture with 167 mm/m total available soil moisture (MOA 2018; OWWDSE 2019). Besides, the irrigation calendar data was collected from the Ziway Dugda woreda irrigation office and Irrigation water users.

Livestock

The livestock population was collected from the woreda Agriculture office and the livestock water requirement was estimated using the International Livestock Research Institute study result (ILRI) (Amenu et al. 2013; Descheemaeker and Tolera 2011; Sileshi et al. 2003). Accordingly, 14.4 li/sec of water consumption was considered for all types of livestock. Cattle, sheep, goats, donkeys, horses, mules, and camels were the main livestock in the study area.

There are a lot of livestock drinking points in the catchment. However, for the water balance modeling, these points were grouped into three convenient points. These are; one at the upriver part, on Kullums -Arata river, where livestock density is relatively small. In the middle, on the Bosha river; and the third downstream of the Arata, near the catchment outlet. The livestock water demand was analyzed by taking the number of livestock in the river catchment and each reach; upriver, middle, and downstream.

Result and discussion

Seasonal and overall system-level annual water flow

According to the catchment area ratio analysis result, the Arata catchment annual yield is 77.1, MCM with 0.11MCM per km^2 yield. The sub-catchments of water resources are presented below (Table 1 and Fig. 4).

August and January are the peaks and the lowest flow months in the sub-catchments, respectively. June, July, August, and September are rainy seasons with relatively high stream flow and November to February are the driest months (Table 2).

Irrigation demand

The irrigation area of the Arata catchment is 490 ha. The catchment has more than seven small-scale irrigations. Wheat is the dominant crop, followed by potato, onion, and tomato (Table 3).

The Ogolcho metrology station climate and Eto data showed that November to May (Table 4) which are the main irrigation months are with high Eto values (Table 5).

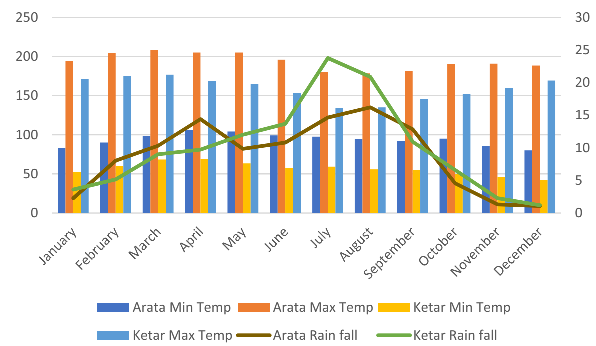

Fig. 4 Climate pattern of Arata and ketar catchment

Table 2 Annual water resources of Ketar and Arata catchment

Catchments	Area (km^2)	Area ratio	Annual water resource (MCM)
K.Abura	3350		408.9
90% flow[a]		1	368
Arata	702	0.21	77.1
Kulumsa	252	0.08	27.7
Chefa	139	0.04	15.3
Bosha	238	0.07	26.1
Other	73	0.02	8

[a] 90% dependable flow is considered

The CropWater estimate for the selected crop is presented below (Table 4). The Cropwat was calculated by taking Ogolcho meteorological station climate data. The average irrigation water requirement found is 603 mm per ha, which is 1206 mm per year including losses which is 12060 m^3/ha/year. The CropWat analysis result showed that the annual Irrigation water demand of the Arata catchment, taking the above crops and proportion, is 6,931,000 m^3. Arata and Bosha irrigations water demands were the first two highest demands in the catchment, 1,8791,400 and 1,687,300 m^3 of water. February, January, and April are the peak irrigation water demand months in order of demand (Table 6). These months are the first irrigation season in the area. June and July are part of the primary rainy season and are under no irrigation water demand.

Table 4 Irrigation area in Arata catchment

Description	Area (ha)
Wheat	245
Potato	122.5
Tomato	49
Onion	73.5
Total Irrigation	490

Livestock water demand

The livestock population for the three points was 5100, 10,900, and 15,110 at the upriver, middle, and downstream, respectively (Table 7).

Taking the average of 14.4 li/day of water consumption the total livestock water demand in the catchment was 466.6 m^3/year. The livestock water demand of the Kulumsa, Chefa, and Arata outlet areas are 76.5, 163.5, and 226.6 m^3/year, respectively.

Seasonal and overall system level annual water balance

In this study, only irrigation and livestock demand were considered (Fig. 5). Other demands like wildlife, birds, and sanitation were not included in the analysis due to a lack of recorded data. However, they are not significant in number. Fish is not available in these rivers (Fig. 6).

The schematics of the Arata rivers and demand site were organized in the WEAP model. The monthly flow amount of each Arata catchment river (Fig. 6), the irrigation area and water demand of each irrigation demand site, and the livestock number and daily water requirement were used as input for the WEAP water balance analysis (Fig. 7).

The total water capital of the Arata catchment is about 76,966 000 m^3 per year (Fig. 8) which is more than the demand of the catchment for irrigation and livestock (Fig. 9).

The result of the water balance analysis showed that all rivers had a deficit or marginal from December up

Table 3 Sub-catchments monthly average flow (m^3/sec)

Catchments	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ketar	1.9	2.4	3.3	4.8	6.2	5.3	16.2	48.6	32.4	12.9	3.8	1.9
Arata	0.4	0.5	0.7	1.0	1.3	1.1	3.4	10.2	6.8	2.7	0.8	0.4
Kulumsa	0.1	0.2	0.2	0.4	0.5	0.4	1.2	3.7	2.4	1.0	0.3	0.1
Chefa	0.1	0.1	0.1	0.2	0.3	0.2	0.7	2.0	1.3	0.5	0.2	0.1
Bosha	0.1	0.2	0.2	0.4	0.4	0.4	1.2	3.4	2.3	0.9	0.3	0.1
Other	0.0	0.0	0.1	0.1	0.1	0.1	0.4	1.1	0.7	0.3	0.1	0.0

Table 5 Climate and evapotranspiration data

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hrs	Rad MJ/m^2/day	Eto mm/day
January	10.3	26.2	65	104	9.1	21.1	3.91
February	12.1	26.6	59	86	8.8	21.9	4.15
March	12.8	27.3	61	86	8	21.7	4.28
April	13.1	28.5	63	69	7.5	21	4.21
May	12.8	28.6	65	69	7.4	20.3	4.1
June	13.3	27	77	130	7.4	19.9	4
July	14.3	24.6	88	95	5.3	16.9	3.22
August	14.1	24.2	91	86	5.8	18.1	3.33
September	13.1	24.3	92	52	5.5	17.7	3.26
October	12.3	26.2	78	69	8.1	21	3.88
November	10.3	25.5	61	104	8.8	20.9	3.95
December	8.8	26.2	61	69	8.5	19.8	3.55
Average	12.3	26.3	72	85	7.5	20	3.82

Table 6 Monthly Irrigation demand per scheme ('000 m3)

Irr	Jan	Feb	Mar	Apr	May	Jun	Jul	Au	Sep	Oct	Nov	Dec	Sum
Sch.1	271.4	362	271.4	217.1	90.5	0	0	0	90.5	90.5	126.6	271.4	1791.4
Sch.2	54.3	72.4	54.3	43.4	18.1	0	0	0	18.1	18.1	25.3	54.3	358.3
Sch.3	253.3	261.0	176.6	248.7	161.2	76.8	0	0	84.4	84.4	164.3	176.6	1687.3
Sch.4	31.3	34.0	23.6	30.0	18.1	7.7	0	0	10.4	10.4	19.2	23.6	207.8
Sch.5	144.8	149.1	101.0	142.1	92.1	43.9	0	0	48.3	48.3	93.9	100.9	964.2
Sch.6	181.0	186.4	126.1	177.7	115.2	54.8	0	0	60.3	60.3	117.3	126.1	1205.2
Sch.7	108.6	144.8	108.6	86.9	36.2	0	0	0	36.2	36.2	50.7	108.6	716.5
Sum	1045	1210	861.4	945.5	531.3	183.1	0	0	348	348.1	597.3	861.4	6930.6

Sch 1- Arata, Sch2 – Balwelde, Sch 3- Bosha, Sch 4- Chefa, Sch 5- Sheld, Sch 6 – Kulumsa, and Sch 7- other irrigation schemes

to March (Tables 8, 9, 10 and 11). Kulumsa river had a 172,000 m^3 water deficit in February, which is the biggest deficit in the catchment. When each river's annual demand and available water were compared, all rivers were positive.

Table 7 Livestock types and population in the Arata catchment

Category of livestock	Population (No)	Avg. Water demand (li/day)
Cattle	16,945	20
Goat	5,291	4
Sheep	5,769	4
Donkey	1,913	12
Horse	851	12
Mule	235	12
Camel	6	37
Sum	31,010	

(Sileshi et al. 2003)

The total unmet demand in the catchment is 58,800 m^3 (Table 12). There is no unmet demand for livestock. The total water capital of the catchment is more than 59,700 000 m^3 per year which is more than the demand of the catchment for irrigation and livestock. However, the catchment needs 58,800 m^3 of

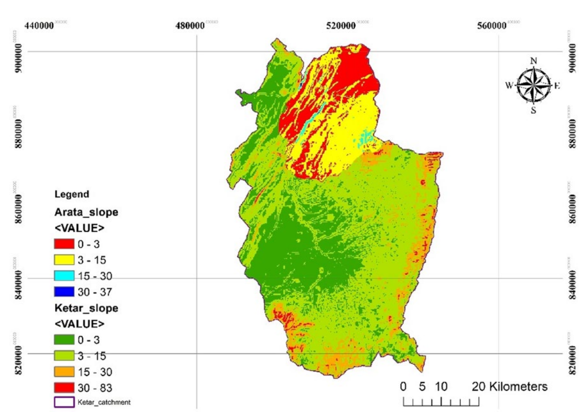

Fig. 5 Slope pattern of Arata and Ketar catchments

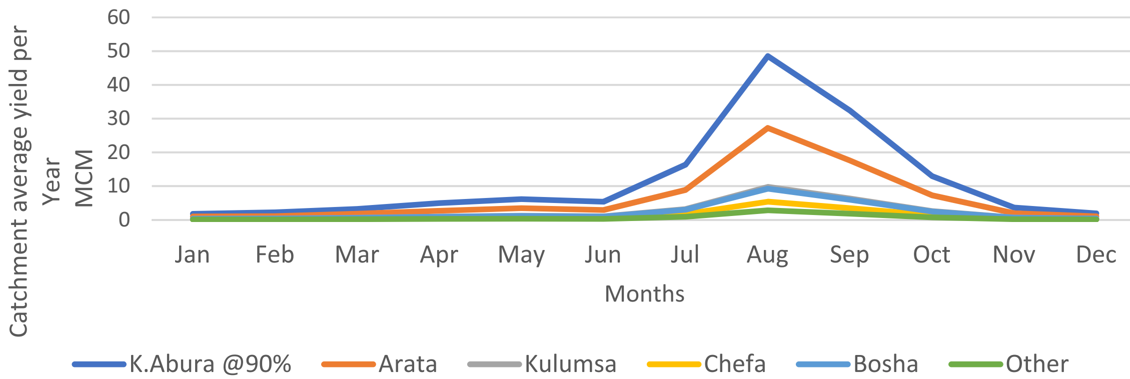

Fig. 6 Mean monthly flow of Arata sub-catchments

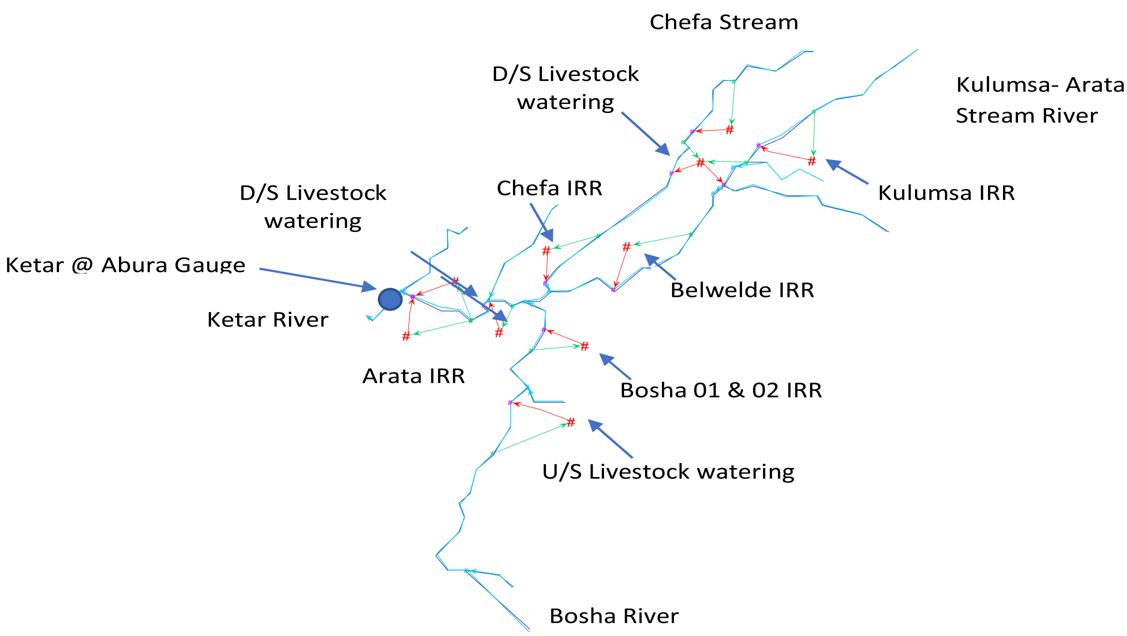

Fig. 7 Schematics of the Arta river water demand analysis (WEAP)

water for January and February to compensate for the deficit (Table 12 and Fig. 10).

Environmental flow

According to the Tennant, Q95, and local thumb rule, the minimum environmental flow for the Arata catchment is 290, 310, and 60 li/sec respectively (Figs. 11, 12 and 13). The Tennant and FDC results showed nearly similar results while the thumb rule result is by far the smallest.

The WEAP and the environmental analysis result showed zero water balance and environmental flow for January and February (Table 13 and Fig. 14).

Discussion

There is no question about the prominence of environmental flow worldwide and its position in Ethiopian water policy (Megan Dyson 2008; MOWR 1999). However, the impact of irrigation water management on environmental flow is soaring. The result of this study verifies the impact of irrigation water management on environmental flow in Arata's small ungauged catchment.

The mean annual flow of water in the Arata catchment was 77.1 MCM. The flow amount of the catchment varies with the rainfall variation; it increases and decreases with an increase and decrease in the rainfall. This pattern

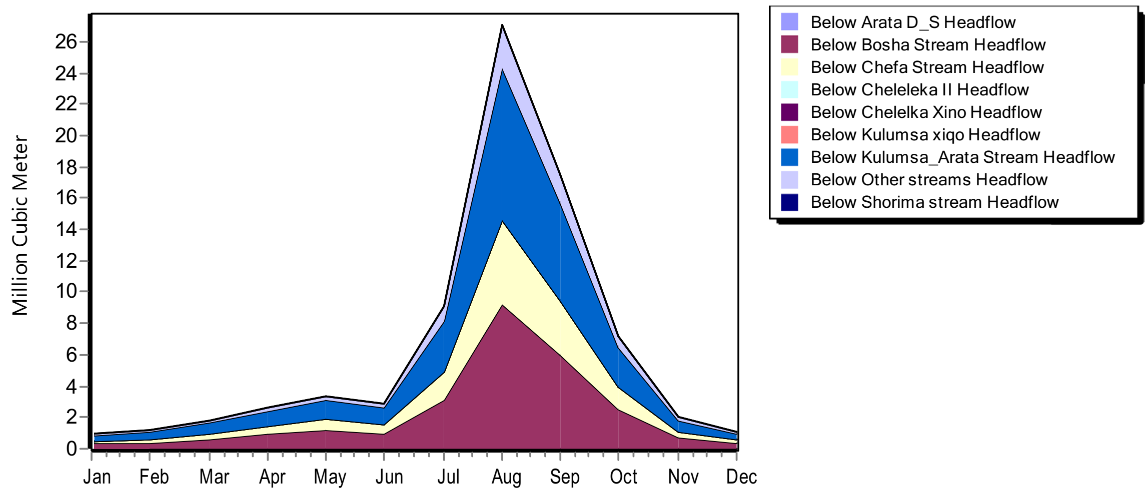

Fig. 8 Average inflows of the sub-catchment

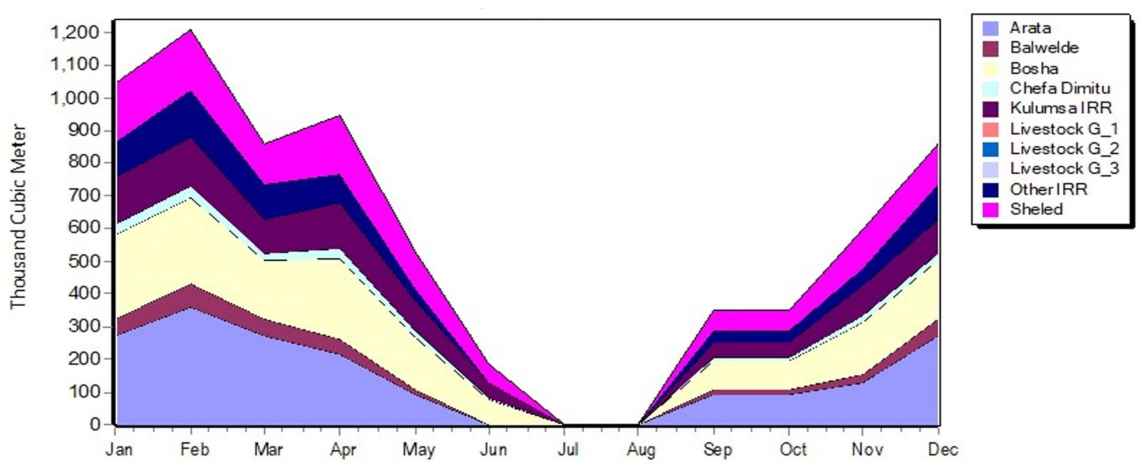

Fig. 9 Total demand for Arata catchment (WEAP Result)

Table 8 Monthly water balance of Kulumsa ('000 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
S. water[a]	346	411	657	950	1205	1034	3251	9659	6228	2579	714	399	27433
Irrigation demand in Kulumsa-Arata river													
Sch-2	54	72	54	43	18	0	0	0	18	18	25	54	358
Sch-6	145	149	101	142	92	44	0	0	48	48	94	101	964
Sch-1	271	362	271	217	91	0	0	0	91	91	127	271	1,791
Livestock	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.08
Sum	470	583	426	402	201	44	0.01	0.01	157	157	246	426	3113
Balance	−124	−172	231	548	1004	990	3251	9659	6071	2422	468	−27	24320

[a] S.water—monthly water in the river

is similar to most catchments in Ethiopia, like Tekeze, Tana, Rift Valley, and Awash catchments (Cherco Jansen, Hurib Hegsdijk, Dagnachew Legesse, Tenalem Ayenew, Petra Hellegers, 2007; Gebremicael et al. 2017; Negash 2011; Seyoum et al. 2015). The flow fluctuation in the rivers over time determines the catchment's water balance

Table 9 Monthly water balance of Chefa River ('000 m3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
S.water	187	227	362	537	683	578	1819	5394	3483	1441	394	214	15,320
Irrigation demand in Chefa River													
Sch-4	181	186	126	178	115	55	0	0	60	60	117	126	1,205
Sch-5	31	34	24	30	18	8	0	0	10	10	19	24	208
Sum	212	220	150	207	133	63	0	0	71	71	137	150	1,413
Balance	−25	7	212	329	550	515	1819	5394	3414	1371	258	64	13,907

Table 10 Monthly water balance Bosha River ('000 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
S.water	348	391	616	907	1178	985	3107	9240	5962	2464	674	375	26,248
Irrigation demand in Bosha River													
Sch-3	253	261	177	249	161	77	0	0	84	84	164	177	1,687
Livestock	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.1
Sum	253	261	177	249	161	77	0.01	0.01	845	157	246	427	3,114
Balance	95	130	439	658	1017	908	3107	9240	5117	2307	428	−52	23,134

Table 11 Monthly water balance other rivers ('000 m3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
S.water	107	120	185	280	341	309	950	2805	1812	745	205	107	7966
Irrigation Demand in Other River													
Sch-7	109	145	109	87	36	0	0	0	36	36	51	109	717
Balance	−2	−25	76	193	305	309	950	2805	1776	709	154	−2	7249

Table 12 Total unmet demand per scheme per month ('000 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Sch.1	0.9	5.5	0	0	0	0	0	0	0	0	0	0	6.4
Sch.2	0.2	1.1	0	0	0	0	0	0	0	0	0	0	1.2
Sch.3	0.8	5.1	0	0	0	0	0	0	0	0	0	0	5.9
Sch.4	4.4	3.8	0	0	0	0	0	0	0	0	0	2	9.8
Sch.5	19	7.6	0	0	0	0	0	0	0	0	0	0	29.8
Sch.6	0.5	2.9	0	0	0	0	0	0	0	0	0	3	3.4
Sch.7	0	2.2	0	0	0	0	0	0	0	0	0	0	2.2
Livestock G_1	0	0	0	0	0	0	0	0	0	0	0	0	0
Livestock G_2	0	0	0	0	0	0	0	0	0	0	0	0	0
Livestock G_3	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum	25.7	28.2	0	0	0	0	0	0	0	0	0	5	58.8

and environmental flow. The smaller the flow in the rivers in the dry period showed correlations with the higher the water demand and the lower downstream flow.

The minimum environmental flow analysis result of the Arata catchment showed 290, 310, and 60 li/sec in the Tennant, Q95, and local thumb rules. The Tennant and the Q95 results are almost similar while the local thumb rule by far varies from the other two. Even though the Ethiopian water policy demands reserve water in the river course, there is zero environmental

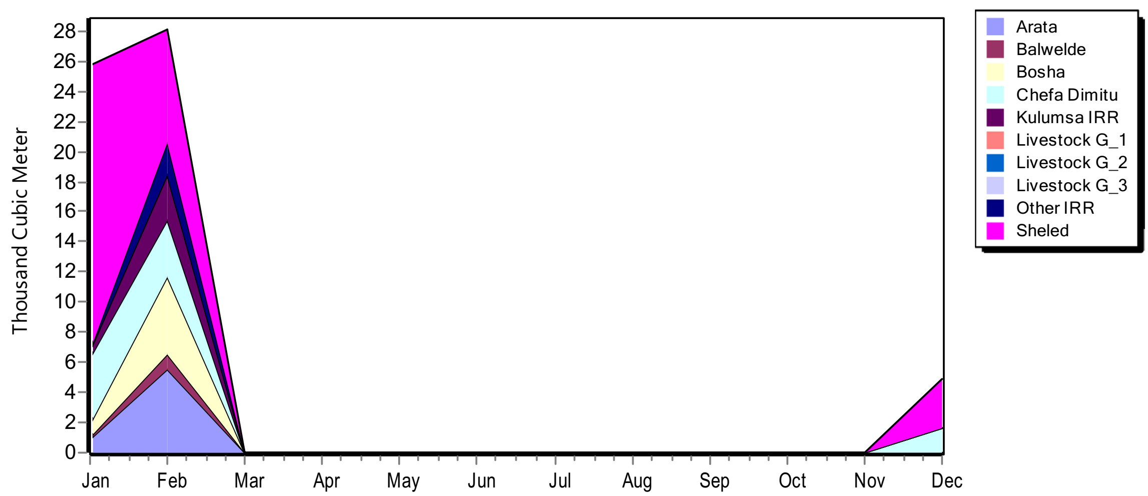

Fig. 10 Unmet demand of the sub-catchments

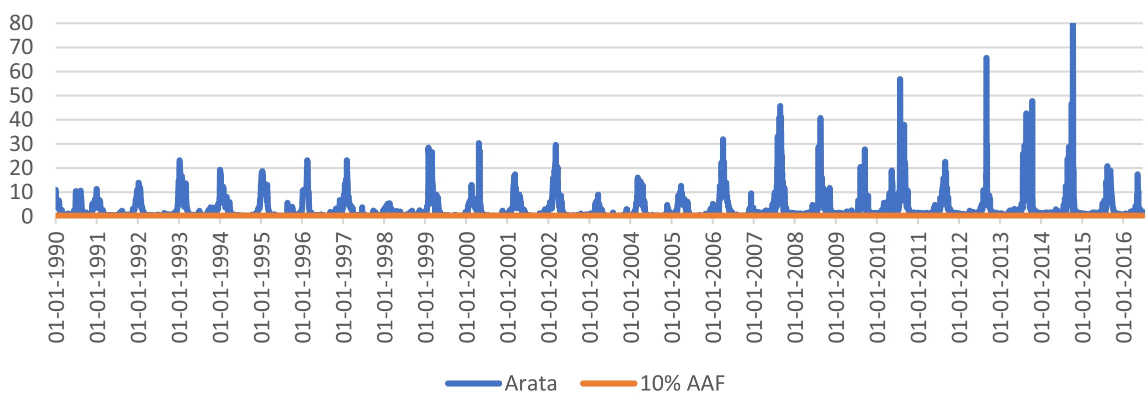

Fig. 11 Ten percent annual average flow of Arata river

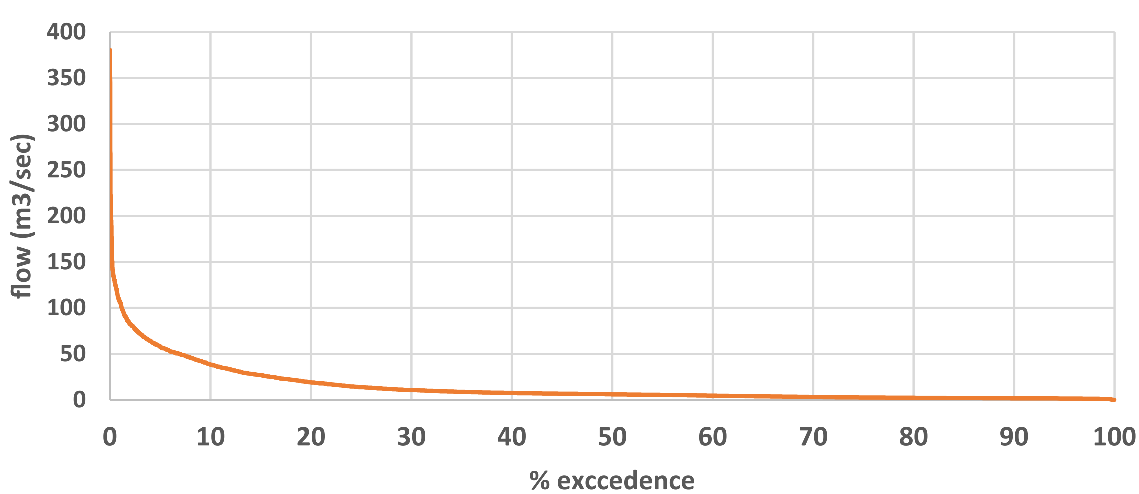

Fig. 12 Ketar river flow duration curve

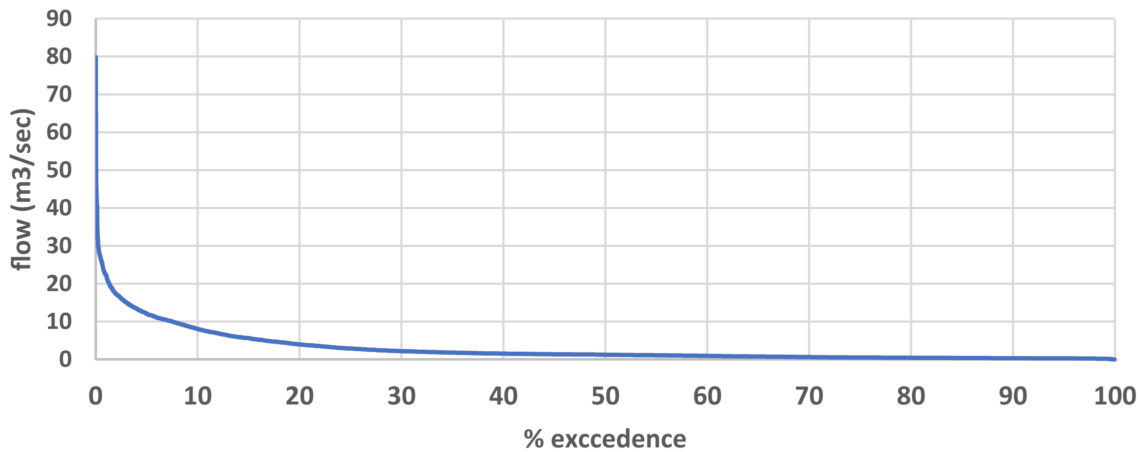

Fig. 13 Arata river flow duration curve

Table 13 The water balance of Arata's catchment ('000 m^3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Flow	989	1149	1820	2674	3408	2906	9125	27099	17485	7229	1987	1096	76966
Demand	1045	1210	861	946	531	183	0	0	348	348	597	861	6931
Balance	−56	−61	959	1728	2877	2723	9126	27099	17137	6881	1390	235	70036
Tennant ENF (%)	*290*	*290*	290	290	290	290	290	290	290	290	290	*290*	
Q95	*310*	*310*	310	310	310	310	310	310	310	310	310	*310*	
LTR **	*60*	*60*	60	60	60	60	60	60	60	60	60	*60*	

* *E.N.F.* Environmental flow

** *LTR* Local thumb rule 15% of January (the driest month of the year)

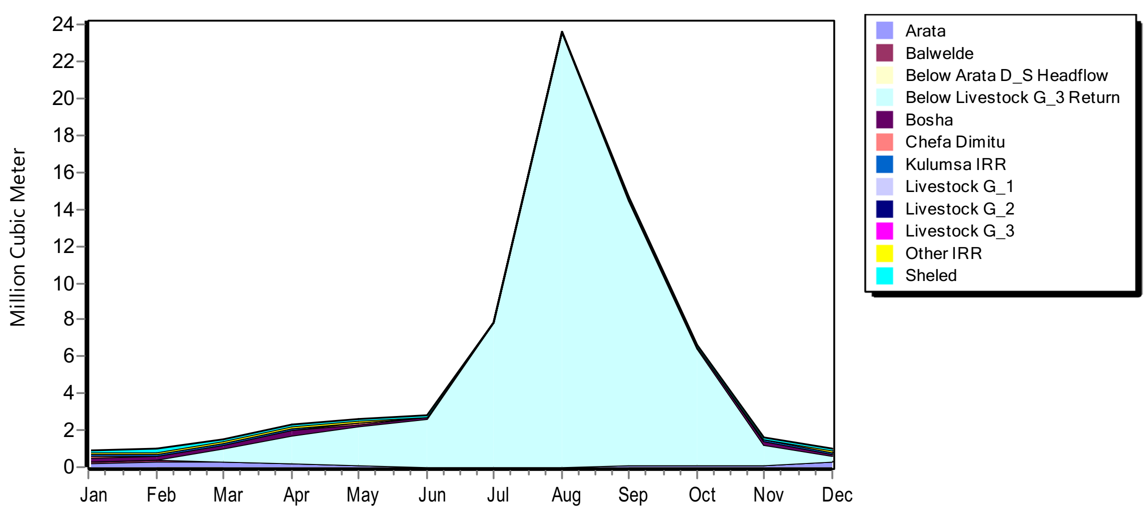

Fig. 14 Environmental flow in Arata catchment

flow in January and February. Smakhtin et al.(2004) state that healthy environmental water requirements range from 20 to 50% of the mean annual river flow. Other fundamental literature recommends at least 20% water release in dry time and about 40% in other times and at least 10% as a minimum requirement (Tennant 1976). In December Tennant's 10% and Q95 recommended environmental flow had 19% and 24%

deficit while the thumb rule environmental flow is 291% more. The rest of the months are by far more than the minimum environmental flow requirement. The highest downstream water releases are in July and August which are part of the main rainy season. To recommend one of the methods and results, a detailed additional investigation on the environmental flow service, especially the dry time environmental flow service, should be conducted.

Irrigation and livestock are the basic elements for the livelihood of the Arata community. The water required for the environment in a catchment is dependent on irrigation water management and abstraction (Pang et al. 2013). For the sustainability of the irrigation development in the catchment, irrigation water abstraction and management should get due attention. The irrigation in the study area only uses 9% of the annual water resource of the catchment, and 91% of the water resource goes downstream to Lake Ziway via Ketar river. The irrigation and livestock water demand of the Arata catchment is similar to other nearby rift valley sub-catchments (Musie et al. 2021; Pascual-Ferrer and Candela 2015; Scholten 2007). However, January and February have 5% and 5.8% irrigation water supply deficits. These 2 months are the months with a water balance deficit and zero environmental flow. These months fail to address the Tennant, Q95, and even the smallest requirement the local thumb rule. Considering further irrigation development expansion and climate change impact, unregulated irrigation water abstraction and management can aggravate the unmet demand and environmental flow.

The Sub Sahara Africa experience is similar to the result of this study. McClain et al. (2013), in Tanzania and Kenya for Ruaha and Mara rivers, where irrigation has a priority, found a zero environmental flow in dry months of the year. The study made by Maliehe and Mulungu (2017) in Lesotho showed irrigation as one factor for unmet environmental flow in a reference year. Another study by Shumet and Mengistu (2016) in central rift valley also came out with a similar result as irrigation being the determinant factor for unmet environmental flow.

The result of this study is mainly limited by the unavailability of historical abstracted water for irrigation and river flow data. Further studies that include the water quality, and detailed ecosystem service to estimate proper environmental flow are important for sound policy recommendations.

Conclusion and recommendation

Environmental flow management in developing countries like Ethiopia is under challenge in the driest months of the year. When it comes to the ungauged small catchments, the emphasis given to knowing the water capital and conducting allocation planning taking environmental flow is insignificant. Small ungauged catchments are ignored and are left as no one's land. This is because the water resource is not quantified accurately and the allocation for development is unintegrated. This study focused on comprehending irrigation's water management impact on environmental flow in ungauged small catchments.

The yearly amount of water available in the catchment is more than the demand for irrigation and livestock. However, December, January, and February are critical months where the irrigation water use is high, and the environmental flow is zero. Small rivers like Arata are the main deficit-prone catchments. However, the abundance of water in the catchment indicates the water balance and environmental flow deficit can be met by constructing a water storage facility. This can be a series of water storage facilities from upstream to downstream that can solve the water balance and the environmental flow deficits. Besides, introducing water-saving irrigation methods and training the farmers in proper irrigation water management can save water for environmental flow.

Given the result, to alleviate the impact of irrigation water use on environmental flow in small ungauged catchments, especially in countries like Ethiopia, a proper water planning policy should be in place, installing flow measuring gauges and organizing historical flow data should get due consideration, irrigation efficiency of the users should be improved with technical support from government and non-government stakeholders. Different storage facilities should be part of such an irrigation system not only considering the crop water demand but also the environmental flow.

In Ethiopia, environmental flow studies are at an infant stage, especially in small ungauged catchments which can be labeled as nonexistent. Rather than a local thumb rule standard environmental flow determination approach should be developed or adopted by additional studies. Environmental flow assessment research that considers the variation of the agroecology of the country that can support policymakers with informed decision-making should be encouraged.

Appendix I

Cropwat results—onion.

Onion							
Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req**
			coeff	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**
Nov	3	Init	0.5	1.91	3.8	0	3.8
Dec	1	Init	0.5	1.84	18.4	0	18.4
Dec	2	Deve	0.53	1.87	18.7	0	18.7
Dec	3	Deve	0.63	2.31	25.4	0.1	25.3
Jan	1	Deve	0.74	2.78	27.8	0	27.8
Jan	2	Mid	0.8	3.12	31.2	0	31.2
Jan	3	Mid	0.8	3.19	35.1	1.1	34
Feb	1	Mid	0.8	3.26	32.6	4.8	27.8
Feb	2	Mid	0.8	3.32	33.2	7	26.2
Feb	3	Late	0.8	3.35	26.8	6.6	20.2
Mar	1	Late	0.77	3.28	32.8	3.8	29
Mar	2	Late	0.74	3.17	31.7	2.7	29.1
Mar	3	Late	0.71	3.03	24.2	7.7	13.6
					341.9	33.9	305.1
					efficiency	0.5	152.55
					T.W. Req		457.65

Cropwat results—tomato.

Tomato							
Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req**
			coeff	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**
Nov	3	Init	0.4	1.53	3.1	0	3.1
Dec	1	Init	0.4	1.47	14.7	0	14.7
Dec	2	Init	0.4	1.42	14.2	0	14.2
Dec	3	Deve	0.41	1.51	16.6	0.1	16.5
Jan	1	Deve	0.57	2.15	21.5	0	21.4
Jan	2	Deve	0.76	2.98	29.8	0	29.8
Jan	3	Deve	0.97	3.86	42.5	1.1	41.4
Feb	1	Mid	1.09	4.42	44.2	4.8	39.4
Feb	2	Mid	1.09	4.51	45.1	7	38.1
Feb	3	Mid	1.09	4.55	36.4	6.6	29.9
Mar	1	Mid	1.09	4.6	46	3.8	42.2
Mar	2	Mid	1.09	4.65	46.5	2.7	43.8
Mar	3	Late	1.02	4.34	47.8	10.6	37.2
Apr	1	Late	0.82	3.46	34.6	23.6	11
Apr	2	Late	0.65	2.72	19	22.8	0
				461.9	83.1	382.5	
				efficiency	0.5	191.25	
				T.W. Req		573.75	

Cropwat results—potato.

Potato							
Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req**
			coeff	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**
Nov	3	Init	0.5	1.91	3.8	0	3.8
Dec	1	Init	0.5	1.84	18.4	0	18.4
Dec	2	Deve	0.51	1.79	17.9	0	17.9
Dec	3	Deve	0.65	2.37	26.1	0.1	26
Jan	1	Deve	0.84	3.17	31.7	0	31.7
Jan	2	Deve	1.02	3.98	39.8	0	39.8
Jan	3	Mid	1.14	4.53	49.9	1.1	48.7
Feb	1	Mid	1.14	4.63	46.3	4.8	41.5
Feb	2	Mid	1.14	4.73	47.3	7	40.2
Feb	3	Mid	1.14	4.77	38.2	6.6	31.6
Mar	1	Mid	1.14	4.82	48.2	3.8	44.4
Mar	2	Late	1.14	4.86	48.6	2.7	45.9
Mar	3	Late	1.06	4.5	49.5	10.6	38.9
Apr	1	Late	0.97	4.09	28.6	16.5	5.1
					494.4	53.2	434.1
					efficiency	0.5	217.05
					T.W. Req		651.15

Cropwat results—wheat.

Wheat							
Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req**
			coeff	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**
Nov	3	Init	0.5	1.91	3.8	0	3.8
Dec	1	Init	0.5	1.84	18.4	0	18.4
Dec	2	Deve	0.56	2	20	0	20
Dec	3	Deve	0.8	2.93	32.2	0.1	32.2
Jan	1	Deve	1.04	3.94	39.4	0	39.4
Jan	2	Mid	1.19	4.64	46.4	0	46.4
Jan	3	Mid	1.19	4.75	52.2	1.1	51.1
Feb	1	Mid	1.19	4.84	48.4	4.8	43.6
Feb	2	Mid	1.19	4.94	49.4	7	42.4
Feb	3	Mid	1.19	4.99	39.9	6.6	33.4
Mar	1	Late	1.12	4.75	47.5	3.8	43.7
Mar	2	Late	0.89	3.8	38	2.7	35.3
Mar	3	Late	0.67	2.85	22.8	7.7	12.2
					458.6	33.9	421.8
					efficiency	0.5	210.9
					T.W. Req		632.7

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Author contributions
All authors contributed to the study conception and design. Material preparation, data collection, analysis, and the first draft of the manuscript writings were performed by the correspondent author, Yohannes Geleta Sida. All the other authors improved the methodology and commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
The manuscript has no individual person's data in any form, hence consent for Publication does not apply to this work.

Competing interests
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