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ADDIS ABABA UNIVERSITY
COLLEGE OF
DEVELOPMENT STUDIES CENTRE FOR
ENVIRONMENT AND DEVELOPMENT STUDIES

**The Impact of Irrigation Water Governance and Performance on Environmental
Flow**

in Ketar Subbasin, Central Rift Valley, Ethiopia

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June 2023

Addis Ababa

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Addis Ababa

Dissertation Approval
Addis Ababa University
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This is to certify that the dissertation prepared by Yohannes Geleta entitled “**The Impact of Irrigation Water Governance and Performance on Environmental Flow**

in Ketar Subbasin, Central Rift Valley, Ethiopia” and submitted in fulfillment of the requirement for the Degree of Doctor of Philosophy (Environment and Development Studies) compiles with the regulations of the University and meets the accepted standards with respect to originality and quality.

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Dedication

Declaration

I, the undersigned, declare that this is my original work, has never been presented in this or any other University, and that all the resources and materials used for the dissertation have been dully acknowledged.

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Annexes 2 Ketar and Arata Schemes Layout

Acronyms

BOAN Bureau of Oromia Agriculture and Natural Resource

CRV Central Rift Valley

CSA Central Statistics Agency

ENMA Ethiopian National Meteorological Agency

ETB Ethiopian Birr

FAO Food and Agriculture Organization

FGD Focus Group Discussion

HH Household

IUCN International Union for Conservation Agency

IWRM Integrated Water Resource Management

IWUA Irrigation Water Users Association

KII Key Informant Interview

MOA Ministry of Agriculture

MoWIE Ministry of Water Irrigation and Energy

MoIL Ministry of Irrigation and Lowland

SSI - Small-scale Irrigation

WB- The World Bank

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Abstract

Failure to maintain adequate environmental flow in quantity, timing, and quality leads to failure to support ecosystems and human livelihoods and well-being. Irrigation is the main contributor to the reduction of water flows in rivers both in quantity and timing. However, it was not thoroughly investigated especially in subbasins and their constitute catchments where small-scale irrigations are dominating. This study was conducted in the Ketar subbasin of Ethiopia to examine the impact of irrigation water governance and performance on environmental flow. The study considered the irrigation season of 2020/21 and 2021/22 taking Ketar Fowafowate, Ketar Genet, Ketar Torben Unshoo, and Arata irrigation schemes as samples. The study looked in depth at the irrigation water governance status, irrigation performance, and water values as determinates of the environmental flow. Data such as the river flow, irrigation, irrigation water user associations (IWUA), and NDVI were collected from different relevant sources using direct observation, MODIS satellite images, surveys from irrigation farmers of the four schemes, and the central rift valley subbasin. The data were analyzed using various tools FAO cropwat 8.0, Arc GIS, Water Evaluation and Planning System (WEAP) tools and Tennant, Flow duration curve, and local thumb rule approach. The result showed that 73% & 21% of the modern and traditional IWUAs in the subbasin were legally registered and collects an average ETB 1200/year/ha which is insignificant for O&M and proper water management. The water distribution disparity among the four schemes from 3.5 – 8.4 li/sec at farmers' plots. 47% of the respondents depicted their dissatisfaction with the water allocation while 62% are satisfied with IWUAs' decision-making transparency. The study also revealed that the IWUAs are compounded with weak infrastructure management that resulted in substantial water loss ranging from 12 to 49%. Regarding irrigation performance as a determinant of environmental flow, the result showed that schemes and irrigation plots near the water resource performed better than the downstream schemes and tail irrigation plots. The average NDVI values of the four irrigation schemes ranged between 0.32 and 0.54 with the highest and lowest at 0.79 and 0.1 respectively. The distribution efficiency of the four schemes was found 49%, 48%, 57%, and 59% for K. Fowafowate, K. Genet, K.T. Unshoo, and Arata Chufa respectively. The result of the multiple values illustrated diverse but also interconnected 24 community-perceived and articulated water values in CRV. In terms of priority water values, the overall result reflects the basic needs of water for food security. The result further illustrates the pluralistic nature of water value and the dichotomy of preference by people of different backgrounds. This shows that irrigation remains to be the dominant water consumer in the subbasin. In general, the total water demand of the subbasin was 27.7 million m³ per year, which is 7% of the mean annual water resource. There was no unmet demand for the water supply and the livestock in the subbasin. Having these in mind, the environmental flow Ketar at Abura was expected to be as 1.4, 1.5, and 0.27 m³/sec according to Tennant, FDC-Q95, and local thumb rule, respectively. Similarly, Ketar at Fite was estimated to be 0.8, 0.9, and 0.28 m³/sec, in the same order as the methods. The overall result of this study showed that up to zero environmental flow in the small catchments of the Ketar subbasin while the main river course, Ketar, is currently safe. In general, there is a deficit for environmental flow in most of the irrigation schemes downstream in December, January, and February. Hence, expanding irrigation without giving

due attention to an environmental flow could lead to more environmental flow risk. To ensure sustainable irrigation development with high water reliability and sound environmental flow, a participatory and implementable water governance policy with tailored technical solutions should come into place. Methodologically, environmental flow estimation and decision support tools must be customized to local ecological requirements by engaging stakeholders (e.g., the local community). Policy-wise, overlapping governance structures are putting multiple water values that are based on environmental flow in CRV under threat. Technically, Ethiopia should standardize irrigation performance measurement by complementing the conventional method with recent remote sensing approaches to alleviate the pressure on environmental flow. Policy directions and decision-making that involve environmental flow and acknowledge its competing uses and aim at reconciling trade-offs are critical for sustainable irrigation development and beyond.

Key Words: environmental flow, irrigation water governance, irrigation performance, water values, ecosystem service

List of Original Papers

1. POLYCENTRIC IRRIGATION WATER GOVERNANCE: IRRIGATION WATER USERS ASSOCIATIONS SERVICE DELIVERY IN KETAR SUBBASIN, ETHIOPIA

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2. IMPACTS OF SMALL-SCALE IRRIGATION ON ENVIRONMENTAL FLOW IN UNGAGGED RIVERS IN AFRICA: EXAMPLE FROM ARATA CATCHMENT, CENTRAL RIFT VALLEY ETHIOPIA

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3. ASSESSING SMALL SCALE IRRIGATION SCHEMES PERFORMANCE: A COMPARATIVE ANALYSIS USING REMOTE SENSING NDVI AND CONVENTIONAL METHODS, AN EXAMPLE FROM ETHIOPIA – AFRICA

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4. SYNERGIES AND TRADE-OFFS OF MULTIPLE WATER VALUES IN THE CENTRAL RIFT VALLEY WATER SYSTEM OF ETHIOPIA

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PART ONE - GENERAL BACKGROUND

1 INTRODUCTION

1.1 Background and Justification

Water is a vital constituent for the economy, socio-cultural, and environment at a global and microenvironment scale. Current global water abstraction is six times larger than 100 years ago and continues to grow at a 1% per year rate(UNESCO, UN-WATER, 2020). Rapid population growth over the last century, urbanization, economic development, improved living standards, and climate changes are the major factors for increasing global water withdrawals (Gleick, 2003; Huitema et al., 2009; Pahl-Wostl et al., 2013). Over 30% of the world's population is living in water scarcity, and the global water demand is expected to increase by 20% to 30% by 2050(Cooley et al., 2013; UNESCO, UN-WATER, 2020). In parallel, waterbody ecosystems globally have been suffering from the growing intensity and over-abstraction of human use (Knieper & Pahl-Wostl, 2016).

The current state of the waterbody ecosystem suffering is explained by the quantity and quality of water resources, resulting in a significant impact on the ecosystem's services such as provisioning, regulation, support, and culture (McClain et al., 2013). This is explained by challenges to food security, safe drinking water supply, cultural and religious ecosystem services, and conflict among users, among others (OECD, 2015; Akhmouch & Correia, 2016). If not efficient water governance and use that responds to who gets what water, when, how, and who has the right to water and related services, and their benefits are in place, the emerging water dilemma will reach the apex and complete environmental flow degradation will be a reality(UNDP, 2013).

According to the report by the World Bank Group (WB, 2016), if the world continues with the current water governance & management approach, global water demand will exceed supply by more than 40% by 2050. This would put at risk 45% of the global GDP, 52% of the world's population, and 40% of grain production(FAO, 2018 citing WEF, 2015; WB, 2016).

Irrigation water governance is a crucial aspect of water governance that can play a significant role in ecosystem services. The irrigation sector, which is the largest consumer of freshwater, utilizes 70% of the world's freshwater (WB, 2016). Irrigation food production is projected to increase by 50% to meet the growing demand for food, which is estimated to increase by 60% by 2050 compared to 2005/7 (FAO, 2017a). This will exponentially increase the amount of water required to produce food for a rapidly growing population, exposing it to more environmental flow degradation and potential ecosystem failure lest improved irrigation water governance and use are in place.

Surface water, mainly river systems, comprises the majority of irrigation accounting for 54% of global irrigation while groundwater irrigation represents 38%. The push on river water is resulting in water shortages for healthy ecosystems (FAO, 2022; Guoyong Leng, Maoyi Huang, Qihong Tang, 2015). Studies tell that 65% of water bodies, including the river systems, are suffering water shortages for healthy ecosystem service (Biemans et al., 2011; FAO, 2022; Palmer et al., 2009). While the pressure is high on rivers, the irrigation water loss between water withdrawal and actual water uptake by the plant is high, specifically in sub-Saharan countries reaching up to 70% (World Bank, 2006). In general, nose-dived irrigation development, poor operation- water use, and water governance alter environmental flow towards nonexistence.

Failure in Environmental flow in quantity, timing, and quality leads to failure to support estuarine ecosystems and human livelihoods and well-being (Brisbane Declaration, 2007). It is more and more clear that failure to address environmental flow requirements has disastrous results for many river users (IUCN, 2003). Studies advised irrigation water governance and use to alleviate the pressure from water bodies like rivers to address proper environmental flow (Batchelor et al., 2014; Enrique Playán, 2018; Kemp & Hafi, 2001; Linstead, 2018; X. Wang, Otto, & Yu, 2013; W. Yu, Uhlenbrook, von Gnechten, & van der Bliet, 2021).

Water governance as the range of political, social, economic, and administrative systems at the right place is a determinant for healthy environmental flow (Claudia Pahl-Wostl, Joyeeta

Gupta, 2008; Rogers & Hall, 2003). The irrigation institutions, policy, and administration which are explained by the level of participation, transparency, effectiveness, efficiency, equity, and administration are other key variables for irrigation water use and environmental flow allocation (Baldwin, McCord, Dell'Angelo, & Evans, 2018; Grigg, 2011; UNDP, 2013).

Water in Ethiopia is an economic, social, political, and environmental entity that needs good governance (MOWR, 1999). Though there are different contradicting data regarding the irrigation potential of country, different data estimate the irrigation potential between 5-21 million ha (GIRDC, 2018; MOWIE, 2018; MoWR, 2009). However, some thing around 7.8 million ha is a verified estimate for the national and regional estimates. The population of the country is growing rapidly at 2.83 %, currently, it is projected to 107,331, 000 (ICPS-CSA, 2013) while urbanization is growing at 3.8% and is expected to reach 5.4% by 2030 (WB, 2016). This results in increased water withdrawals, predominantly for irrigation, which is expected to increase the Small Scale Irrigation (SSI) from the current 0.58 million ha to 1.4 million ha (MOA, 2022)¹ and the medium and the large scale irrigation from 0.5 million ha to 1.2 million ha (MoWIE, 2021). Subsequently, the current irrigation water consumption of 8.7 BCM will rise to 12.2 BCM per irrigation season, in parallel, urbanization demands more water than the current situation. On the contrary, the water resource in Ethiopia is limited, which only covers 0.7 percent compared to 99.3 % (1.13 million Km²) of the land surface.

Ethiopian water resources are classified into streamflow (135BCM), open natural water resources (31BCM), and ground water (60BCM) and the manmade (artificial) open water resource storage is reaching 123 BCM with the completion of the Great Ethiopian Renaissance Dam (GERD) (MOWIE, 2018). Studies indicate that only 12.5BCM exploitable water resources are stored in freshwater (MOWIE, 2018). The majority of the water that accounts for 96% of the water is withdrawn from the surface and groundwater is used for agricultural purposes (Zaki, Haghghi,

¹ Irrigation data in Ethiopia is not well verified, however this data is used in the Ten year strategic plan of the country.

Rossi, Xenarios, & Kløve, 2018, MOWIE, 2018). This has affected the quantity, quality, and timing that constitutes the environmental flows (Linstead, 2018; Causapé et al., 2006; Kendy and Bredehoeft, 2006; Richter and Thomas, 2007; Poff and Zimmerman, 2010; Jägermeyr et al., 2017).

Despite Ethiopia's integrated water resource management approach, which promotes efficient, equitable, and optimum utilization of available water resources to achieve significant socioeconomic development on a sustainable basis, the country is facing water governance and systematic environmental flow considerations. Current environmental flow practices in the country indicate the traditional human-nature paradigm which is 'mankind versus nature' that focuses on the exploitation of natural resources for the needs of people with less regard to the needs of natural ecosystems (PETTS, 1996). As a showcase, Lake Haramaya, which was covering 4.72 km² with an average depth of 3.13m, and 0.15 km³ in 1987 deteriorated to be an ephemeral lake (Lemma, 2011; Spliethoff et al., 2009). Similarly, Lake Abijata experienced a significant reduction in volume and chemistry from 1160MCM (1996) to 599MCM (2009) (Ayenew, 2007). Among many water bodies in the country, the Rift Valley Lakes, Awash, Tekeze, and Wabi Shebelle basins faced water scarcity (MOWR, 2002; Negash, 2011), the surface areas of few lakes have shrunk (Ayenew and Legesse, 2007), and riverine flow in some areas dried (Desalegn et al., 2006) in the name of development. Therefore, it is necessary to examine the irrigation water governance and use impact on environmental flow.

1.2 Statement of the Problem:

The modifications on water bodies, alterations or abstractions, compel environmental flows less reliable for different ecosystem services (Gilvear et al., 2013). These anthropogenic interventions have impacted rivers around the world in declining quality, quantity, and reliability (Knieper and Pahl-Wostl, 2016; Naiman and Dudgeon, 2011; UNEP, 2022). Anthropogenic interventions on rivers are mainly motivated by economic reasons, such as irrigation, industry, and transportation, which can affect environmental flows (Yeakley et al., 2016) and consequently impacting significantly ecosystem services (Acreman, 2016; Anderson et al., 2019a; Gilvear et al.,

2013; Hirwa et al., 2022; Naiman and Dudgeon, 2011; Yeakley et al., 2016). These impacts were explained by fish disaster (Kim, 2019; Palmer et al., 2009), scarcity of water supply (Das Gupta, 2008), food shortage (Stein et al., 2018), cultural and religious water value failure (Dissanayake and Smakhtin, 2007) and conflict within the basin and subbasin on different use (Legesse and Ayenew, 2006) and other problems.

Water bodies in Ethiopia are on the verge of degradation from water grabbing in the name of development, in quality, quantity, and reliability as it is well articulated by Olagunju et al., (2019) due to infrastructural deficits, weak institutional capacity, and palpable political instability in the continent. This failure in quality, quantity, and reliability is hindering the extent of the ecosystem services of the water bodies. Even though Ethiopia has set up a water policy, legislation, and strategy based on IWRM principles & approaches and Basin master plans (MoWR, 1999) with major institutional arrangements at the federal and regional levels including basin authorities, which are in place, the country is failing in water governance specifically in irrigation water governance and environmental flow that benchmarks river ecosystem services.

Studies carried out on irrigation water use, irrigation efficiency, such as Hussain, Hussain, Sial, Akram, & Farhan (2011) shows, 32% of diverted water was used for crop consumptive use, the rest 68% of the water was lost in the irrigation system due to efficiency, which is 35% badly low, besides the main canal and application water loss is 25% for each. Similarly, studies conducted in Ethiopia also shows irrigation water loss as 50% which indicates high water loss (Teshome, Biazin, Wolka, & Burka, 2018). Van Halsema, Keddi Lencha, Assefa, Hengsdijk, & Wesseler (2011) estimated the overall irrigation scheme efficiency in Ethiopia as 35% which is classified as low. Other studies also witnessed 35%, 73%, and 69 % conveyance, water distribution, and water application efficiency respectively, which is classified under poor efficiency or performance (Teshome et al., 2018).

Environmental flow studies clearly show modifications on water bodies- altering or abstracting, limited ecosystem services in the form of goods and services (Gilvear, Spray, & Casas-mulet, 2013). In addition, other studies tells that the change in quantity, quality, and time of the

water available in the river system affects the ecosystem services of the water bodies. These system challenge were indicated by fish disaster (Kim, 2019; Palmer et al., 2009), scarcity of water supply(Das Gupta, 2008), food shortage (Stein, Pahl-Wostl, & Barron, 2018), cultural failure (Dissanayake & Smakhtin, 2007) and conflict within the sub-basin(Legessee & Ayenew, 2006). In Ethiopia, according to Shiferraw & Mccartney, (2019) the hydropower generation of Tis Abay undermined one of the environmental flow service requirement, which is essential for Tis Abay fall. On another account, Tesfaye & Gosain depicted the fish related impact(Tesfaye & Gosain, 2020) in Omo Gibe river. Another study by Derseh, Nigatu, Mhired, & Steenhuis (2020) on environmental flow of Tana and Koga showed the impact of environmental flow on social value of water, pollution, and downstream irrigation users under critical challenges.

In Ethiopia, the water governance that can play an optimization role between Irrigation water use and the environmental flow by determining who gets what and when (Henning Bjornlund, 2016; Loë & Bjornlund, 2008) is not on the right track, due to this the ecosystem suffers badly and irrigation sustainability also is in jeopardy. The irrigation governance in a developing country is portrayed by a lot of limitations; mainly unstable institutions, financial problems, low irrigation fee collection, weak operation and maintenance service, undefined water allocation system, equity, and gender issue, scheme poor efficiency(Enrique Playán, 2018). Different studies conducted in Ethiopia regarding irrigation efficiency (Etissa, Dechassa, Alamirew, Alemayehu, & Desalegne, 2014; Teshome et al., 2018;) indicated governance as one of the critical gaps. However, these studies didn't realte the irrigation governance with environmental flow. As a matter of fact, there are limited studies that try to link environmental flow and irrigation water use; study conduted by Setegn, Chowdary, Mal, Yohannes, & Kono, (2011) tried to show the reason for Lake Harmaya ephemerality due to intensive irrigation in the area. Hailelassie et al., (2016) in their central rift valley study indicated that farmers' poor irrigation water management as the contributor for water shortages at the sub-basin level and within the scheme which results from water governance challenge.

Most of the studies conducted either in irrigation water use, irrigation governance or environmental flow were conducted in a piecemeal, not linked to each other. The impact of one on the other is not researched significantly. In addition, environmental flow study methodologies were not tested in Ethiopia in response to sub basin for environmental flow threshold determination. All the studies conducted worldwide on environmental flow have contributed either to methodology or in defining the river ecosystem services. However, looking to the Ethiopian condition, specifically the data limitation in terms of availability and quality, focusing on environmental flow and methodological verification studies conducted up to now are not significant. This research in its exploratory approach intends in achieving familiarity on the irrigation water governance system in the subbasin, to look for new insights about the environmental flow and irrigation water use efficiency and trinitarian linking. In this process, each theme will be examined scientifically looking into determinants of the irrigation efficiency, the status of the environmental flow, and the irrigation water governance in terms of policy gaps, water allocation limitations, existing water right entitlements gaps, and impacts on environmental flow and damages on ecosystem service and the way-out. By doing this, it will contribute to the world of stock of knowledge and initiates environmental flow studies to establish a customized or new methodology for Ethiopia.

This study will be conducted in Ketar Riverine, Lake Ziway eastern subbasin for various empirical reasons. The river is a significant part of the central rift valley, which is suffering from the result of intensified irrigation schemes, with poor irrigation water use, on the verge of environmental flow failure, and indistinct irrigation water governance (Pascual-ferrer & Candela, 2015; Seyoum, Milewski, & Durham, 2015; Teferra & Beyene, 2014; Yohannes H, Mohammed A, & Elias E, 2017). Ketar is one of the two main tributaries of Lake Ziway that contributes 392 M m³, from eastern aspects of the sub-basin, 9.8 Mm³ /year (Lemi, 2019) water is diverted to irrigate 6055ha in one season. This amounts increase of 50-75% based on the irrigation intensity per year. This, in addition to other factors, has resulted in a significant decrease in lake Ziway water depth from 0.5-0.8m is observed since 2002 (Herco Jansen, Huib Hengsdijk, Dagnachew Legesse, Tenalem Ayenew, Petra Hellegers, 2007; Lemi, 2019). Besides, the rapid population and

economic growth of the subbasin, plus the expansion of water supply and irrigation services are overwhelming the capacity of water governance to manage the resource effectively.

The inefficiency of each irrigation scheme water use has resulted in excess water loss that contributed to impeding the ecosystem service of Ketar river, that can be explained by limiting lake Ziway filling (Herco Jansen, Huib Hengsdijk, Dagnachew Legesse, Tenalem Ayenew, Petra Hellegers, 2007) and decreasing the fishing production of the lake Ziway indirectly (Spliethoff et al., 2009) and limiting Soda Ash production indirectly (Ayenew, 2007; Fetahi, 2016; Shumet & Mengistu, 2016), decreasing the favourable sanitation environment of the community nearby the river, limiting the livestock water supply at downstream- specifically in tributaries (Pascual-ferrer & Candela, 2015), challenging the cultural service of the river to the nearby community, of and constraining the expansion of new irrigation schemes at downstream (Adane, 2014; Shumet & Mengistu, 2016). In general inefficient irrigation is challenging the fauna and flora of the Ketar riverine.

With all anthropogenic triggered stresses in the Ketar river sub-basin, the governance is not effective, even can be said non-existent in terms of demarcated water allocation, and outlined environmental flow procedures. Where there is scanty effort, it ignores the realization that water challenges are multifaceted that require a multidisciplinary approach: hydrology, engineering, economics, political and socio-cultural aspects, more often than not, engineering solutions are still viewed as the answer to water scarcity problems (Olagunju et al., 2019). Dessalegn (1999) observing this situation articulated the condition as “ most water development in Ethiopia focuses on technical matters rather than participatory law and regulation formation, institutions, and participation”. Besides, there is no ecosystem service auditing that is based on environmental flow. This is also asserted by Pahl-Wostl et al. (2013) that there is a large absence of systematic comparative research on water governance systems. Besides, studies that linked irrigation and environmental flow in quality, quantity, and timing can be non-existent (Billib, Bardowicks, & Arumí, 2009)

In general, the sub-basin is suffering due to fragmented water governance institutions in quality, quantity, and timing that may lead to environmental flow failure which makes the riddle vicious. The Ketar subbasin is at risk due to the constraint in the water governance in addition to the technical limitations (Maas, 2011; Stein et al., 2018).

This study tries to understand the methodological and the awareness of the environmental flow gap in the academic, policy, and practitioners and examined the impact of irrigation water use on environmental flow in a scientific way. Accordingly, it will amalgamate the social, policy, institutions, administration, and technical matters like water availability, demand, allocation, and efficiency in examining the irrigation water governance impact on environmental flow specifically in the Keter-Ziway sub-basin. The study will explore the interlink of Irrigation water governance, irrigation performance, and environmental flow in the sub-basin. The existing traditional & modern water governance policy, institutions, and administration including the irrigation water demand, allocation, efficiency, and environmental flow will be considered in the study. In addition it will look at the trinitarian link of the irrigation water use governance and environmental flow in terms of irrigation sustainability.

1.3 Research Objective

1.3.1 General Objective

The major objective of the study is to investigate the effects of irrigation water governance and performance on environmental flow; assessing the interaction of irrigation water governance, irrigation performance, and environmental flow and their implications for the sustainability of irrigation and the environment in the Ketar subbasin.

1.3.2 Specific objectives

. The specific objectives are:

1. To assess the state and challenges of small-scale irrigation water governance in the Subbasin

2. To analyse the irrigation schemes (K. Fowafowate, K. Genet, K.T. Unshoo, and Arata) performance
3. To investigate the effects of the irrigation schemes' water abstraction and use in the Ketar Subbasin on the environmental flow
4. To compare the minimum environmental flow results obtained and recommend minimum environmental flow threshold for small rivers to promote ecosystem services

1.4 Research Questions

This research intended to respond to the following research questions;

1. What is the status of irrigation water governance in the Subbasin?
2. What is the position of the irrigation performance in the Subbasin?
3. How does the environmental flow is affected by irrigation water performance?
4. What is the threshold environmental flow recommended for ecosystem service in the Subbasin?
5. Which method can address the Ketar riverine system threshold environmental flow estimate?

1.5 Literature Review

1.5.1 Water Governance

Water governance has been practiced for more than 5000 years, dating back to the early periods of the Euphrates and Tigris and the Nile(Haddad, 2021; Rost, 2017). It is linked with the beginning of agriculture, settlement, and human self-protection from a flood. Ancient people were able to tame floods and manage irrigation (Moss & Newig, 2010; Wittfogel, 1957). The ancient era was a time of controlling and taming rivers. According to Agyenim, (2011), water governance has evolved from the idea of managing water wisely. The emergence of using water, in addition

to agriculture, industry, energy, transport, and the environment increased the anthropogenic pressure on water that demanded more water management.

The landmark for water governance commencement was tied with Mar del Plata - Argentina in the 1977 water conference. The conference aimed to “ promote a level of preparedness at the national and international level, which would contribute to avoiding a water crisis of global dimensions by the end of the 20th century” (UN, 1977). The conference endorsed continent and function-specific recommendations as a milestone of water governance. Though there were different initiatives between 1980 and 1990 the next water governance milestone was the 1992 Dublin conference. The Dublin conference aimed at integrated water Resource Management (IWRM) and sustainable water development generating four principles; freshwater as a finite and vulnerable resource essential to sustain life, development, and the environment; participatory water development approach; women's role in water management; and recognizing water as an economical value. Then different high-level international conferences continued to address the problem of water resources; like 2000 The Hague Water Security in the 21st Century, the 2001 international conference on Freshwater, 2002 the world summit on Sustainable Development, and the 2003 Kyoto 3rd world water forums and others. All these summits and initiatives recommended different water management policies and action plans. However, the issue of water governance is still the highest priority on the world stage.

The benchmark definition of water governance is the one given by the Global Water Partnership (GWP) that states water governance is the range of political, social, economic, and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society (Rogers & Hall, 2003; UNDP, 2000). Standing on this definition institutions and scholars tried to zoom in and gave amplified and empirical definitions. UNDESA (2003) defines water governance as comprising all social, political, economic, and administrative organizations and institutions, as well as their relationships to water resources development and management. UNDP (2004), describes water governance to comprehend the political, economic, and social processes and institutions by which governments,

civil society, and the private sector make decisions about how best to use, develop and manage water resources. UNDP (2013), more elaborated on the definition and expounded on water governance as who gets what water, when and how, and who has the right to water and related services, and their benefits. These definitions showed the attributes of water governance, their relationship, process, and decisions making as the determinates.

Defining water governance was not obstructed by the above definitions, rather different scholars tried to come up with different definitions and clarifications. For example, Tropp (2007), came with governance as the process of making choices, decisions, and tradeoffs and also indicated the stakeholders ranging from the government up to the private sector. Bjornlund (2014), defined governance as the institutions and processes of decision-making. On the other hand, Pahl-Wostl et al. (2008), zoomed in and defined it as the development and implementation of norms, principles, rules, incentives, informative tools, and infrastructure to promote a change in the behavior of actors at the global level in the area of water governance. Pahl-Wostl, (2015) redefined water governance in her “Water Governance—Concepts, Methods, and Practice” book as “... the social function that regulates development and management of water resources and provisions of water services at different levels of society and guiding the resource towards a desirable state and away from an undesirable state”. Bjornlund (2014) and Ricart et al. (2018), draw water governance as allocating and distributing water equitably, and efficiently, integrating water management approaches, and formulating, establishing, and implementing water policies, legislation, and institutions. The current international arena for water governance is the Sustainable Development Goal (SDG) platform. It has given due emphasis to water governance in its SDG 6 (SDG-UNDP, 2016) “ensure availability and sustainable management of water and sanitation for all”. The agenda argues for water use efficiency, sustainable water withdrawal, and distribution to reduce water scarcity, promote IWRM, debate for protection and restoration of water ecosystem services,

All the above definitions are about the rule of the game and highlight tradeoffs and sustainability. All these definitions are add-ons and supplement each other in giving details about water governance. Besides, the definitions brought on board different stakeholders governmental,

civil society, and non-governmental. Implementable policies, laws, institutions, and stakeholders are the main takeaway of these definitions. Moreover, identifying stakeholders with their roles and responsibilities is key. Water planning, allocation, distribution, water rights, pricing, and governing quantity and quality of water are the key attributes of good water governance.

1.5.1.1 Models of Water Governance

Taking water as a common and global pool resource, a non-excludable public good but with rivalry in consumption (Claudia Pahl-Wostl, Joyeeta Gupta, 2008; Sehring, 2009) and its peculiar characteristics like mobility, spatial and temporal variability and its multiplicity (Sehring, 2009) scholars, policymakers and practitioners have developed different models of water governance from different perspectives. These models can be summed up as monocentric and polycentric governance. Some of these models are based on boundaries like a local, national, basin, and global (Claudia Pahl-Wostl, Joyeeta Gupta, 2008; Moss & Newig, 2010), while others give more consideration to the flexibility of the governance system and propose adaptive water governance, and others being adaptive water governance but focus on multi decision center that is polycentric governance.

According to Claudia Pahl-Wostl, and Joyeeta Gupta, (2008), local-level governance promoters argue water problems as a local problem and it is local problem that should be answered locally. According to these promoters, resource governance has essentially been seen as a local-level issue (Claudia Pahl-Wostl, Joyeeta Gupta, 2008). Malzbender, Goldin, Turton, & Earle (2005) indicated the benefit of such type of governance playing a significant role in the overall water management framework in terms of social adaptive capacity in response to inadequate water supply providing a vehicle to ensure sustainable water resource management at a grass-roots level.

The National-level governance focuses on the benefit of the national economy and society: domestic interests come first. According to this thinking, water is a national resource that should be governed at the national level for the national economy and society's benefit (Claudia Pahl-

Wostl, Joyeeta Gupta, 2008). While the basin-level governance advocates justify this approach as a tool for addressing water governance problems in a systematic and hydrological approach, looking at the problem from the resource (Herrfahrdt-Pähle, 2010).

Scholars like Hoekstra (2011), argue for the global perspective of governance that assumes many water problems go beyond the boundary of local communities due to upstream-downstream connections within river basins. The commodification of water and climate change are pieces of evidence for this argument. on the governance of water. According to this model addressing water problems at the river basin level is not always sufficient. In these cases, it is important to address issues at a global level. Thus, growing attention is being given to multilateralism in the international politics of water and the recognition that local, national, and basin-level water issues are interlinked within a global water system.

Another mode of governance, a lot discussed in numerous pieces of literature, is Adaptive water governance (Claudia Pahl-Wostl, Joyeeta Gupta, 2008; Huitema et al., 2009; Jiménez et al., 2020; Pahl-Wostl, Lebel, Knieper, & Nikitina, 2012). Adaptive water governance is a systematic process for improving management policies and practices by systemic learning from the outcomes of implemented management strategies and by taking into account changes in external factors in a proactive manner. Adaptive water governance is an evolutionary approach process-oriented that accepts and lives with uncertainties, polycentric with multiple centers of power, cross-sectoral analysis, multiple scales of analysis and management, and with comprehensive understanding and integration (Huitema et al., 2009; Leimgruber, 2019; Pahl-Wostl, Holtz, Kastens, & Knieper, 2010). Adaptive water governance is closely associated with polycentric governance (Huitema et al., 2009; Marshall, 2015).

1.5.1.2 Polycentric Irrigation Water Governance

Irrigation water governance is not merely a technical field that can be addressed through infrastructure provision and scientific expertise, but also a political and social one that involves

human values, behavior, and organization (Ricart et al., 2018). Water resources management for irrigation is not only an objective on the farm level but also an overall goal at the basin scale (Billib et al., 2009). Over the past few decades, irrigation management has undergone a remarkable shift from the traditional focus on technical and engineering-based solutions to the construction of robust, flexible, and sustainable institutions and decentralized integrated management (H. H. Yu, Edmunds, Lora-wainwright, & Thomas, 2016).

Polycentric water governance as one of the water governance systems that emerged from the general polycentric governance system that was pioneered by Ostrom in 1961 (McGinnis and Walker, 2010). Polycentric governance is governance with a multi-power center with overlapped multiple authority layers in decision-making and discursing community users who play a critical role in their common resource governance at the micro-environment level (Huitema et al., 2009; McGinnis, 2013; Ostrom, 2014; Vala et al., 2014). It is a multi-level nested relationship having multiple centers among key stakeholders (Bruns, 2021; Carpenter et al., 2017). Other researchers also witnessed that polycentric water governance is an effective tool to solve environmental problems allowing lower-level institutions to exercise localized measures to their local conditions considering the local skill and experience and hard to feel due to multi-checking layers (Bekele and Mekonnen, 2021; McGinnis and Walker, 2010; Ostrom, 1990). Polycentric-Centric Irrigation Water Governance is exercised in different parts of the world as one of the water governance systems (Baldwin et al., 2018; Muchara et al., 2014; Özerol et al., 2018). In such a governance model, IWUAs get a due place in regulating, allocating, empowering irrigators, infrastructure management, and being responsible for well-defined water rights (Grigg, 2011; Veetil et al., 2011).

Irrigation water governance is about a micro-environment level, within a particular type of irrigation, institutional framework, and with different cropping systems (Veetil, Speelman, Frija, Buysse, & Van Huylbroeck, 2011). Irrigation water governance is reliant on the water source and land, involved in irrigation, water users' characteristics, and the institutional environment (X. Wang et al., 2013). Akuriba et al. (2018) promote irrigation governance as the use of rules and

regulations to guard water extraction against irrigation facilities and to enforce order in the management of irrigation resources for long-term sustainable use. This governance concept of global water governance in general and irrigation development in particular centers on polarized views towards centralization and decentralization (Hoanh, Suhardiman, & Anh, 2014). Irrigation water governance in its' institutional form is reliant on Water Users Association which is decentralized governance responsible for well-defined water rights (Veetil et al., 2011). Grigg (2011) defines irrigation water governance as regulating allocation, empowering irrigators, and overseeing organizers.

The above definitions, explanations, clarifications, and amplifications of irrigation water governance can be explained as; an activity of water regulation, allocation, and overseeing by decentralized local, like IWUA, and Subbasin or basin-level water sector institutions for crop production based on the water source and irrigation type. However, being polycentric is not always an advantage, some researchers like Huitema et al., (2009) depicted the disadvantage of polycentric governance systems in terms of economies of scale that may be lost, especially if the basic units in the system are very small. Moreover, collective decision-making is difficult because of the need to accommodate the complexity of spatial patterning, multiple functional overlays, partial polity formation, and variable system coupling. There is no single model of effective water governance; indeed to be effective governance systems must fit the social, economic, and cultural particularities of each country. Nevertheless, there are some basic principles or attributes that are considered essential for effective water governance which is incorporated in the polycentric governance.

1.5.2 Irrigation

Irrigation is the artificial application of water to the soil for crop production (Micheal, 1978). Micheal Bojornberg (2013) defined irrigation as the process of supplying and applying water to the soil by artificial means, primarily to meet the water needs of a growing plant. It is also explained as vital for dry season crop production and to increase land productivity (Akuriba et al.,

2018; Yan et al., 2018). Irrigation also supplements crop water demand by compensating for low precipitation (Siebert et al., 2015). The principal goal of irrigation is to satisfy the crop water requirement amount of water and timing that is determined by the climate of that specific area, the crop type and its stage of growth, soil characteristics, and root development (Herrmann and Bucksch, 2014). In general, irrigation can be explained as the production of more crops with optimum drops.

The history of irrigation dates back to ancient times, with various cultures and civilizations. The International Commission on Irrigation and Drainage (ICID, 2019), takes the history of irrigation back to the Mesopotamian era. According to the ICID (2019), ancient Egyptians practiced basin irrigation using the Nile flood, the Nubians exercised irrigation developing a water wheel-like device, and sub-Saharan Africa started irrigation in the Niger valley by the first or second millennium before Christ, based on water harvesting.

Currently, irrigation is one of the main users of water in most basins worldwide, alongside industrial use, hydropower, water supply, and fisheries. On a global scale, most water use occurs in agricultural production, which is strongly related to irrigation. Irrigated agriculture is recognized as a water-intensive development due to the high dependency of crops on water resource use and management (Morillo et al., 2015). The irrigation sector, as the largest water-using sector in the world, consumes 70% of the freshwater (Billib and Bardowicks, 2009; FAO, 2019; WB, 2016).

1.5.2.1 Irrigation Performance

In the past, studies on irrigation performance had come up with numerous definitions, frameworks, and methodologies for evaluating irrigation, including indicators such as water conservation (Perry, 2011; Santos Pereira et al., 2012), crop water productivity (Molden, D.J. Bos and Burton, 2005; Svendsen, 1992), and socio-economic development (Molle and Wester 2009). Abernethy, (1991) proposed irrigation performance measurement to be aligned with the goals of irrigation schemes such as productivity, equity, profitability, sustainability, and quality of life, and

also to be measured in adequacy, timeliness, and equity. Svendsen(1992) classified irrigation performance into operational, accountability, and intervention assessment. According to Svendsen (1992), irrigation performance assessment can be approached with two complementary models, goal-oriented and natural system-oriented. Both models address irrigation performance to take place in the agricultural main system focusing on acquisition and distribution functions giving due room for operation, maintenance, and support. The goal-oriented performance model focuses on the purpose of the irrigation system, set by influencers like individuals, groups, or institutions, while the natural system-oriented performance assessment model focuses on the system's ability to get input for its existence and expansion.

Bos et al. (1993) and Molden, D.J.Bos, and Burton (2005) classified irrigation performance assessment into five types; operational, strategic, diagnostic, comparative, and benchmarking. Operational performance assessment deals with the daily and routine activities of the irrigation system to ensure doing things right. The strategic performance assessment addresses the efficient utilization of resources and making the right decisions. The diagnostics assessment looks into areas in need of improvement, while the comparative performance assessment compares different irrigation schemes to set a benchmark for better performance. Besides, Molden, D.J.Bos, and Burton, (2005) developed conventional irrigation performance indicators such as the total value of production, water productivity production value per unit of water, and delivery performance.

1.5.2.2 Conventional Irrigation Performance Indicators

The conventional irrigation performance indicators are water conveyance efficiency, distribution efficiency, application efficiency, and water productivity (Howell, 2003; Marinus, G., 2011; Molden, D.J.Bos & Burton, 2005; ORSON W. ISRAELSEN, 1932; Z. Wang, Zerihun, & Feyen, 1996). Irrigation efficiency is one of the widely accepted criteria to measure irrigation development in terms of water use(Clemmens & Molden, 2007; Descheemaeker & Haileslassie, 2011; Herrmann & Bucksch, 2014; Lankford, 2006; Molden et al., 2010). Efficiency in irrigation water use is a ratio of output to input to measure the efficient use of water in irrigation (Molden,

D.J.Bos & Burton, 2005; ORSON W. ISRAELSEN, 1932). These indicators show the effectiveness of the physical system to supply irrigation water from a source to the crop and can be measured separately as conveyance, distribution, irrigation application efficiency, and overall irrigation efficiency(Bos & Wolters, 1990; FAO, 2018; A. Haileslassie et al., 2016; Irmak, S., Odhiambo, L.O., Kranz, W.L. & Eisenhauer, 2011; Molden, D.J.Bos & Burton, 2005).

Conveyance efficiency is the ratio of water delivered to the farm where there is no distribution system or at a distribution point in respect of the diverted water. It tells the proportion of the amount of water loss in the conveying canal(Jensen, 2007; ORSON W. ISRAELSEN, 1932). On the hand, Isrelsen (1932) defined irrigation water-application efficiency as “the ratio of the amount of water that is stored by the irrigator in the soil root zone and ultimately consumed (transpired or evaporated or both) to the amount of water delivered to the farm.’ It is the ratio of the amount of water that is stored in the soil root zone to the amount of water delivered at the farm. The overall irrigation efficiency is the input-output ratio of the whole irrigation scheme in terms of water usage. It considers the conveyance, distribution, and application efficiency(Arara & Wang, 2013; Howell, 2003; Molden, D.J.Bos & Burton, 2005; ORSON W. ISRAELSEN, 1932).

Water productivity is theoretically defined as crop yield per unit volume of water, that is ‘green’ water which is effective rainfall, and ‘blue’ water that is abstracted from water bodies for irrigated areas(Cai & Rosegrant, 2009; Clemmens & Molden, 2007; Molden et al., 2010). However, in this study, only blue water only will be considered for water productivity.

1.5.3 Environmental flow

The generally accepted belief of the Environmental flow concept is set by IUCN ‘Environmental flow is 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’ (IUCN, 2003). This theory evolved from the traditional development rationale, utilization of the water resource for the needs of only human beings exclusive of the requirement

of other ecosystem services (PETTS, 1996; V. Smakhtin, 2008). Still, some consider environmental flow only from the perspective of human direct and indirect benefits from the environmental flow via ecosystem services (M. Acreman, 2016; Bunn & Arthington, 2002), while others consider the water body ecology as one beneficiary for a human being (Naiman et al., 2002; N. L. R. Poff & Matthews, 2013). According to Davis & Hirji (2003), the ecosystem is further 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 most scientists, and which will hold the center stage in this study, 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; N. L. R. Poff, Tharme, & Arthington, 2017a). The environmental flow at the basin level should consider three key principles: equity, efficiency, and sustainability (L. Wang, Fang, & Hipel, 2008).

1.5.3.1 Multiple value of Water for Environmental flow

The redefinition of environmental flow by the Brisbane and Global Agenda highlighted the use of environmental flow for human culture. In parallel, in July 2018, the UN’s High-Level Panel on Water (HLPW) underscored the need to understand, value, and manage water better to meet the Sustainable Development Goal on water and Sanitation, SDG6, and initiated Valuing Water Initiative -VWI (NewForesight, University Nyenrode Business, Wageningen University and Research, & Government of the Netherlands, 2020).

Valuing water is gauging the importance, worth, desirability, and tradeoff strength between different water values. It is complex and can not be rationalized in one constituent owing to the unit, the tool to measure it, and its worth. The delineation of water value is subjective, context-specific, spatial, and time-based. It is valued in different units and instruments. Besides the value being unstable changes and shifts in availability, demand, economic development, and policy

(NewForesight et al., 2020). Values are measured by biophysical, economical, and sociocultural indicators (Balvanera et al., 2022).

Understanding the multiple value of water makes environmental flow assessment comprehensive. The traditional water valuation is economic, monetary, and single-unit focused (Bryan, Raymond, Crossman, & Macdonald, 2010; Costanza et al., 1997; Paudyal, Baral, & Keenan, 2018; Rapport, Costanza, & McMichael, 1998; Smith & Sullivan, 2014). This valuation overlooks the sociocultural value which is intrinsic, instrumental, and relational (Amare Hailelassie, Ludi, Roe, & Button, 2020) and ignores the water share for sociocultural in the environmental flow estimation. The socio-cultural value of water is beyond and above the economic and monetary value and is also difficult to express in monetary terms (Dissanayake & Smakhtin, 2007; Gretchen C Daily, 1997; Amare Hailelassie et al., 2020).

The cultural and spiritual rituals that are directly linked to river flow components have an economic, social, and ecological worth. The high flows use for channel maintenance, the moderate for organic matter recycling, and the low flows are for water quality, local use of people, and other uses. (Dissanayake & Smakhtin, 2007). The low flow usually is linked to the economic and social services of the river system population (Hirji & Davis, 2009) which is exposed to tradeoffs among different water services that usually lead to the degradation of the river water which in turn leads to the loss of important social and cultural benefits besides economic loss (The Brisbane Declaration, 2018).

1.5.3.2 Environmental flow Assessment Methodologies

Environmental flow scientific examination emerged on the realization and apprehensions, over the extent & acceleration, of the flow degradation, deterioration, and impairment of ecosystem function of rivers due to the increasing hydrological alteration and modification on a global scale, and its subsequent environmental degradation (Arthington, 2020; Davis & Hirji, 2003; Livelihoods, 2016; N. L. R. Poff & Matthews, 2013; N. L. R. Poff et al., 2017a; Tharme,

2003). It dates back to the 1940s and got momentum in the 1970s (Arthington, 2020; PETTS, 1996). Since then, considerable scientific literature on environmental flow assessment methodologies developed (JM King, Tharme, & de Villiers, 2008). These environmental flow assessment methodologies are based on hydrology that is flow regime analysis, and ecology studies (M. Acreman, 2016; Arthington, 2020; N. L. R. Poff et al., 2017a; Tharme, 2003; Zeiringer, Seliger, Greimel, & Schmutz, 2018). In general, the decision to determine the environmental flow and the ecosystem service can be considered a hybrid of Science and Social choice decision. The social decision incorporates human interventions and alterations like water abstraction for any development while the science focuses on the quantification and the quality of the water and ecological services.

The academia classifies the environmental flow indicators in a hydrological pattern that is in terms of flow components: low flow, extremely low flow, high-flow pulses small floods, and large floods (Piniewski, Laizé, Acreman, Okruszko, & Schneider, 2014). These flow patterns are measured in five flow component indicators magnitude, frequency, duration, timing, and rate of change of flow (M. Acreman, 2016; N. L. Poff et al., 2013). The variation of hydrological patterns explained in the flow component affects the ecosystem service which is also an indicator of the environmental flow in terms of the ecology (Buchanan, Moltz, Haywood, Palmer, & Griggs, 2013; Tegos, Nalbantis, & Tegos, 2017; Zeiringer et al., 2018).

In optimization of the environmental flow concept, significant progress has shown from the time it came bold from an emphasis on a flat line minimum flow requirement to the development of a holistic, regime-based, approach to flow management, and to natural flow regime which considers whole aquatic ecosystem (Buchanan et al., 2013; Davis & Hirji, 2003; Jager, 2014; Suen & Eheart, 2006). 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, Cross, Dustin, & Duval, 2016; Karakoyun, Yumurtaci, & Dönmez, 2018). The majority of Environmental flow assessment methodologies, more than 200 methods, are categorized into four categories; hydrological,

hydraulic rating, habitat simulation (or rating), and holistic methodologies, (Jackie King, Brown, & Sabet, 2003; N. L. R. Poff, Tharme, & Arthington, 2017b; Reitberger & McCartney, 2011; Tharme, 2003)

1.5.3.2.1 Hydrological method

Hydrological methodologies use simple rules based on flow duration or mean discharge of a river system, it uses readily available flow data (M. C. Acreman & Dunbar, 2004; Karimi, Yasi, & Eslamian, 2012; Tharme, 2003). The main attraction of hydrological techniques is the fact that an answer can be obtained rapidly if gauged records - flow duration and mean discharge- are available, eliminating the time and cost of field data collection. Some methods require the modeling of naturalized streamflow records. There are more than thirteen methods under this category (Lozano Sandoval et al., 2015). The methods do not require a detailed understanding of the ecosystem (Jacobson et al., 2016). This method is dependent on hydrological data and its desktop-based method that uses summary statistics of flow, which may or may not be ecologically relevant, to advise on suitable flows for ecosystem service (Jackie King et al., 2003). This method can be addressed in the Desktop reserve model, tenant, low flow index, and/or flow duration curve analysis(Karimi et al., 2012). The method focuses on identifying the environmental flow-based minimum flows characteristics

1.5.3.2.2 Hydraulic Rating Methods

The hydraulic rating method is sometimes also named habitat retention (Tharme, 2003), transact method, or wetted perimeter (Jacobson et al., 2016) method. It considers changes in wetted perimeter, depth, and other hydraulic variables, measured across single, critical river cross-sections that are assumed to be limited to target biota. The method engages a quantifiable relationship between the quantity and quality of instream ecosystem services and discharge. According to Jacobson et al (2016), it is assumed that a threshold value of the selected hydraulic parameter maintained in the regulated flow regime will maintain stream health and efficiency in ecosystem

service. Besides this method is useful on a local scale(Pastor, Ludwig, Biemans, Hoff, & Kabat, 2014).

1.5.3.2.3 Habitat Rating Methods

Habitat rating methods consider not only how physical habitat changes with streamflow but combine this information with the habitat preferences of a given species to determine the amount of habitat available over a range of stream flows (Jacobson et al., 2016). These simulation models make use of ecohydrological relationships. It is based on correlations between hydraulic parameters and certain ecosystem services (Pastor et al., 2014). The results of this method are presented in the form of specific ecosystem services and stream discharge (Jacobson et al., 2016).

1.5.3.2.4 Holistic Methods

Holistic methods are an amalgamation of hydrological, hydraulic, and habitat simulation methods, and expert knowledge (JM King et al., 2008; N. L. Poff et al., 2010). The approach considers significant flow events, critical flow, and characteristics like flow magnitude and timing for all ecosystem services (JM King et al., 2008; Tharme, 2003). While the hydrological, hydraulic rating and habitat rating systems consider more limited ecosystem services, the holistic approach gives focus on comprehensive ecosystem service, (Jacobson et al., 2016). This method demands years to complete for just one reach (Kendy, Apse, & Blann, 2012)

1.5.4 Empirical studies on Irrigation water governane and environmental flow

Environmental flow studies start to get due attention around the world over the past 50 years employing different approaches from simple to detailed analysis (M. C. Acreman & Dunbar, 2004; McClain, Kashaigili, & Ndomba, 2013). The studies were more focused on determining or deciding the type of river in terms of specific ecosystem services like fish (Bunn & Arthington, 2002; Jacobson et al., 2016; Jager, 2014), reinstating ecological normality and river services(M. C. Acreman & Dunbar, 2004; Tegos et al., 2017) and testing of methodologies (Buchanan et al.,

2013; Ge, Peng, Huang, Qu, & Singh, 2018; JM King et al., 2008; Martin, Labadie, & Poff, 2015; N. L. R. Poff et al., 2017a, 2017b; N. L. Poff et al., 2010). The hydrological and the hydraulic rating approaches are widely used due to their fewer data and time requirement (Challenge, Providing, Flow, Sustain, & Ecosystems, 2006; Lozano Sandoval et al., 2015; Mathews & Richter, 2007; V. U. Smakhtin, Shilpakar, & Hughes, 2006; Tegos et al., 2017).

Among many, the study by Mazvimavi, Madamombe, & Makurira, (2007) has been conducted on environmental flow estimation for 151 Subbasin in Zimbabwe using a desktop hydrological method can be taken as one example. Their finding indicates that the environmental flow demand varies based on the season from 30-60% mean annual runoff in perennial regions, while 20-30% in dry areas. Shiferraw & McCartney, (2019) has exercised environmental flow requirement determination downstream of Lake Tana of Ethiopia. The researchers employed the desktop reserve Hydrological method. The research result indicated that maintaining the basic ecological functioning in this reach requires an average annual allocation of 862Mm³ (i.e. equivalent to 22% of the mean annual flow). Besides, it is depicted to sustain the natural conditions of the ecosystem service the absolute minimum mean monthly allocation, even in dry years, should not be less than 10 Mm³ which is 3.7 m³/sec.

The assessment and application of environmental flows have advanced considerably in the last ten years (Moore, 2004). However, most of the environmental flow studies focused on specific ecosystem services like fish (Bunn & Arthington, 2002; Jacobson et al., 2016; Jager, 2014), reinstating ecological normality and river services (M. C. Acreman & Dunbar, 2004; Tegos et al., 2017) and testing of methodologies (Buchanan et al., 2013; Ge et al., 2018; JM King et al., 2008; Martin et al., 2015; N. L. R. Poff et al., 2017a, 2017b; N. L. Poff et al., 2010). The scientific study of environmental flow has expanded spatially and methodologically. Pieces of literature depict that the USA has been the leading in developing and applying the approaches in recommending environmental flows (Tharme, 2003), and South Africa is also playing a significant role (JM King et al., 2008; N. L. R. Poff et al., 2017a; Sood et al., 2017). All the studies conducted on Environmental flow, including the limited study conducted in Ethiopia, have contributed either to

methodology or to defining the river ecosystem. However, looking at the Ethiopian condition, specifically the data limitation in terms of availability and quality, focus on environmental flow, and methodological verification the study conducted up to now is not significant.

During the second half of the 20th century, world-wise irrigated areas doubled from 140 million hectares (ha) in 1950 to 280 million ha in 2000 (Molle, Wester, & Hirsch, 2010). Zooming in to Sub-Saharan Africa shows the doubling of the irrigated area to increase irrigation's contribution to the food supply from only 5% now to an optimistic 11% by 2050 (Molden, 2013). Between the 1950s and 1980s, vast investments were made in poor countries to increase the area served by large-scale irrigation systems dependent on surface water. A central purpose of this effort was to reduce poverty and to attain national food self-sufficiency (M. Svendsen, 2009). These influenced more irrigation studies to focus on looking for measures that would produce more crops per drop.

Researchers such as Molle et al., (2010), Scott et al. (2014), and Zarghaami (2006) believed improving irrigation efficiency saves water within the scheme and basin, and the saved water either be allocated for environmental flow or to increase irrigation land. Others argue that irrigation efficiency improvement affects the environment by reducing the groundwater recharge and other ecosystem services within the irrigation scheme and it only brings other lands to irrigation (Batchelor et al., 2014; Grafton et al., 2018). Hussain, Hussain, Sial, Akram, & Farhan (2011) conducted a study on the 'Water Balance, Supply and Demand and Irrigation Efficiency of Indus Basin'. The study provided scientific results on water balance and use efficiency estimates. According to this study, 23% of the water is lost in the system besides the outflow to the sea. The empirical results also revealed that the gross water supply for irrigation was about a 10% deficit which will extend to 13%. Also, the study revealed that only 32% of the water was used for crop consumptive use, the rest 68% of the water was lost in the system due to efficiency which is 35% badly low. The main canal and application water loss is 25% for each. The finding showed the water scarcity for additional water use in the system. The analysis followed the normal water

balance equation of the ratio of input to output. This study similar to other studies ignores other ecosystem services other than irrigation, industry, and domestic water supply.

Similarly, there is a lot of irrigation efficiency-related academic work done in Ethiopia (Awulachew & Ayana, 2011; Etissa et al., 2014; Kedir, 2015; Teshome et al., 2018; Van Halsema et al., 2011). These were done to compare modern and traditional, schemes with the same watershed and crop-based efficiency. These studies witness the impact of irrigation water use on environmental flow in one or the other way; the conversion of Lake Harmaya to ephemeral is mainly attributed to the large-scale water withdrawal of lake water to expand irrigation (Setegn et al., 2011), Teshome, Biazin, Wolka, & Burka (2018), in their study of Evaluating the performance of traditional surface irrigation techniques in Cheleleka watershed in Central Rift Valley, Ethiopia, identified the irrigation water loss as 50% which indicates high water loss, Van Halsema, Keddi Lencha, Assefa, Hengsdijk, & Wesseler (2011) estimated the overall irrigation scheme efficiency as 35% which is classified as low to poor conveyance efficiencies and low application efficiencies, and Etissa, Dechassa, Alamirew, Alemayehu, & Desalegne (2014), indicated that there was serious competition among water users in the Awash basin when irrigation water sources are from same sources like rivers and communal schemes. However, Researches conducted in this area mainly focus on irrigation efficiency and farmers on-farm water management. This study wants to go one layer to the deep and consider water availability, allocation, and water governance.

The study conducted by Van Halsema et al. (2011) on the performance assessment of smallholder irrigation in the Central rift valley of Ethiopia revealed an increase in smallholder irrigation schemes in the Central Rift Valley has been associated with the overexploitation of water resources, while the economic viability of these schemes has been questioned. Besides, this study identified the small-scale irrigation efficiency of some schemes as 35%. Poor on-farm water management like inappropriate irrigation scheduling, non-uniform on-farm water distribution, wrong duration of irrigation that emanates from both excesses and insufficient allocation of resources that enables optimum and timely water supply, and also plant water uptake practices result in water shortage in the basin which also result in conflict with the down streamers due to

low or zero flow. Farmers lack sound knowledge of on-farm water management, particularly on how much to irrigate and when to irrigate, as they tend to over-irrigate as long as the water is available, results in water shortages at the Subbasin level and within the scheme which results in water governance challenge (A. Hailelassie et al., 2016).

Teshome et al. (2018) researched the performance evaluation of traditional surface irrigation on three rivers Wessa, Worka, and Wodesa in the central rift valley. According to these research findings, the schemes were characterized by 35%, 73 and 69 % conveyance, water distribution, and water application efficiency respectively, which is classified under poor efficiency or performance. The research concluded the water utilization of these schemes is poor and causes conflict with downstream users which is part of the environmental ecosystem service.

Awulachew & Ayana (2011) in the research conducted to look at the performance of irrigation in Ethiopia at different scales came up with findings that the conveyance efficiency of selected schemes as 58%, 79.7%, 88.6%, 87%, and 78.7% for Hare, Sille, Biltae, Metahra, and Wonji Irrigation schemes respectively. which are inferred as below the benchmark which is 90% for surface irrigation except for Bilate a special case, which is nearly equal to the benchmark, which has a pipe conveyance system. This research deduced that irrigation schemes in Ethiopia are not functioning at their optimal capacity in terms of water use efficiency. Though the research was a landmark in the sector, it was conducted with a limitation of data; dominated by secondary data collected for other purposes like inputs for the master plan and database establishments. Besides, it is limited to only indicting the performance of irrigation schemes deprived of relating to the efficiency impact with environmental flow ecosystem service.

Undoubtedly, irrigation expansion has led to major gains in agricultural production and food security, crop diversification, and profitability (Falkenmark and Lannerstad, 2005), while on the other hand, the development caused significant negative environmental effects by reducing the total flow of many rivers and altering both the seasonality of flows and the size and frequency of flow(Karimi et al., 2012). The irrigation water supply infrastructures like storage, channels,

pumping networks, and groundwater wells alter the free flow of the natural water (Buchanan et al., 2013) and negatively impact ecologically important river flows, and deplete groundwater (Siebert et al., 2015). On the other hand, efficient water management is considered one of the key elements in the successful operation of irrigation schemes to minimize the effect on the natural flow.

Even though studies that relate to environmental flow are increasing, studies that relate to water governance, and irrigation are very limited (Brinegar & Ward, 2009). These efforts are rarely examined with competing water uses in mind, and they are even less frequently analyzed in the context of multifunctional irrigation systems (Ricart et al., 2018). Much of the world's food production depends on water for irrigation (Doll and Siebert, 2000; Howell, 2001; Causapé, Quílez, & Aragüés, 2004). It is therefore essential that the farming sector take a responsible approach toward the sustainable use and conservation of freshwater

The common reasons for environmental flow shortage include the poor performance of irrigation systems and unplanned expansion and intensification. There are many scientific works conducted on irrigation water use in terms of performance assessment and efficiency evaluation. However, these works were significantly steered to compare irrigation schemes performance (Barker & Molle, 2004; Clemmens & Molden, 2007; Derib, Descheemaeker, Haileslassie, & Amede, 2011a; Marinus, G., 2011; Teshome et al., 2018; Z. Wang et al., 1996). There is no significant work-related irrigation water use with the environmental flow.

1.5.5 Conceptual framework

The conceptual framework of this proposed study is developed from literature review based on selected variables among many that affect environmental flow. It focused mainly on irrigation water governance & performance as the determinant variables (Arthington, 2020; Tharme, 2003; The Brisbane Declaration, 2007). It is based on the causal relationship of the variables, connecting them following the theory underlying their relationship. The below flow diagram (Figure.1-1) illustrates the categories; Irrigation water governance, Irrigation performance, environmental flow

policy & institution, and socioeconomic factors and environmental flow with their significant variables and casual relationship. However, this study mainly focused on the irrigation governance and performance variables.

Water governance can be seen in two terms; in terms of the river and the irrigation. This study tried to show the irrigation water governance and performance on the availability of water in the river courses. For ecosystem services. The irrigation and the environmental flow affect each other, when irrigation water use is high the environmental flow quantity and quality will be affected. When the environmental flow is below the threshold and degraded in quality irrigation water availability will be in question. The governance is the mediator or the optimizer for sustainable irrigation and healthy ecosystem service through sound environmental flow.

In general, the irrigation water governance is depicted in terms of the national, and local water governance policy, organizations and water resource administration (availability, allocation and equity). The irrigation performance is explained by the irrigation efficiency, water productivity, and crop coefficient versus NDVI. The irrigation impact on the environmental flow is mainly measured on the quantity and availability of water in time.

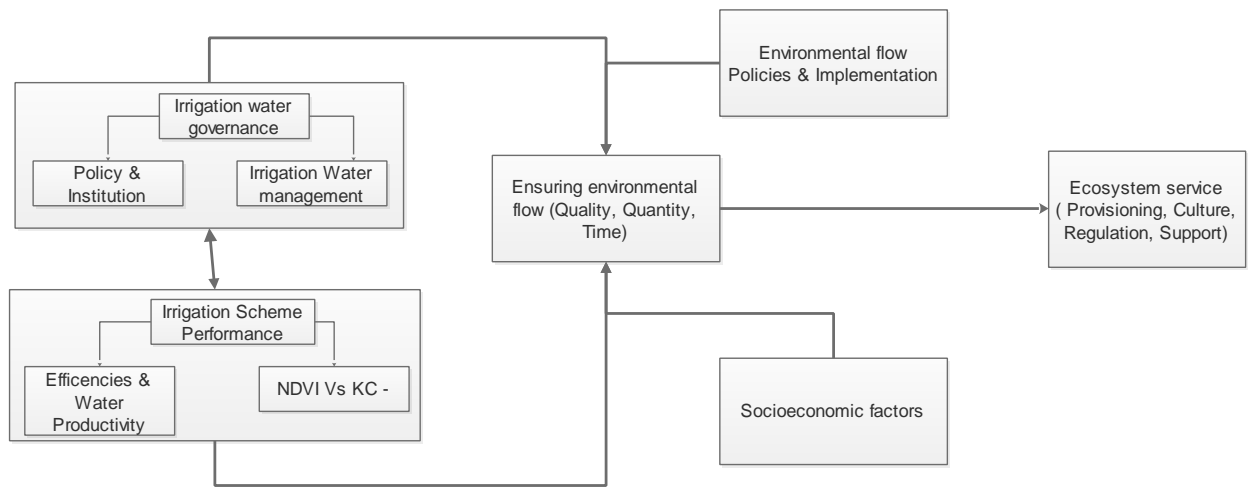


Figure 1-1 The general conceptual framework for Irrigation water use & governance impact on environmental flow

1.6 Study Area

Ketar Subbasin is located in the Ethiopian Central Rift Valley (CRV) lake basin at 160 km south of the capital city, Addis Ababa, Ethiopia between 38°00'-39°30' East, longitude and 7°00'-8°30' North, latitude (Figure.1-2). It encompasses five woredas of the Oromia region, of Arsi and East Shoa Zones; Limu fi Bilbilo, Munesa, Digelu fi Tijo, Tiyo, and Ziway Dugda (East Shoa Zone). The subbasin encompasses 55% of six woredas²; Tiyo and Digalu fi Tijo woredas fully, Lemmu fi Bilbilo, Munesa, Hetosa, and Enkolo Wabe woredas partially (Figure.1-3). The Ketar subbasin is divided into 105 kebeles. It is 3350 km² with a 103.1 km long river course called Ketar.

The subbasin is gauged only at Ketar river at two points Ketar at Fite 505512.9E 859977N and Ketar at Abura 505509E, 892036.8N. The mean perception of the subbasin is 1075 mm while it is typified by 8.2⁰C and 24.5⁰C mean minimum and maximum temperatures in January and February respectively.

² Federal, Region, Zone, woreda, and Kebele are Ethiopian governmental administration structures from top to bottom

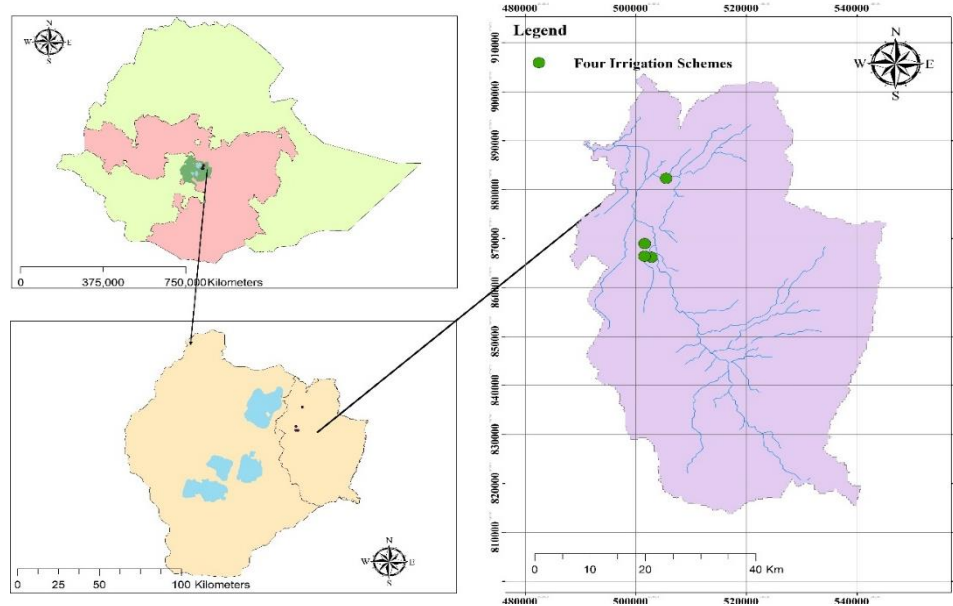


Figure 1-2 Study area Location Map (Ethiopia-Oromia-RiftValley- Ketar-Subbasin)

1.6.1 Rationale for the selection of the study area

Ketar is known for its small-scale irrigation and indistinct irrigation water governance (Pascual-ferrer & Candela, 2015; Seyoum, Milewski, & Durham, 2015; Teferra & Beyene, 2014; Yohannes H, Mohammed A, & Elias E, 2017). It is one of the two tributaries that contribute 57% (396 MCM) of water per year for lake Ziway (Herco Jansen, Huib Hengsdijk, Dagnachew Legesse, Tenalem Ayenew, Petra Hellegers, 2007). 9.8Mm³/year of water is diverted from Ketar to irrigate 6055ha (Lemi, 2019) in one season, this amount can increase by 50-75% based on the irrigation intensity per year. In addition, it is the indirect feeder of the Bulbula River and Lake Abijata and indirect supplier of water for 24754 ha smallholder irrigation farmers that are under irrigation from lake Ziway (BWILDO, 2019).

Moreover, the climate change, population growth, urbanization, and lifestyle change in Ethiopia, particularly in the study area is pressurizing fresh water bodies like rivers. Ketar river with its small feeder streams are exposed for more economic water abstraction overlooking other

water ecosystem services. This initiated to study how irrigation water use and governance affects the environmental flow of Ketar and its tributaries.

The Ketar river system has 30 modern and 184 traditional small-scale irrigation schemes that irrigate (AZILDO, 2017). The number and the area of the irrigation schemes in the subbasin and reduction flow in the downstream areas highlights the environmental flow challenge in the subbasin. Besides, as the subbasin irrigation development is the first in irrigation area in Oromia region and considered as a model for other parts of the region and the country, a study finding in this subbasin can impact other irrigation developments and environmental flows.

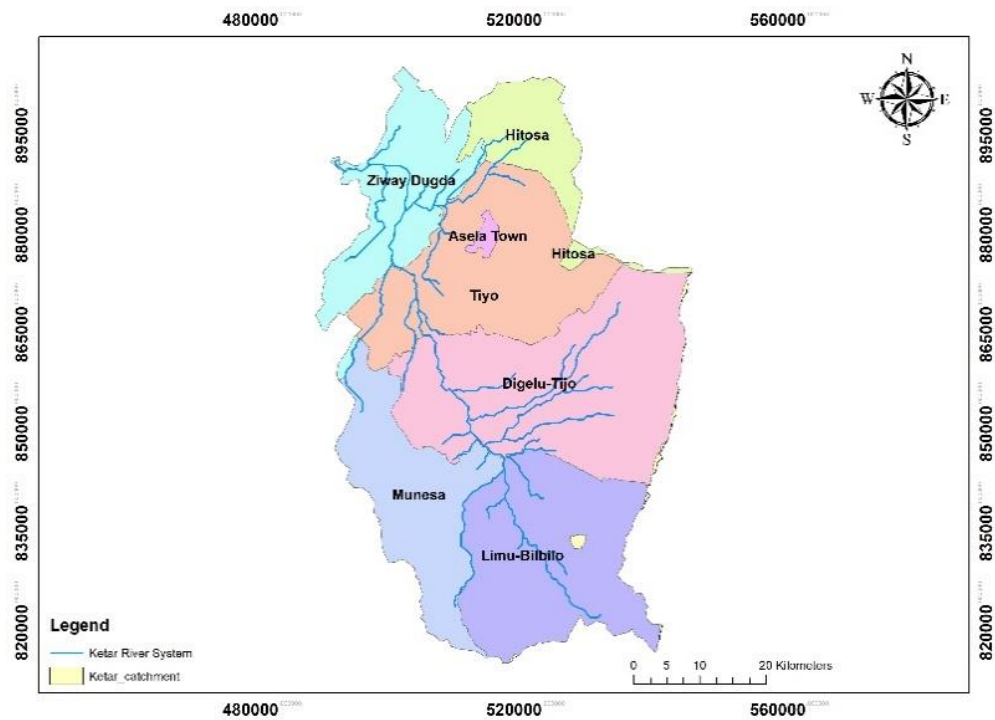


Figure 1-3 Ketar River System and Woredas in the subbasin

1.6.2 Population

According to the Central Statistics Bureau of Ethiopia, the population of the Ketar watershed was 695, 323 (CSA, 2007) (Table.1-1). According to the CSA projection for 2022 the population of the project area is 981,866, which 45.4% and 54.6% are male and Female respectively(CSA, 2022). The religious composition that can draw different water sociocultural water values of the woreda population is 47.4% Christian, 52.1% Muslim, and the rest indigenous religion and others(CSA, 2007). The subbasin serves 1.6 million livestock.

Table 1-1 Ketar watershed Population

Woreda	Population		
	Male	Female	Total
Limu fi BilBilo	89,352.00	91,343.00	180,695.00
Munesa	82,559.00	83,980.00	166,539.00
Diaglu fi Tijo	69,503.00	70,963.00	140,466.00
Tiyo	43,463.00	43,298.00	86,761.00
Ziwau Dugda	60,379.00	60,483.00	120,862.00
Total	345,256.00	350,067.00	695,323.00

Source: CSA 2007

1.6.3 Hydrology, Climate and Soil

The Ketar watershed is characterized by a climate that ranges from sub-humid to semi-arid. The subbasin run down from Kaka mountain, which has an altitude of 4100 meters above sea level, to Lake Ziway at an altitude of 1600 meters. According to Ogolcho and Kulumsa meteorological station data, the mean rainfall amount in the catchment ranges between 620- 1400 mm, and the mean daily temperature ranges from 5⁰C – 28⁰C. The river in general can be specified with an average of 2.5% slope.

The soil in the Subbasin can be classified based on the FAO soil classification system is Chromic Luvisols, Eutric Vertisols, Haplic Luvisols, Mollic Andosols, and Vertic Cambisols(Sime et al., 2020). In terms of land use and land cover, the Ketar watershed is 55.16% agriculture, Afro

plain 17.04%, grassland 14.33%, built-up area 8.65%, wetland 4.09%, and water body 0.06%. The agricultural system in the area is dominated by a mixed farming system.

1.6.4 Irrigation

The subbasin has 30 modern and 184 traditional small-scale irrigation schemes that irrigate (AZILDO, 2017) (Table.1-2). 13 of the modern irrigation schemes are located on the upstream (u/S), 11 in the middle, and 6 downstream (d/S) side of the subbasin. Four schemes; three from the middle and one from the d/s of the subbasin were purposely selected in consultation with the Arsi Zone Irrigation and Pastoralist Development office (AZIPDO). The schemes were selected based on their long-year irrigation experience.

The selected irrigation schemes, Ketar Fowafowate (K. Fowafowate), Ketar Genet (K. Genet), Ketar Torben Unshoo (K.T.Unshoo), and Arata irrigation were considered for irrigation water governance, use, and environmental flow. According to the community, K. Fowafowate's irrigation development was started in 1985 and completed in 1991, while K. Genet, K. T. Unshoo, and Arata were completed in 1993, 1997, and 1992 respectively.

Table 1-2 The study area location and irrigation beneficiaries

Scheme	Location (UTM)		Area (ha)	Beneficiary (HH)		
	East	North		M	F	Total
K. Fowfowate	502848	866068	91	199	56	55
K. Genet	501580	866285	210	265	58	323
K. T. Unshoo	501603	868881	121.7	297	65	362
Arata Chufa	505472	882219	100	279	45	324
Total			522.7	1040	224	1264

Source: Survey (2021)

K. Fowfowate, K.Genet, and K.T.Unshoo are three separate schemes that share one abstraction and conveyance system and are located at the U/S, middle, and D/S of the Ketar river (Anex.2). Each scheme has its independent water user association and a full governance mandate. Arata Chufa is located on the d/s side of the subbasin on the stream called Chufa river.

The primary irrigation crops in the four schemes were onion, potato, tomato, pepper, cabbage, wheat, and maize. However, wheat, potato, onion, and tomato were selected for this study; wheat has a high emphasis in this research due to the encouragement given by the Ethiopian government. It is a strategic crop currently farmers are encouraged to plant by the Ethiopian government while other crops were the default irrigation crops in these schemes.

1.7 Materials and Methods

This section illustrates how the research was carried out, including data collection, organization, and analysis. The required data and analysis methods were identified based on a literature review and data collection experience. The methodology was further enriched through additional literature review sessions and data collection time. The subsection below discussed about the study area, research method, design, data type, and source, as well as sampling, data collection tools, procedures, methods of data analysis for each specific objective to ensure reliability and validity. The detail materials and methods are described in each specific objective section.

1.7.1 Research Approach and Design

Both qualitative and quantitative approaches were employed in this research, with appropriate tools and instruments employed to generate data suitable for both approaches. Primary sources such as focus group discussions (FGD) and interviews with experienced irrigation and environmentalists, communities, and government organizations were used to generate qualitative data, while secondary data were collected from sources such as literature reviews, design documents, archives, and reports. Quantitative data were generated using different measuring tools and questioners, including water flow measuring tools, handheld GPS devices to measure elevations/datums, stopwatches to observe irrigation hours, handheld tapes to measure length and depth, and parshall flumes for flow measuring gauges.

1.7.2 Sampling Techniques and Selection

The Ketar subbasin has 30 modern and 184 traditional small-scale irrigations scheme that irrigates 2188 ha and 4439 ha respectively; a total of 6627ha of land is under irrigation (AZILDO, 2017) upstream of the Ziway lake. The sampling techniques for this research is based on the specific object to address. Each sampling techniques were discussed in each specific objective manuscript. In general, a multi-stage sampling procedure with a mix of probability and non-probability sampling techniques was applied.

In the first stage, the Ketar subbasin is stratified into upstream, middle, and downstream based on location and professional judgment (Table 1-3 & Figure 1-4). Leaving the upstream part which is not dense in irrigation, the middle and downstream were selected for irrigation water governance, use, and irrigation performance sampling purposes. After this stratification, the existing irrigation schemes were categorized into modern and traditional irrigation schemes. Then, modern irrigation schemes were selected taking into account their consideration of environmental flow. Accordingly, four small-scale irrigation schemes, K. Fowafowate and K. Genet from the middle and K. Torben Unshoo, and Arata Chufa from the downstream were selected for water governance and irrigation performance in discussion with Oromia regional, zone, and woreda Irrigation and agriculture offices. These schemes were selected purposively believing they flag and represent the subbasin. All the selected are gravity-fed irrigation systems and are located between 2264 m and 1725m above sea level (a.s.l).

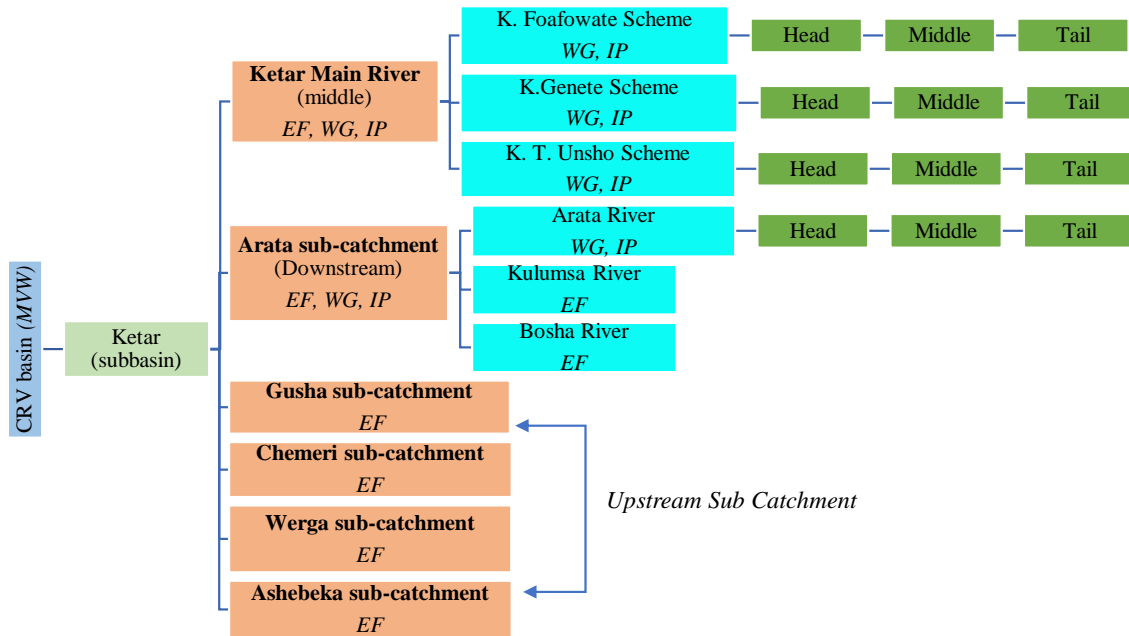


Figure 1-4 Stratification of the study area³

Regarding, the environmental flow to understand the subbasin as a whole and at sub-catchments levels almost all sub catchments (six sub-catchments including Ketar the main subbasin) were considered as a unit of analysis. Even, to learn more about the multiple value of water, the study went one step up to CRV level and collected data and made an assessment. This much data frame is believed to represent and flag the subbasin in terms of irrigation water governance, use, irrigation performance and environmental flow.

Table 1-3 Number of SSI schemes and area in the Ketar subbasin

Reach	Woreda	Modern SSI		No Traditional SSI	
		No of Schemes	Area (ha)	No Schemes	Area (ha)

³ MVW, Ef, WG and IP means selected for multiple value of water, environmental flow, water governance and Irrigation performance assessment

Upstream	Limu fi Bibilo	8	478	39	1102
	Munesa	1	50	7	207
	Diglu fi Tijo	8	629	61	1720
Middle	Tiyo	5	606	19	570
	Ziway Dugda	8	425	28	840
Total		30	2188	154	4439

Source: Survey (2021)

The four selected schemes were stratified into the head, middle, and tail based on the water source proximity. From each scheme, three farmers' plots - from head, middle, and tail - were selected randomly. A total of twelve farmers' plots were observed for irrigation water use.

Regarding the individual irrigation beneficiary household, a random sampling probability method is employed. The total sample size for this study is determined by Yamane Taro (1963) cited in Israel, (2013). Accordingly, 311 irrigation households were selected.

$$n = \frac{N}{1 + N(\alpha)^2}$$

- Where, N is the total number of irrigation household units in the selected SSI (Ketar, and Arta.) which is 1398.
- n is the sample size,
- α Is the level of significance for the present study and it is fixed at 5%.

Based on the above formula, the sample size for the study is determined.

$$n = \frac{1398}{1 + 1398(0.05)^2} \approx 311$$

1.8 Data Types and Source

This study comprehended the independent and dependent variables that vary in quantity or quality. The following independent variables were collected to look at their effect and association with the dependent variables, which were derived based on the specific objective of the research. The independent variables were collected using direct methods such as transact walk, observation, field survey, interview, key informants interview, FGD, documents, and different satellite images.

The primary and secondary data of the subbasin were mainly collected in field observation, from the Oromia region, Arsi zone, Tiyo and Ziway Dugda woreda irrigation, agriculture, environment, and livestock government offices and Irrigation water user associations. Besides, data for environmental flow and multiple values of water were collected from the CRV-constituting areas.

Irrigation data such as area and crops for the year 2015/16 - 2020/21 and livestock data were collected from the woreda irrigation and agricultural offices. River flow data of Ketar at Abura and Fite of 45 years (1972-2016) was collected from the Ethiopian Ministry of Water and Energy (MoWE). The flow data of Ketar at Abur and Fite were used to estimate the sub-catchment rivers flow. The subbasin catchment and rivers were synthesized from 20m X 20m DEM data. The collected data quality was checked, adjusted, and synthesized for the analysis of the water balance and environment flow of the subbasin.

1.8.1 Irrigation Water Governance Inputs

The irrigation Water governance looked at the water governance legal framework, policy, and local institutions (organizations) of Ethiopia. It attempted to inquire into the effectiveness and efficiency of the water allocation system, transparency, and management at the subbasin level. The inputs for examining water governance are:

- i. *Institutional data*: The existence of the irrigation water user association, the legal status, fee collection, committee structures, and gender composition were collected. Except for

the gender composition, all the data are categorical and binary. The gender data is qualitative. These data were collected from IWUA members, Zone, and Woreda Water and Agriculture offices.

- ii. *Water allocation*; Under this category the irrigation water allocation turn modality data were collected (crop-based, time, reach consideration). It is categorical data. These data were collected from the IWUA and its members.
- iii. *Stakeholders*: the stakeholders of the irrigation governance were collected in FGD and KII from IWUA and woreda line institutions.
- iv. *Communication and decision making process*: The communication status, media, directions, effectiveness, and decision making process were collected. These data were collected from region, zone, woreda, and IWUA members.
- v. *By-law*: the existence of the by-law and its implementations on the IWUA level were collected. It is categorical data. This data were collected from the IWUA and its members.
- vi. *Operation and Maintenance (O&M)*: The O & M data is about the modality of the O&M of the scheme, schedule of maintenance, irrigation season, water turn, and agricultural development plan. It is qualitative data. This data were collected from the IWUA and its members.
- vii. *Equity*; The water allocation and distribution approach in respect of gender, the proximity of the plot to the canal, and the source. It is qualitative data. This data were collected from the IWUA and its members.
- viii. *Financial capacity*: *The financial capacity data is about the collection fee, the amount, and its sufficiency for the O&M of the irrigation schemes. .*

1.8.2 Irrigation Performance Inputs

The irrigation efficiency, as discussed in the literature review, considers the water abstraction, conveyance, distribution, and application of the irrigation system. It is about the amount of water from the source up to the tail in delivering water for productivity. The type of data identified in the literature review was broken down conveniently so that they can be collected

as primary or secondary data and also to fit the analysis model where possible. The irrigation efficiency of a scheme is the dependent variable that is determined by different independent variables. The determinant independent variables selected for the analysis of the irrigation scheme efficiency were:

- i. *Water (flow) amount diverted:* The amount of flow diverted from the source, Ketar, and Arata rivers, at the diversion point before it was distributed to the system. This is a continuous quantitative measurement in li/sec or m³/sec throughout the irrigation season. The data were collected as primary data using the parshall flume and repetitive floating methods where the parshall flume measurement was not convenient.
- ii. *Flow at different points on conveyance before distribution:* The amount of water that reached the distribution point, before the distribution structure, was measured to analyze the conveyance efficiency of the system which is part of the scheme efficiency. The flow was measured in li/sec or m³/sec as continuous quantitative data. Less flow from the abstracted amount at different conveyance points indicates a decrease in conveyance efficiency. The data were collected as primary data using the parshall flume, manning's and repetitive floating methods where the two methods were not convenient. It was cross-sectional data.
- iii. *Flow after distribution:* This is the flow that was allocated to one secondary or tertiary irrigation block based on the irrigation system. The flow was taken to analyze the distribution efficiency, which is also part of the scheme efficiency. The flow was measured in li/sec or m³/sec. This flow amount was the base for distribution efficiency. The data were collected as primary data using the parshall flume, manning's and repetitive floating methods where the two methods were not convenient. It is continuous quantitative cross-sectional data.
- iv. *Flow at the farm gate:* This is the flow to one irrigation unit and is very critical for the irrigation efficiency at the farm gate and water productivity. The flow was measured in li/sec or m³/sec. This flow amount indicates the distribution efficiency. The data was

- collected as primary data using the parshall flume. It is continuous quantitative cross-sectional data.
- v. *Crop type*: The crop type is the crop planted during the irrigation season on the whole scheme on the selected plot. It is categorical qualitative data. The crop water requirement of a scheme is dependent on the type of crops. The data was collected from woreda offices and the farm as primary data by observation and inventory.
 - vi. *Crop coefficient*: The crop coefficient is the coefficient that determines the water demand of the crop at a different stage. This data was collected from FAO literature. This was used to compare the water requirement of the crop during the length of the growing period (LGP) and the amount of water supplied during each stage and analyze the efficiency.
 - vii. *Soil type*: The soil type of both irrigation schemes was collected from Oromia Irrigation Potential Assessment Study (OIPA) conducted in 2018. This was an input for the crop water requirement calculation. It helped to know the infiltration rate of the soil and rooting depth. The soil data were verified using the physical observation and feel method in addition to secondary sources like satellite image data. The qualitative texture and type identification was interpreted into quantitative data like the infiltration rate and root depth based on the soil categorical data property from scientific documents and project documents.
 - viii. *Climate data*: The climate data like rainfall, temperature, humidity, wind, sunshine, and others were collected to estimate the crop water requirement. All these data were continuous quantitative time-series data. The data source for the climate was Ethiopian National Meteorological Agency (ENMA) and satellites.
 - ix. *Irrigation Calendar*: The irrigation calendar data is about when the irrigation season or time is; the land preparation and the first planting date and month. These data were collected from the IWUAs.
 - x. *Irrigation Type*: The irrigation type is a significant variable for irrigation efficiency analysis, therefore the irrigation type of the scheme as a whole and specifically the selected

plot were collected by transacting walk and observation. These data are categorical qualitative data.

- xi. Irrigation area (ha):* The scheme's total irrigation area and the irrigation cover in the season are also an input for the scheme's efficiency. It is continuous quantitative data. The data source were satellite images, topography surveys, design data, and observation.
- xii. Structure inventory:* The scheme structure inventory was collected to determine the efficiency of the structures; specifically the canal type and shape. This is qualitative data that indicated the structure status and water loss. The data source was direct observation and inventory.
- xiii. Operation & maintenance* status gives a reason for the irrigation efficiency of the scheme concerning loss and ease of conveyance. The data source was direct observation and inventory.
- xiv. Yield (qun/ha):* The amount of yield gained from the scheme was collected to analyze the water productivity of the scheme. This is quantitative data and was collected based on the type of crop through direct measurement during the harvest time using a balanced scale, woreda agriculture, and from Kulumsa Research center.
- xv. NDVI - MOD13Q1 image data;* The MOD13Q1 image is 250m resolution composite data derived from Moderate Resolution Imaging Spectroradiometer (MODIS) observations that were used for examining the greenness of the crops in each crop development stage. The MODIS Vegetation Index (VI) products provide consistent, spatial, and temporal time series global vegetation conditions at 16-day and monthly intervals. Two-irrigation seasons MOD13Q1 data, from Nov -May 2020-22, were downloaded from the MODIS website -<https://ladsweb.modaps.eosdis.nasa.gov>. A total of 18 months of 36 image data were acquired for NDVI processing.

1.8.3 Environmental flow Inputs

The Environmental flow is explained in terms of the ecosystem services like the provisioning and sociocultural and in water quality, quantity, and timing required to satisfy these services. The

environmental flow data encompasses flow in the river course, before and after abstraction for irrigation, to sustain the ecosystem service of the Ketar riverine system. To examine the environmental flow of the Ketar subbasin, in this study, only two ecosystem service variables namely economic and sociocultural variables were collected. The remaining variables like regulation and supporting service were out of the scope of this work due to the time, finance, and detailed lab requirement.

Provisioning (economic variable): under the provisioning ecosystem service irrigation and livestock data was collected. These data were collected from the MoWE, directly from the field level and woreda offices. The main variables were :

- i. *River Flow (discharge)*: This is a time series of quantitative data. The daily and monthly flow data were collected where measuring gauges were installed. The data were in monthly maximum, minimum, and average and it is measured in m^3/sec .
- ii. *Flow downstream at different reaches*: This is cross-sectional data that was collected at different points or reaches of the river before irrigation water diversion. This data was quantified in li/sec or m^3/sec . The floating and parshall flume was used to measure the flow.
- iii. *Water allocations (flow) for ecosystem service*: This data was inquired from the basin administration, zone, woreda offices, and the community. The data was collected in terms of m^3/sec or river flow mark that was converted to volume and flow per time.
- iv. *Irrigation schemes; The irrigation schemes located on the main river course within the basin were collected. These data are the Number of schemes (quantity), the area under irrigation (ha), and the water requirement of the schemes (m^3/sec or li/sec). This data was collected from woreda agriculture, irrigation, water offices, Kulumsa research, IWUA committees, and IWUA members.*
- v. *Livestock*: The livestock data type and amount, water demand (li/day), and point of water supply (X- Y coordinate data) were collected from woreda agriculture and water offices.

- vi. *Cultural/ Religious ceremonies (Epiphany, Irricha & Tsebele)*. These data were collected using interviews and FGD from the woreda environment, water offices, religious institutions, and communities.
- vii. *Recreation and aesthetics; It is binary data (yes or no) that is present and non-presence in the flow time series, monthly and high, medium, and low flow periods. This data was collected using interviews and FGD from woreda environmental and water offices and communities.*
- viii. *Water value perception, plurality, priorities, and risks*: Households representing different community segments (religion, culture, level of education, etc.) and gender were selected randomly. A questionnaire covering priority water values, values at risk, value complementarity, and conflict was developed and pretested. The household survey was supported by Focus Group Discussion (FGD) and Key Informants Interview (KII) at CRV, Ketar, and its catchments. Topics for FGD and KII cover issues on trends of ecosystem services for triangulation of literature and the household survey results and water value perception and associated plurality, priorities, and risks. Information regarding the water-related events calendar (irrigation, scenery, Thanksgiving Day⁴; orthodox church epiphany, holy water use, etc) was collected through FGD and KII.

In general, This research generated thirty-one categories of independent variables both qualitative and quantitative on the principle of ‘specific data for a specific problem’ (Huitema et al., 2009). The data collected are historical, current, consistent, and relevant for irrigation and environmental flow study.

⁴ Irrecha is the annual Thanksgiving Day of the Oromo people which celebrate annually by the last week of September around major water bodies

1.9 Methods of Data Analysis

1.9.1 Irrigation Water Governance

The method of analysis for this specific objective is qualitative and quantitative. The governance-related data were collected on Likert based on the strength of the governance determinants or characteristics. Accordingly, the data were analyzed in descriptive statistics and qualitative analysis.

- i. *Governance type, effectiveness, and efficiency*: The main governance indicators variables such as fee collection, conflict management, by-law and regulation implementation, water allocation, Operation, and management strength were measured on a Likert scale and were analyzed in descriptive statistics. Besides, the setup of the water governance policy, framework, and institutions was analyzed qualitatively.
- ii. *Water allocation efficiency/ effectiveness*; The irrigation water use key areas of interest or indicators such as water allocation modality, crop type, O&M of the scheme, by law, fee collection, transparency in a decision, water right, attitude about downstream users' interest, and ecosystem services of the river were qualitatively analyzed.

1.9.2 River Flow Estimations

1.9.2.1 Float method river discharge estimation :

The flow amount of the ungauged rivers were estimated using float method, parshall flume and catchment transfer. The float method is mathematically expressed as follows:

$$Q = VA \text{----- eq.1}$$

$$V = dc / t \text{-----eq.2}$$

$$A = w_{av} / de_{av} \text{----- eq.3}$$

Where Q is a discharge in m^3/sec , V – Velocity (m/sec), d_c – longitudinal distance for float (meter), t – time for a float to travel the longitudinal distance marked (sec), w – width of the river at different cross-section (m), d_e – depth of water at the different cross-section where w is measured (m)

1.9.2.2 Catchment Area Ratio Method;

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.

Accordingly, the Ketar river annual mean flow was estimated from the daily flow data while the small catchments river flow was estimated in the catchment ratio method using the 90% dependable flow of Ketar and verified with direct float measurement in January 2020. For the catchment area ratio method and for float discharge measurement the following equation was used.

$$Q_{Sc} = A_{G/A_K} * Q_K \text{ ----- eq.4}$$

Where Q_{Sc} is the discharge of the Small Catchment river m^3/sec , A_G – is the catchment area of Gonde river, A_K – is the catchment area of Ketar (km^2), Q_K is the discharge of Ketar river m^3/sec

The flow result obtained for each rivers were graphed to associate the yearly flow components and the sociocultural water services.

1.9.2.3 Crop Water Requirement

The Irrigation Water Requirement (IWR) for wheat is estimated using CROPWAT-8.0. The Crop coefficients and root depth data were used from FAO 56 - Irrigation drainage paper for crop evapotranspiration and FAO 24 Irrigation drainage paper for crop water requirement (Allen, 1998; Doorenbos & Pruitt, 1977). The climatological data for Arata and K.T.Unshoo was taken from Ogolcho meteorological station, while Kulumsa meteorological station data was used for K. Fowafowate and K. Genet.

1.9.2.3.1 Crop Selection

According to the woreda irrigation office, the dominant crops of the area which were used for this analysis were Tomato, Potato, Onion, 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 as the base year due to the introduction of wheat which is set as a strategic crop for food security and import substitution by the Ethiopian government.

The past three years (2018/19 - 2020/21) irrigation coverage data of the area is considered for the water balance analysis. Accordingly, the irrigation water demand of wheat covering 50%, potato 25%, tomato 10%, and onion 15% of the irrigation area in the catchment was assumed. The 2021/22 irrigation wheat crop coverage growth in the subbasin raised to 95%. 55% of overall irrigation efficiency accounted for the catchment irrigation water requirement (Doorenbos & Pruitt, 1977; Van Halsema et al., 2011).

1.9.2.3.2 Soil

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 FAO (2014) soil survey guideline for soil classification and FAO (2006) field description guideline. Hence, the catchment soil is classified as clay loam in texture

with 167mm/m total available soil moisture(Ethiopian Ministry of Agriculture, 2018a; OWWDSE, 2019). Besides, the irrigation calendar data was collected from the Ziway Dugda woreda irrigation office and Irrigation water users.

1.9.3 Irrigation Scheme Performance Based on the Conventional Methods

1.9.3.1 Seasonal Irrigation Water Supply (SIWS) Vs Irrigation Water Requirement

The SIWS at the plot level was compared to the estimated IWR. The ratio of SIWS to IWR showed the difference between the supplied and the estimate as excess or deficit. One is the theoretical best result of the ratio.

1.9.3.2 Irrigation Efficiencies

All the conveyance, field, and distribution efficiencies were estimated based on FAO Irrigation drainage paper 24 guidelines for predicting crop water requirements and compared with FAO recommendations(Doorenbos & Pruitt, 1977).

1.9.3.2.1 Conveyance efficiency (ϵ_c):

The conveyance or the main canal efficiency is calculated as the ratio of water delivered from the source (Q_s)to the water reached the end of the main canal or distribution point (Q_d) (Doorenbos & Pruitt, 1977; Jensen, 2007; ORSON W. ISRAELSEN, 1932). Mathematically the scheme efficiency is explained as :

$$\epsilon_c = \frac{Q_s}{Q_d} * 100 \text{ ----- Equ.5}$$

1.9.3.2.2 Field canal efficiency (ϵ_f):

The distribution efficiency is calculated based on the FAO guideline for Guidelines for predicting crop water requirements as the ratio of water delivered at the beginning of the secondary

canal (Q_d) to the water reached to field point (Q_f) in this research case (Doorenbos & Pruitt, 1977; Jensen, 2007; ORSON W. ISRAELSEN, 1932). Mathematically the distribution efficiency is explained as :

$$\epsilon_f = \frac{Q_d}{Q_f} * 100 \text{ ----- Equ.6}$$

1.9.3.2.3 Distribution efficiency (ϵ_d)

The distribution efficiency is calculated as the product of the conveyance and field canal efficiency. The ratio of water delivered at the beginning of the distribution point, in this case, the beginning of the secondary canal (Q_d)to the water reached the end of the Secondary canal or field point (Q_f) in this research case(Doorenbos & Pruitt, 1977). Mathematically the distribution efficiency is explained as :

$$\epsilon_d = \epsilon_c * \epsilon_f \text{ -----Equ 7}$$

1.9.3.2.4 Farm Level Water Productivity;

Water productivity is theoretically defined as crop yield per unit volume of water, that is ‘green’ water which is effective rainfall, and ‘blue’ water that is abstracted from water bodies for irrigated areas(Cai & Rosegrant, 2009; Clemmens & Molden, 2007; Molden et al., 2010). However, in this study, only blue water which is supplied at the farm level only is considered for water productivity. It can be termed farm-level water productivity.

the Farm level water productivity (FWP) is the ratio of the yield obtained to the amount of water supplied at the plot level, excluding the conveyance and field canal losses. Mathematically the FWP is explained as;

$$FWP_p = \frac{Y_i}{Q_p} \text{ ----- Equ.8}$$

Where FWP_p = water Productivity at plot level (kg/m^3), Y_i yield in kg, Q_p Water delivered at plot level in m^3

Crop yield is directly correlated with high NDVI(Poudel, Stephen, & Ahmad, 2021); hence high NDVI values are considered a high yield taking other factors as constant. Other factors such as agricultural inputs, agronomic practices, and other related activities were considered the same for all the schemes taking into account their similar irrigation experience and the same government support. Hence, irrigation water is accounted as the main determinant factor for the performance of the irrigation schemes.

1.9.3.3 Irrigation Performance Based on NDVI

The MOD13Q1 is a composite image for NDVI, using blue, red, and near-infrared reflectance, centered at 469 nanometres, 645 nanometres, and 858 nanometres, respectively, to determine the MODIS daily vegetation indices. MODIS vegetation indices are multiple spatial resolutions that provide a spatial and temporal comparison of vegetation canopy, greenness, a composite property of leaf area, chlorophyll, and canopy structure. The VIs are produced in multiple spatial resolutions, providing consistent spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll, and canopy structure(Didan, Munoz, & Huete, 2015). The NDVI is one of the VI products of MODIS since 1981. The NDVI is a normalized transform of the NIR to red reflectance ratio designed and commonly expressed as:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \quad \text{----- Equ.9}$$

The result swings between -1 and 1; -1 and near -1 indicates no or little vegetation while the 1 and near 1 value shows dense and green vegetation.

The MOD13Q1 image is composed of 12 sub-datasets numbered from 0 to 11, with sub-dataset 0 representing NDVI. The raw image is scaled to 0.0001, with pixel values ranging for

example from -1999 to 1993 which requires a raster calculation with 0.0001 to adjust the value between -1 and 1 for the actual NDVI values. Once the scale is adjusted, the MOD13Q1 raster data were prepared for analysis by clipping to the study area, applying appropriate symbology for classification, and reclassifying for NDVI index area analysis.

1.9.3.4 Overall Irrigation Performance Analysis

The analysis of the four irrigation schemes counts on data from MODIS NDVI, weather, and irrigation data such as irrigation water supply and crop. The MOD13Q1 remote sensing image data is used to extract NDVI values for two irrigation seasons, Feb-May 2021 and 2022, The evapotranspiration is computed based on the weather data from the nearby Ogocho station. Data on irrigation crops such as crop type, growing period, and yield were collected from Zone and woreda irrigation offices and the Kulumsa research center. The crop coefficient (KC) value was considered from FAO irrigation and drainage paper 24 – Guideline for predicting crop water requirement (Doorenbos & Pruitt, 1977). After having the NDVI value, irrigation water supply, irrigation efficiencies, and crop yield, both intra and inter-scheme comparative performances were conducted.

1.9.4 Environmental flow

The water balance and environmental flow of the Ketar subbasin were analyzed using Water Evaluation and Planning System (WEAP), Cropwat 8.0, the Tennant method, Flow Duration curves (FDC), and the Local Thumb Rule (LTR). The water balance of small catchments and the Subbasin were analyzed independently and as aggregate. Each river 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 Ketar river as a main water course and other streams. Alongside, two economic and sociocultural water services showcase - the Ketar main river and Gonde small river showcases- were qualitatively analyzed to show the status of the subbasin economic and sociocultural water services management.

The water balance and environmental flow mainly considered economic water value specifically expressed in irrigation and livestock and sociocultural water values like Timikete, Tsebele, and waterfalls.

The irrigation demand was estimated based on the irrigation area and season assuming the critical irrigation period. The irrigation demand sites were grouped based on their sub-catchments for the convenience of modeling. Accordingly, the upstream irrigation demands were considered for one irrigation season while two irrigation seasons were assumed for the middle and downstream areas based on the field assessment. Some small supplementary irrigations, (using the seasonal stream as a water source) in the upstream area that the farmers use were not considered in the model.

The livestock population was collected from the woreda Agriculture office and the livestock water requirement was estimated accordingly. 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 sake of the water balance modeling, these points were grouped into convenient points at the upriver part, in the middle, and downstream. The livestock water demand was analyzed by taking the number of livestock in the river catchment and each reach; upriver, middle, and downstream reach.

The qualitative location data of the livestock watering points, Timikete, Tsebele, and waterfall points were converted to coordinate location data using Google Earth and Google Maps. Then converted locations were mapped in GIS along the irrigation schemes in the subbasin to show their relation with irrigation schemes. Concomitantly, the water demand and management of the sociocultural water services and their relation with irrigation were estimated with key informants.

1.9.5 Water Balance

Water Evaluation and Planning System (WEAP) tool was selected for the analysis of the water balance and environmental flow 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 & Purkey, 2015). Irrigation areas, livestock, and other environmental services were configured as demand-side water uses in the tool. The Arata catchment rivers; Arata, Kulumsa, Bosha, Chefa, and other small rivers were configured as the water supply sources. The result of the WEAP was validated with ground observation and FGD with the irrigation water user association of the Arata irrigation scheme.

Both irrigation and livestock demands were given priority 1 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 & McCartney, 2007). The return flow from the irrigation is very small due to the strict control of the irrigation water user associations and the absence of a drainage system. Besides, 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.

1.9.6 Reliability of Demand sites on the Water Supply sources

The reliability of the demand sites on their water source is the percent of the timesteps in which a demand site's demand was fully satisfied. It is estimated considering the unmet demand duration (months) compared to the demand met duration. Mathematically it is explained:

$$\text{Reliability} = (\text{Demand met months} - \text{unmet months}) / (\text{Demand met months} + \text{unmet months}) \text{----- Equ.10}$$

In general, the result found was verified at the field level in observation and FGD with irrigation farmers and Ziway Dugda and Tiyo woreda irrigation office. The validation was based on the existing irrigation farmers' experience, identifying the water conflict period between upriver and downstream users, and the irrigation area management practice of the woreda.

1.9.7 Environmental flow assessments Methods

In this study, two hydrological methods, the Tennant and Flow duration Curve methods, which uses limited variables were employed for the analysis. Besides, the local area thumb rule experience was used to learn and compare the existing practice with the scientific methods.

1.9.7.1.1 The Tennant Method

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 the Ketar river was used to estimate the Ketar subbasin and its catchment environmental flow.

1.9.7.1.2 Flow duration curves

Besides, 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.

1.9.7.1.3 Thumb Rule

At last, in Ethiopia, specifically the Oromia area, a thumb rule in the ungauged small catchments environmental flow is estimated considering the dry month flow which is estimated by direct measurement in the driest part of a year using the float method. Then, 15% the driest month flow, most of the time the flow of January, is taken as the environmental flow. In this study, the results of the three methods were compared and synthesized.

1.10 Operational definition of Key Terms

Ketar subbasin; Ketar subbasin the part of the Central Rift Valley (CRV) subbasin which in turn is the part of the rift valley basin. Ketar subbasin is interchangeably named as watershed and subbasin in different documents.

River :A river is a natural water course. The United States Geological Survey (USG) defines a river as a system from which water is flowing because of the gravity from a higher altitude to a lower altitude. Rivers ultimately complete their journey by moving into the Lakes, and oceans or infiltrating the ground or an artificial reservoir(Kammerer, 1987). Ketar river is the main watercourse in the subbasin that consists of numerous streams as tributaries.

Low Flow: Low flows are dominated by small, physiologically tolerant, and generalist species(Bunn & Arthington, 2002). Besides low flows occur during times of dry season or period (McMahon & Finlayson, 2003). Low flows determine the temperature, flow velocity, and connectivity, of aquatic habitat that is available for a significant period in the year (Mathews & Richter, 2007; Pahl-Wostl et al., 2013). Sustaining a minimum flow is usually important to guarantee the survival of aquatic species (Hughes & Rood, 2003). However, in this study low flow represents the yearly dry season flow period.

Environmental Flow Alterations :The challenge to environmental flow is due to the human water security often achieved with little consideration of environmental consequences that are by the trade-offs between human and environmental water needs increasing in frequency and amplitude (Pahl-Wostl et al., 2013). The human water security flows for development, require hydraulic infrastructure such as dams and weirs that can cause severe alterations to natural hydrological regimes (Nilsson, Reidy, Dynesius, & Revenga, 2005; Reitberger & McCartney, 2011). There are three types of alterations of the water body flow regime: reservoirs, intersystem water transfer, and irrigation consumption (Dynesius & Nilsson, 1994; Jackie King et al., 2003; JM King et al., 2008). In this study case, the main alteration is the diversion weir for irrigation.

Integrated Water Resource Management (IWRM): Dyson, Bergkamp, & Scanlon (2008) asserts environmental flow is one of the key areas in integrated water resources management. IWRM is a comprehensive way of water management throughout all sectors guaranteeing inclusive participation in decision-making of the water resource (Giordano & Shah, 2014). According to Global Water Partnership, IWRM is “a process which promotes the coordinated development and management of water, land, and related resources, to maximize the resultant economic and social welfare equitably without compromising the sustainability of vital ecosystems.” (Hassing, Ipsen, & Clausen, 2009). Hassing, Ipsen, & Clausen, (2009) explains as IWRM is not a scientific theory that is exposed for proving or disproving. Rather, the execution of IWRM gives room for environmental flow to be considered as one component in trade-offs among ecosystem services.

Modern irrigation in Ethiopia context is schemes that has undergone through scientific studies and constructed by professionals.

Traditional Irrigation is scheme that the water diverted and supplied is by the community local knowledge and local materials.

Irrigation Performance : Irrigation performance is a measure of input-output at the process and results at the irrigation scheme level. It shows the water use efficiency and the water productivity in terms of yield and economy.

1.11 Scope and Limitations of the study

The study is bounded spatially to the Ketar main river course, specifically to its middle and downstream reaches. Besides, the study used one irrigation season primary data that may not represent the irrigation schemes' full performance and environmental flow status. The study was limited in data collection, analysis, and financing, which were partly due to COVID-19, unrest, and limited research funds. In addition flow measurements in the canals is conducted using parshall flume and when parshall flume was not convenient manning and float methods were used. Regarding the NDVI use, all other factors that can affect the yield were assumed similar to sampled

irrigation schemes as all of them have similar irrigation experience and input services. Water quality, and soil data were extracted from the recent Oromia Irrigation Potential Assessment Study Report (OIPA). Besides, the study mainly focused on the instrumental and cultural, and religious value of water. Regarding the methodology, the study considered irrigation field efficiency based on existing literature, and the analysis for environmental flow adopted a hydrological approach leaving other methodologies that need more time and multi experts.

1.12 Structure of the Dissertation

The dissertation is arranged in three sections; section one consisted the first chapter that dealt with the general background, research objective, literature review, study area and the method and materials. The method and materials part discussed the data type, data acquisition and methods of analysis.

The second section of the paper having the second chapter presented the result of the specific objective one; the irrigation water governance status of the Ketar subbasin, finding in published manuscript format. It depicted the model of the irrigation governance in the subbasin and the performance of the sampled four irrigation schemes namely the K. Fowafowate, K. Genet, K.t. Unshoo and Arata irrigation schemes in the eye of the existing policy and irrigation water users perception. The third section consisted the third chapter that presented the irrigation performance status of the K. Fowafowate, K. Genet, K.t. Unshoo and Arata irrigation schemes in conventional indicators and NDVI.

The fourth section consisted of three chapters; chapter Four, Five and Six. The chapter four depicted the synergy of the multi water values in the subbasin as the part of the ecosystem services and the main cultural ecosystem service as a showcases. Chapter five showed the impacts of the irrigation water use on the environmental flow in ungauged sub-watersheds in terms flow amount in time. Chapter six depicted similar work as chapter five but for the Ketar river main course including irrigation water reliability and coverage in the Ketar river system. The last section

presented chapter seven, the Synthesis, Conclusion and Recommendation of the study that summarizes and presents the main take away of the research.

PART TWO – IRRIGATION WATER GOVERNANCE

2 POLYCENTRIC IRRIGATION WATER GOVERNANCE: IRRIGATION WATER USERS ASSOCIATIONS SERVICE DELIVERY IN KETAR SUBBASIN, ETHIOPIA

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Abstract

Polycentric irrigation water governance allows community institutions to deliver better irrigation services. This study examined the Irrigation Water User Associations service delivery performance in the Ketar subbasin, Ethiopia, focusing on four irrigation schemes. The irrigation water user associations in the subbasin were measured on their legal registration and financial status, while the four schemes were examined on their bylaw implementation, decision transparency, water allocation, and infrastructure management. Three hundred eleven (311) randomly selected irrigators were surveyed. The study showed that 73% & 21% of the modern and traditional IWUAs in the subbasin are legally registered and collect an average ETB 1200/year/ha which is insignificant for O&M. The four schemes' water distribution disparity ranges from 3.5 – 8.4 li/sec at farmers' plots. 47% and 62% of the respondents depicted their dissatisfaction with the water allocation and satisfaction with IWUAs' decision-making transparency respectively. The study also revealed that the IWUAs are compounded with weak infrastructure management that resulted in substantial water loss ranging from 12 to 49%. Besides, 70% of respondents witnessed a lack of gender-based irrigation incentives for female irrigators. Improving these services makes the polycentric irrigation water governance play an exponentially beneficial role in alleviating the consequence of unregulated water use.

Keywords: Polycentric Irrigation Water governance, water allocation, decision making, Irrigation water user association

2.1 Introduction

Where water governance is not in place, water abstraction is a substantial risk to food security, healthy ecosystems, and water supply. Water governance at the highest level can be defined as the range of political, social, economic, and administrative systems that are in place to develop and manage water resources and the delivery of water services at different levels of society (Rogers & Hall, 2003; UNDP, 2000). At the operational level, it is set to be measured as the development and execution of norms, values, rules, incentives, informative tools, and infrastructure availability and management (Claudia and Joyeeta, 2008).

Different water governance principles emerged to optimize finite water resources considering the multi-use nature of water, its attributes, its finiteness, and the governance system. Polycentric water governance as one of the water governance systems that emerged from the general polycentric governance system was pioneered by Ostrom in 1961 (McGinnis & Walker, 2010). Polycentric governance is governance with a multi-power center with overlapped multiple authority layers in decision-making and discursing community users play a critical role in their common resource governance at the micro-environment level (Huitema et al., 2009; McGinnis, 2013; Ostrom, 2014; Vala et al., 2014). It is a multi-level nested relationship having multiple centers among key stakeholders (Bruns, 2021; Carpenter, Baldwin, & Cole, 2017). According to Ostrom and other researchers, it is an effective tool to solve environmental problems allowing lower-level institutions to exercise localized measures to their local conditions considering the local skill and experience (Bekele & Mekonnen, 2021; McGinnis & Walker, 2010; Ostrom, 1990).

Irrigation is the main water consumer that needs proper water governance (Bruin et al., 2012; FAO, 2006; WB, 2016). Irrigation Water Users Associations (IWUAs) as key irrigation water governors, at the lower level of the community with other governmental and non-governmental organizations at different levels, portray the polycentric governance model. Though it is not fully demonstrated, Polycentric-Centric Irrigation Water Governance is exercised in different parts of the world as one of the water governance systems (Baldwin et al., 2018; Muchara et al., 2014;

Özerol et al., 2018). In such a governance model, IWUAs get a due place in regulating, allocating, empowering irrigators, infrastructure management, and being responsible for well-defined water rights (Grigg, 2011; Veetil et al., 2011). Mapping the place of IWUAs' structural position and measuring their irrigation water governance services in terms of their capacity to regulate, allocate, their meaningful transparent communication and participatory level, blended along with infrastructure management (Atosina et al., 2020) sum up the irrigation water governance status of a country.

Irrigation water governance in Ethiopia is set at two tiers, national and regional levels. The national level institutions, the Ministry of Water and Energy (MoWE) and the Ministry of Irrigation and Low Land Development (MoILD) are mandated to regulate and set the country's water resources and irrigation development policies, respectively. Likewise, regional states govern intra-region water resources in their respective areas through the regional, zone, and Woreda water and irrigation development mandated offices. At a micro-environment level, the IWUAs are accountable for irrigation water governance and development.

Irrigation in Ethiopia, size-wise, is classified as small (<200ha), medium (200-3000ha), and Large (>3000ha) scale (MOWR, 1999). Besides, irrigation in the country is also classified as traditional⁵ and modern⁶. The IWUAs are responsible for field-level water governance for large and medium irrigations and for scheme administration of small-scale irrigations that includes infrastructure management, water governance, and the micro-environment. IWUAs in the Ethiopian case are legal bodies for the micro-environment level irrigation governance (FDRE, 2014; ORNG, 2017). Besides, they are key determinants for new irrigation development and up and downstream water management.

⁵ Traditional Irrigation scheme is where the water is diverted and supplied by the community with their own local knowledge and local material

⁶ Modern irrigation in Ethiopia context is schemes that has undergone through scientific studies and constructed by professionals

This paper tried to show the irrigation water governance in Ethiopia at a community level; IWUAS' service delivery performance as a community-level irrigation water governor entity. The study was conducted taking all irrigation schemes in the Subbasin while focusing on four irrigation schemes namely; Ketar Fowafowate, Ketar Genet, Ketar Torben Unshoo, and Arta Small-scale Irrigations (SSI). First, the study compared the legal registration status and financial capacity of the irrigation schemes in the subbasin to show the selected IWUAs' legal and financial capacity compared to other irrigation schemes in the subbasin. Then, zooming into the selected four schemes, it examined in-depth the bylaws implementation, water allocation, IWUA planning and decision-making transparency, irrigation infrastructure management, and gender-based irrigation incentives to show their service delivery performance in the eyes of their members.

The study was conducted on the proposition that community-level irrigation water governance effectiveness demands more empowerment of irrigation users technically, financially, in planning & decision making, and beneficiaries' participation. Thus, the findings of this study give to some extent an in-depth sight of Ethiopian IWUAs' irrigation water governance for the Ethiopian government and academia, including the Sub-Saharan Africa Region (SSA) community. Local, regional, and national governments can learn about the strong side, and the missing and weak links of the existing practices. Moreover, the study contributes to the betterment of water governance in general and irrigation water governance in particular.

2.2 Materials and Methods

Primary and secondary data were generated based on qualitative and quantitative methods. Two types of primary data were collected; irrigation water governance status perception water data at the scheme and farmers' plot level. The perception data were collected from 311 randomly selected respondents from four schemes, Ketar Fowafowate (K. Fowafowate), Ketar Genet (K. Genet), Ketar Torben Unshoo (K.T. Unshoo) which have one common water abstraction structure and system, and from Arata Irrigation located in the same Subbasin but a different stream. The

projects were selected to represent the Subbasin in consultation with zone-level⁷ government officials. Respondents were selected from Ketar Fowafowate, Ketar Genet, Ketar Torben Unshoo, and Arata as 71, 81, 77, and 78 respectively proportionally based on their irrigation user members. The total sample size for this study is determined by Yamane Taro (1963):

$$n = \frac{N}{1 + N(\alpha)^2}$$

- ☛ Where N is the total number of irrigation household units in the selected SSI (Ketar and Arta.) which is 1398.
- ☛ n is the sample size,
- ☛ α Is the level of significance for the present study and it is fixed at 5%.

Based on the above formula, the sample size for the study is determined.

$$n = \frac{1398}{1 + 1398(0.05)^2} \approx 311$$

The perception of satisfaction on water allocation and distribution service, bylaw implementation, and decision-making by the IWUAs committee was measured on the Likert scale as excellent, Very good/Very satisfied, good/satisfied, bad, and very bad (Likert, 1932). The flow data were collected from randomly selected ten farmers' plots from the four schemes using a three-inch Parshall flume and float method at canals to verify the water allocation equity and the infrastructure management. GPS was used to collect the scheme's location, water-measured points, and farmers' plot locations.

⁷ Ethiopia is classified as a federal state with National, Regional, Zone, Woreda and Kebele administrative units.

Secondary data were collected from MoWE, Ministry of Agriculture (MoA), Oromia region, Zone, and Woreda water and irrigation offices in the Subbasin. The data collected included the spatial and policy mandate of the institutions, water availability, water allocation mechanism, equity, crop and plot data, planning and decision transparency, operation and maintenance fee, conflict management, and water use rights in ten Focus groups (FGDs), five Key Informant Interviews (KIIs) and literature review. The FGDs were conducted with twenty-nine different experts and IWUA committee leaders in the selected scheme areas.

The data collected were tested for validity and reliability and analyzed using Stata. All the determinant variables were analyzed qualitatively, in descriptive statistics and Arc GIS (Geographic Information System), and compared within and across the irrigation schemes. The results are presented in narratives and infographics and governance maps.

2.3 Results and Discussion

2.3.1 Demographic Result

2.3.1.1 Sex, and age of Respondents:

Age and education play a significant positive and negative relationship in technology adaptation and leadership role in irrigation governance (Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009; Hamidov, Thiel, & Zikos, 2015; Imburgia, 2019; Shah, 2004). The respondents from K.Fowafowate, K. Genet, K. T. Unshoo, and Arata schemes are 90% male and 10% female, where 5, 5, 4, and 16 females in number are female respectively. Age-wise 15% of the respondents were between 21-30 years of age, 42% were 31-45 years, 29% are 45-60, and the remaining 13% are above 61 years of age and the mean age considering all the schemes is 43.5 years.

2.3.1.2 Education and irrigation experience of Respondents:

9% of the respondents have no regular school exposure- neither they can read nor write, 54% were categorized between grade 1-8 (elementary school in Ethiopian case), 33% were between

grade 9-12(high school) and only 3% joined Technical vocational school or college. Of women respondents, 6% were found only between grades 1-8 while 4% have completed high school. According to this study all respondents, male and female, have more than ten years of irrigation experience.

2.3.1.3 Marital status and Family size:

Of the respondents of this study in general 2.9 % are single, 89.7% are married, 1.9% are divorced, and 5.47 % are widowed. *The average family size of the respondents is 6, 6.7, 7, and 5.7 at K. Fowafowate, K. Genet, K.T. Unshoo, and Arata respectively with an average of 6.3 for all schemes, which is above the average rural family size of the 2007 Ethiopian census that is 5.1.*

2.3.1.4 Irrigation Land holdings:

92% of the respondents have irrigation land, 7% are rented, and 1% got the land in investment(at Arata SSI). The average total agricultural land of a respondent in the four schemes is 2 ha and the average irrigation land holding for the schemes is 0.5 ha (Figure 2-1). Females in the four schemes have an average of 1.6 and 0.38 ha of total agriculture and irrigation land holding respectively. The irrigation land holding of the country, specifically the Oromia region, allows irrigators to have a maximum of 0.5 ha on government-built irrigation developments(ONRS, 2007).

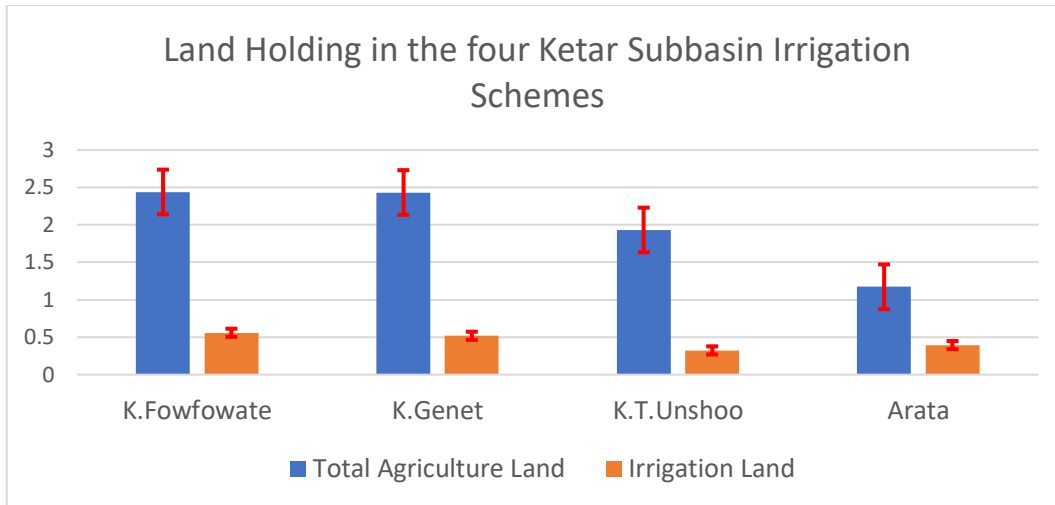


Figure 2-1 Landholding (ha) in Ketar subbasin

2.3.2 Irrigation Water Governance at the Microenvironment level

2.3.2.1 Irrigation Water Users' Structural position in Ethiopia:

IWUAs in Ethiopia is the center of irrigation water governance where they are accountable for scheme operation & maintenance (O&M), scheme level water allocation, bylaw development and implementation, O&M fee collection, microenvironment level water resource management, and environmental protection at proximity level (FDRE, 2014; ORNG, 2017). Structurally they are nongovernment community actors at the irrigation scheme level but are monitored by government institutions (Figure 2-2). The discussions made with key informants depicted that, regional irrigation offices are mandated for river water abstraction and scheme-level water governance. However, practically IWUAs are more active, especially in scheme-level water governance, than government offices.

When the Ethiopian water governance structure is compared to Sub Saharan Africa (SSA) countries, studies portray that most SSA country's water governance organizations are at the National, basin, subbasin, and IWUA level, which is similar to the Ethiopian case except for the

subbasin level(Cambaza, Hoogesteger, & Veldwisch, 2020; Dinar, 2016). On the other hand, in the Ethiopian case, the regional irrigation sector and IWUAs are more involved and active in irrigation water governance while in SSA the basin and subbasin structures are stronger.

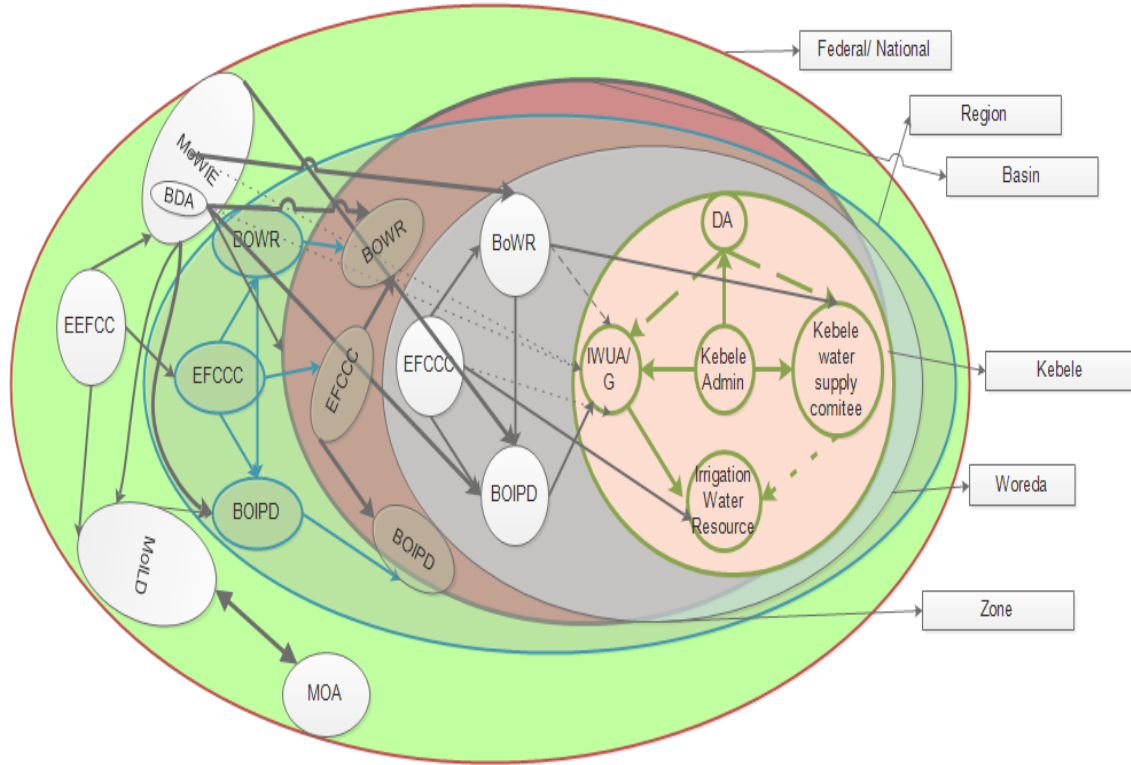


Figure 2-2 Irrigation Water Governance institutions map of Ethiopia (Ketar subbasin)

2.3.2.2 Legal Status of IWUA in Ketar subbasin:

The document review and FGD with the Arsi zone irrigation sector office showed that out of 184 irrigation schemes existing in the subbasin, 30 are modern & 154 are traditional irrigation schemes. only 73% of the modern and 21% of the traditional irrigation schemes IWUAs have legal entities and are legally registered. The four sampled irrigation schemes K. Fowafowate, K. Genet, K.T. Unshoo, and Arta Small-scale Irrigations are among the registered ones. Most of the registered modern irrigation schemes IWUAs are located downstream of the subbasin (Figure .2-

3). KII indicated that the downstream irrigators respond to the irrigation policy and rules better than upstream farmers because of their drought proneness, downstream water use right, and more dependency on irrigation than the upstream users. According to these findings, modern irrigation IWUAs are more legally registered than traditional irrigation IWUAs in the subbasin. The FGD with the government officials and IWUA committees showed that the traditional irrigation IWUAs are not much interested in legal registration unless they want to upgrade and modernize their scheme and need irrigation extension services by government or nongovernmental organizations.

Studies made in different parts of Africa like Kenya, Tanzania, and Mozambique showed that IWUAs are required legally to be recognized like the Ethiopian case (Eefje Aarnoudse, 2018; Richards, 2019). Moreover, these studies depicted, IWUAs not legally registered, theoretically, do not benefit from legal water use rights, banking systems, and legal financial audit support (Eefje Aarnoudse, 2018). However, these studies argue that no evidence showed that legalization produces a better governance capacity or service delivery. In the Ethiopian case, the registered IWUAs have an advantage in project fund access for upgrading or new development to have a bank account in their association name rather than individuals name and to get legally access to loan .

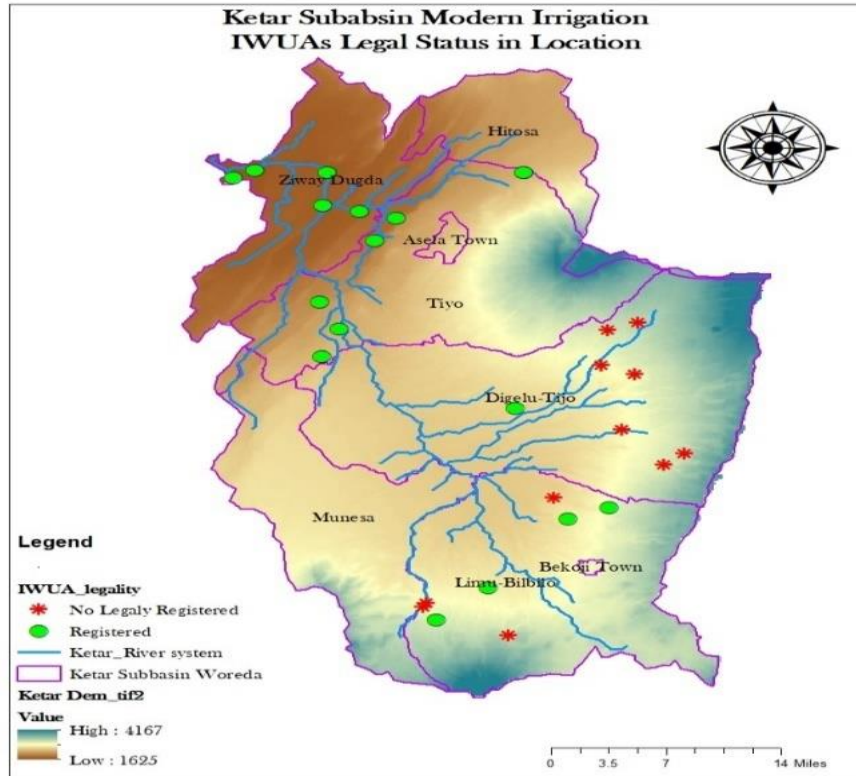


Figure 2-3 IWUAs legally registered and non-registered locations in Ketar subbasin.

2.3.2.3 *The By-Law Implementation Status of the four IWUAs:*

The bylaws, IWUAs members developed and ratified internal law, mainly consisted of and focused on penalizing for absence from meetings, maintenance programs, water theft, extravagant water use, illegal water abstraction, and delay or lack of regular fee payment. It has no water allocation modality except the principle of fairness in water allocation. During the FGD with IWUA committees, the participants emphasized that water theft and absence from maintenance are taken as significant indicators for the by-law implementation.

The descriptive statistics result shows the transparency of bylaw implementation in each scheme with a mean value of 3.3, 2.9, 2.5, and 3.5 for K. Fowafowate, K. Genete, K.T. Unshoo, and Arata respectively with similar std. error of 0.1. Gender-wise, this transparency is rated as 3.01

and 3.04 mean values for the Likert with std of 0.06 and 0.02 for male and female respondents respectively. The result showed that Arata and K. Fowafowate are relatively more satisfied than the other two. This is due to both schemes being located the upstream of Ketar and Arata rivers where there is relatively more water. Gender-wise, the result showed the absence of significant difference, both male and female irrigators were equally satisfied with the current bylaw implementations.

2.3.2.4 IWUAs transparency in Planning:

The study made regarding the planning transparency of the IWUAs on the four schemes showed the IWUAs in each respective scheme are transparent in planning. 86% of the respondents witnessed that they are called for an annual planning and review meeting twice per year. However, 20% of the respondents, though there is a call for planning and review, and participation, have explained their grievances in the planning process.

2.3.2.5 Irrigation Water Use Right:

In all four schemes, water is allowed and allocated only for self-use. Selling, lending, and transferring once self-use-turn is not allowed. According to the discussion made with irrigation users and IWUA committees of the four schemes, irrigation turn for one user is once per week for twenty-four hours regardless of the land size and crop type. According to the FGD, this type of water allocation is due to the capacity limitation of the IWUA's in crop water requirement and water measuring knowledge and infrastructure. However, the water turns can be modified by the IWUA committees when water scarcity occurs.

2.3.2.6 IWUAs Water Allocation and Distribution Decision-Making Transparency:

The Water allocation and decision-making transparency were by the level of satisfaction of the respondents with the water allocation transparency and decision-making of the IWUAs committee on five scales Likert. The result indicated that 53% and 47% of Ketar Fofwote and

Ketar Genet respondents were dissatisfied while the dissatisfaction with K. T. Unshoo and Arata Irrigation schemes is 35% and 10% respectively. The dissatisfaction at K.T. Unshoo and Arata is relatively small to the other two; the FGD discussion accounted for these results as “the more the water is scarce, the better the water allocation transparency”. The latter two schemes are located at a downstream location where water is relatively scarce and needed critical governance.

In the water allocation service transparency, female respondents, except for K. Genet, in each scheme are less satisfied (Figure 2-4). In general, the female respondents rated the service a 2.8 mean value while male respondents rate 3.4 with std. error of 0.05 and 0.01 for females and males respectively. Women irrigators are less satisfied than male irrigators; female irrigators complain the water allocation does not suit their additional domestic burdens and there is no special water allocation modality for female irrigators.

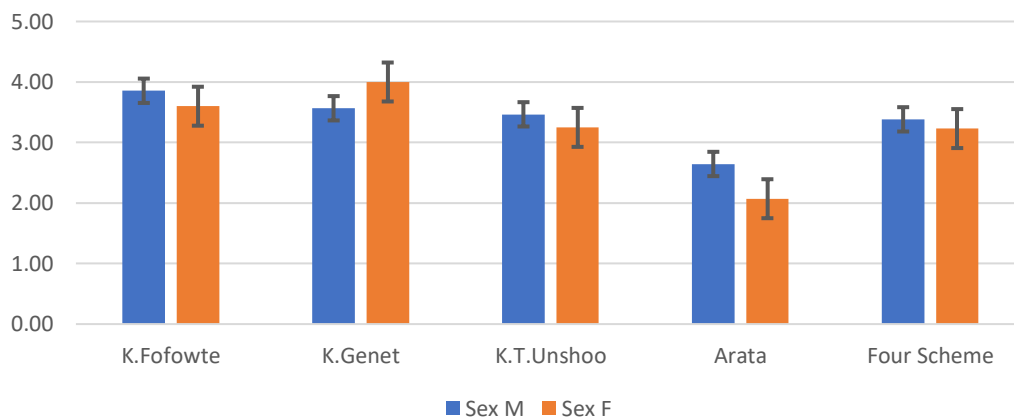


Figure 2-4 Irrigation Water allocation Transparency (Likert Scale)

In terms of the volume of the water allocation, the result found by measuring water distributed, using the Parshall flume at ten randomly selected irrigation users in the four schemes, showed big variability (Table 1). The water allocation and distribution vary ranging from 3.5 li/sec

– 8.4li/sec and 4320 m³ -9676 m³ flow amount in one irrigation season regardless of the type of crop

Table 2-1 Water allocation disparity by IWUAs at plot level

Scheme	Owners	Plot location (UTM)		Crop Planted	Average flow measured at the site level (li/sec)	Plot area (ha)	Water supplied in one season (m3)	Water supplied in one season (m3)/ha	FAO- CWR estimate (m3)/ha
		East (X)	North (Y)						
Ketar Fowfote	P. A	503414	866394	Potato	8.4	0.75	7257	9676	5000-7000
	P. B	502744	865626	Wheat	3.5	0.25	982	3931	4500-6500
Ketar Genete	P. C	502492	867610	Wheat	4.2	0.25	1209	4838	4500-6501
	P. D	501957	868530	Potato	5	0.25	1728	6912	5000-7000
Torben Unshoo	P. E	501473	868803	Onion	4.2	0.05	347.6	6955	3500-4500
	P. F	501442	869068	Wheat	5	0.036	270	7500	4500-6500
	P. G	501319	869110	Potato	3.5	0.036	252	7000	5000-7000
Arata Cufaa	P.H	507066	882593	Cabbage	5.8	0.25	1044	4176	3500-5000
	P. I	505428	881973	Potato	5	0.25	1440	5760	5000-7000
	P. J	504893	881516	Potato	5	1	4320	4320	5000-7000

Empirical studies of SSA regarding IWUA's capacity in water allocation and distribution decision-making transparency verify similar results. Most SSA IWUAs are suffering from capacity limitations to be transparent and give due decisions to their members with a lack of professional

support and little know-how about irrigation water management(Mutambara, Darkoh, & Athlipheng, 2016).

2.3.2.7 *The financial status of IWUAs:*

In the observation made on IWUAs and FGD at the zone level, all irrigation schemes in the Ketar subbasin collect irrigation operation and maintenance fees from their members on their members' decisions, based on landholdings. The amount of money collected by all IWUAs in the subbasin including the four schemes is very small ranging from ETB⁸ 200/year/ha to ETB 2000/year/ha. The study made on the four selected schemes confirmed the same result; Ketar Fowofte collects 1600ETB/year/ha, Ketar Genete 800ETB/year/ha, Torben Unshoo 1800ETB/year/ha, and Arata 2000ETB/year/ha. Still the two downs stream schemes Ketar Torben Unshoo and Arata contribute relatively higher fees. However, according to the woreda irrigation office, all four IWUAs' fee collection is below the required amount for their yearly critical operation and maintenance costs.

2.3.2.8 *Gender inclusiveness:*

The study also looked at if any gender and other inclusiveness principles and implementations are in the bylaws and their implementations. The IWUAs establishment documents encourage women to be in the position of the IWUA leadership to play a significant role and benefit from irrigation water governance. However, the result showed that each of the four IWUAs has only one woman member on its committee. In the survey, 70% of the respondents explained the absence of any gender-related incentive instruments in their IWUAs. The result is the same across each scheme. The FGD decision showed that this is due to the community attitude, and the overburden of the women in the community.

⁸ 1USD is equivalent to 46.00 ETB (at the time of data collection)

2.3.2.9 Irrigation Infrastructure Management as Governance Indicator:

The water abstraction, water conveyance, division, and distribution infrastructures management of irrigation in the Ketar Subbasin is under the mandate of IWUAs. The irrigation infrastructure of the four schemes is broken, breached, and deteriorated. Water is leaking, seeping, and overtopping here and there, earthen canal's shape is completely distorted from its original design and capacity.

The Arata irrigation scheme diversion weir is completely silted. The upstream of the weir which was constructed for water regulation is serving currently as an illegal irrigation plot by private investors. Ketar Fowafowate main canal, especially the sheet metal aqueduct was constructed to convey $1\text{m}^3/\text{sec}$. The measurement conducted using the Parshall flume at the outlet and floating method indicated currently showed it is conveying only $0.875\text{m}^3/\text{sec}$ which is a reduction of 12.5% from the design. This reduction of flow can be accounted for by the deterioration of the structure. The maintenance of this structure is beyond the IWUAs capacity in terms of finance and skill.

The hydraulic assessment for the conveyance and main canal structures conducted in flow measurement showed; 31% water loss at K. Fowafowate before the water reaches K. Genet due to canal breaching, and seepage; 12% additional loss at K. Genet due to the earthen canals deterioration, breaching, and domestic and livestock consumption before it reaches K.T. Unshoo; and a total of 49% water loss which is a $0.37\text{ m}^3/\text{sec}$ water loss at K.T. Unshoo was observed. All these losses are due to the irrigation infrastructure governance drawbacks in terms of rehabilitation and regulation (Figure 2-5). These have resulted in inequity in water distribution among its members and depicted the weak water management of the IWUAs'. Similar studies made on irrigation infrastructure management as a cause for poor irrigation water governance witnessed the same results(Akuriba et al., 2018; Dirwai, Senzanje, & Mudhara, 2019; Fufa, 2017).



Figure 2-5 Breached structures, stone-regulated offtake, fully silted diversion weirs, and multi-use supply canal at Ketar and Arata Irrigation schemes.⁹

2.4 Conclusion and Recommendation

The study looked at the IWUAs position in the Ethiopian irrigation water governance structure that constitutes the polycentric governance model. According to this study, the IWUAs are the key role players in irrigation water governance. However, there are rooms for improvement to make the IWUAs more productive. The result of the IWUAs performance at the microenvironment level, taking four irrigation schemes in the Ketar subbasin as a showcase, portrayed the determinants variables to get due attention for better irrigation water governance.

IWUAs becoming legal entities is a positive finding to enhance the Irrigation water governance in the area of capacity building in finance, knowledge, and skill. In addition, the legal registration gives room for the IWUA to have a legal mandate to get a loan. On the hand, the bylaw implementation of the IWUAs tends to punishment rather than equitable water distribution and infrastructure management. The IWUAs are stronger in conducting a planning and review meeting

⁹ Pictures taken in March 2021 as a part of data collection by the researcher.

at least two times per year. However, some of the irrigators showed a limitation in the planning process and the participation level.

The IWUAs irrigation water governance performance in terms of water allocation and distribution has a disparity at the scheme level between users, and male and female irrigators. The water allocation and distribution of all four schemes didn't account for plot location, canal length, conveyance time, and crop type. This is ascribed to the IWUAs' financial, knowledge, skill, equipment, and technical capacity gap.

In general, even though polycentric irrigation water governance which gives a key role in the local community was supposed to deliver better governance service at a local level, the findings of this study showed a mixed result; encouraging results in bylaw implementation, and planning and drawbacks in water allocation, infrastructure management, water management, and fee collection services.

To make Irrigation water governance more result-oriented and satisfactory, IWUAs should be empowered in water distribution and measuring infrastructures and equipment, O&M fee collection, water allocation basics, and gender inclusiveness. The IWUAs should be supported by the government and other stakeholders in installing water measuring structures and water allocation recording for equitable water distribution services which should be based on land size, crops, and plot locations rather than blanket allocation and distribution. In addition Women, irrigators should get due attention in the irrigation governance leadership and water use. The government should assign irrigation experts in proximity based on irrigation size, water scarcity, and the density of irrigation on water resources.

For the water governance of the country in general and in particular the irrigation water governance, to be improved the IWUAs should be capacitated with incentives for good water governance.

PART THREE – IRRIGATION SCHEMES PERFORMANCE

3 ASSESSING SMALL SCALE IRRIGATION SCHEMES PERFORMANCE: A COMPARATIVE ANALYSIS USING REMOTE SENSING NDVI AND CONVENTIONAL METHODS, AN EXAMPLE FROM ETHIOPIA – AFRICA.

Abstract

The Performance of irrigation schemes has been assessed using conventional methods. In this study, both the conventional method and remote sensing NDVI value analysis was used. The study favors the benefits of using multiple indicators, including remote sensing NDVI values in assessing irrigation performance. The study assessed the Ketar Fowafowate, Ketar Genet, Ketar, Torben Unsho, and Arata irrigation schemes over two seasons (2020/21 and 2021/22) using NDVI values, irrigation efficiencies, and water productivity. The result showed that schemes and irrigation plots near the water resource performed better than the downstream schemes and tail irrigation plots. The average NDVI values ranged between 0.32 and 0.54 with the highest and lowest at 0.79 and 0.1 respectively. The NDVI values showed that three of the schemes improved their performance from 2020/21 to 2021/22 at 94%, 82%, and 74% while the Arata irrigation scheme declined by 3%. The conveyance efficiency of the four schemes was found 79%, 59%, 49%, and 80%, the field canal efficiency was 62%, 64%, 73%, and 76% and the distribution efficiency was 49%, 48%, 57%, and 59% for K. Fowafowate, K. Genet, K.T.Unshoo, and Arata chufa respectively. Additionally, the Field water productivity of wheat is found 0.74 kg/m³ 0.69 kg/m³ 0.86 kg/m³ 0.80 kg/m³ for the above schemes respectively. The average water productivity of wheat in USD is found to be \$0.78/m³. Comparing the three indicators helped to identify each scheme's strengths and weaknesses from different perspectives, highlighting the importance of using multiple indicators in assessing irrigation performance. The study asserts that looking at irrigation schemes from multiple angles helps to understand schemes properly for effective intervention.

Keywords: Irrigation performance, NDVI, Irrigation efficiencies, water productivity

3.1 Introduction

Food production is estimated to ascend by 70% in 2050 compared to 2000 (Bruinsma, 2012) for a rapidly growing world population. Irrigation, a vital aspect of agricultural production, will expand at 0.12% per year, which will be 6% by the year 2050, with developing countries taking the largest share (FAO, 2017a). It consumes 70% of the freshwater (FAO, 2017a; T. W. B. G. WB, 2016). Zooming into developing countries, the role of smallholders and small-scale irrigation in promoting and improving food security and a reduction in rural poverty within the current food production system is irreplaceable (W. B. WB, 2019). In addition, irrigation farmers increasing demand for export-oriented high-value crops, along with evolving dietary preferences, is driving extensive irrigation development and water abstraction (Clemmens & Molden, 2007; FAO, 2017b; W. B. WB, 2019). In general, as the demand for food intensifies and irrigation lands expand, the pressure on freshwater increases globally. Hence, it is crucial to understand and improve irrigation schemes' performance to ensure sustainable food production to meet the needs of a growing population and the quality of the environment (Molden, D.J. Bos & Burton, 2005). The focus of discussions on irrigation performance has coupled water supply to farms with monitoring water productivity for sustainable environmental outcomes.

In the past, Irrigation performance studies came up with numerous detailed definitions, determinants, frameworks, and methodologies for evaluating irrigation performance (Molden, D.J. Bos & Burton, 2005; L. E. S. and M. Svendsen, 1992). Abernethy, (1991) articulated irrigation performance measurement to the goals of irrigation schemes like productivity, equity, profitability, sustainability, and quality of life. Moreover, the researcher recommended adequacy, timeliness, and equity as performance-measuring indicators. Svendsen (1992) classified irrigation performance into operational, accountability, and intervention assessment. According to Svendsen (1992), irrigation performance assessment can be approached through either a goal-oriented or a natural system-oriented model. The goal-oriented performance model focuses on the purpose of the irrigation system, set by influencers like individuals, groups, or institutions, while the natural system-oriented performance assessment model focuses on the system's ability to get input for its

existence and expansion. Svendsen(1992) viewed both models as complementary and discoursed irrigation performance to be addressed in the agricultural main system focusing on acquisition and distribution functions giving due room for operation, maintenance, and support.

Bos et al. (1993) and Molden, D.J.Bos, and Burton (2005) classified irrigation performance assessment into five types; operational, strategic, diagnostic, comparative, and benchmarking. The operational performance deals with the daily and routine activity assessment ensuring doing things right, while the strategic performance assessment addresses the efficient utilization of resources and making the right decisions. The diagnostics assessment looks into areas in need of improvement, while the comparative performance assessment compares different irrigation schemes to set a benchmark for better performance. Besides, Molden, D.J.Bos, and Burton, (2005) developed conventional irrigation performance indicators such as the total value of production, water productivity production value per unit of water, and delivery performance.

In general, irrigation performance assessment entails substantial water and crop data; water supplied and used per unit area, crop water use - evapotranspiration, crop yield, and irrigation type. Elshaikh et al., (2018) summarized irrigation performance methods as a Fuzzy set theory, direct measurements of indicators, analysis hierarchy, and remote sensing. The fuzzy set theory considers the uncertainties and irrigation management of schemes (Elshaikh et al., 2018; Knieper and Pahl-Wostl, 2016), while direct measurements mainly include productivity, water efficiency (equity, reliability, adequacy, timeliness, utility, cost-effectiveness, sustainability, maintenance, environmental sustainability), and socio-economic factors, and finance (Abernethy, 1991; Bos et al., 1993; Elshaikh et al., 2018; Molden et al., 1998; Svendsen, 1992). The analytic hierarchy process evaluates a multi-criteria decision-making technique that entertains numerous problems in their relative importance for action(Elshaikh et al., 2018). The remote sensing approach uses remote sensing data of irrigation schemes such as crop growth and density in real-time performance(Ayyad et al., 2019; Elshaikh et al., 2018; Foley et al., 2020; Ignacio and Tasumi, 2010). Accordingly, many studies on Irrigation scheme performance assessment used the conventional performance assessment such as conveyance efficiency, distribution efficiency,

application efficiency, and water productivity as key indicators (Agide et al., 2016; Derib, Descheemaeker, Hailelassie, & Amede, 2011b; Doorenbos & Pruitt, 1977; FAO and UN Water, 2021; Herrmann & Bucksch, 2014; Jensen, 2007; Marinus, G., 2011; Molden, D.J.Bos & Burton, 2005; Molden et al., 2010; ORSON W. ISRAELSEN, 1932; W. B. WB, 2019). Currently, the advancement in remote sensing technology has added the use of the Normalized Difference Vegetation Index (NDVI) to assess irrigation performance.

Employing NDVI data in analysing yield and water productivity as a complementary to the aforementioned indicators gained worldwide popularity (Genesis T. Yengoh, David Dent, Olsson, Lennart Olsson, Anna E. Tengberg, 2014; Lenny Wall, Denis Larocque, 2006; Mkhabela, Mkhabela, & Mashinini, 2005; Naser, Khosla, & Longchamps, 2020; Poudel et al., 2021; Yameen, Arshad, & Saqlain, 2019). Vegetation Indices (VI) are robust, empirical measures of vegetation activity at the land surface (Didan et al., 2015). NDVI tells the health of crops (greenness) at each growing stage and the density of vegetation; it indicates water stress – low NDVI value, excess water supply – high NDVI value, and helps in improving irrigation water efficiency and increasing crop water productivity (Sultana et al., 2014; Yameen et al., 2019). NDVI is directly proportional to the crop coefficient (K_c) (Poudel et al., 2021). High NDVI value, and greenness, are related to high K_c value, high water use, and high productivity keeping other parameters like soil type, weather condition, and farmers' crop management ideal (Adamala, Rajwade, & Reddy, 2016; Aranguren, Castell, & Aizpurua, 2020; Guan, Fukami, Matsunaka, Okami, & Tanaka, 2019; Naser et al., 2020). These NDVI values are used to compare irrigation schemes' performances (Yameen et al., 2019). Especially, NDVI which is the result of spectral reflectance measurements is one of the established assessment methods for crop health and productivity estimates for wheat and barley (Sultana et al., 2014). In general, The selection of the irrigation performance assessment method depends on the irrigation system, evaluation purpose, data availability, and capacity (Genesis T. Yengoh, David Dent, Olsson, Lennart Olsson, Anna E. Tengberg, 2014; Naser et al., 2020; Poudel et al., 2021; Yameen et al., 2019).

The assessment of irrigation performance in Ethiopia has been a topic for the last decade (Agide et al., 2016; Amede, 2015; Fufa, 2017; Hailelassie et al., 2016; Tebeba and Ayana, 2015; Weldeabzgi, 2021). These studies have used the conventional method; relative irrigation water supply (RIS), uniformity of irrigation water supplied - dependability, adequacy, equity, deficiency, the effectiveness of infrastructure, water surface elevation ratio, sedimentation, delivery duration ratio, sustainability of Irrigated area, and land and water productivity as indicators. However, none of them have incorporated the use of NDVI along the above indicators as a performance indicator. This study aimed to fill that gap by incorporating NDVI values to assess the performance of irrigation schemes and irrigation areas within a scheme in conjunction with irrigation water supply (SIWS), conveyance efficiency (ϵ_c), field canal efficiency (ϵ_f), distribution efficiency (ϵ_d), and farm-level crop productivity to evaluate the performance of four Irrigation schemes Ketar Fowafowate (K. Fowafowate), Ketar Genet (K. Genet), Ketar Tourben Unshoo (K.T.Unshoo), and Arata during the main irrigation season of November to May 2020/21 and 2021/22, with wheat as a main crop. The actual yield of crops, including wheat, is different from the potential yield because of a variety of internal and external factors. Among, these factors, irrigation water supply takes a substantial role. Whether there is an excess or a deficit irrigation water supply, it affects the physiology and yield of wheat, keeping other factors constant (Hordofa, Leta, & Alamirew, 2022; Kaini, Harrison, & Gardner, 2022; Mirbahar, Markhand, Mahar, & Abro, 2009).

The use of these combined indicators is believed to provide a comprehensive view of the performance of the irrigation schemes in delivering irrigation water to crops, water productivity, and the sustainability of the selected irrigation schemes.

3.2 Materials and Methods

3.2.1 Study area

The Ketar subbasin is a constitute sub-catchments of the Ziway basin in the Ethiopian rift valley. It contributes 396 MCM of water per year to Lake Ziway, accounting for 57% of the lake's

total water (Cherco Jansen, Hurib Hegsdijk, Dagnachew Legesse, Tenalem Ayenew, Petra Hellegers, 2007). The subbasin has 30 modern and 184 traditional small-scale irrigation schemes, covering 2464 ha (AZILDO, 2017). The modern irrigations are located upstream (13), in the middle(11), and downstream (6) (Figure 3-1). Four irrigation schemes were selected from the subbasin for performance assessment in consultation with the Arsi Zone Irrigation and Pastoralist Development office (AZIPDO). Two schemes from the middle and two from the d/s were selected based on their long-year irrigation experience to represent the subbasin performance (Table 3-1).

Table 3-1 Study Area Profile

Scheme	Reach	Location (UTM)		Altitude (m) a.s.l	Area (ha)	Beneficiary (HH)			Established (year)
		East	North			M	F	Total	
K. Fowafowate	Middle	502848	866068	2264	91	199	56	255	1987
K. Genet	Middle	501580	866285	2170	210	265	58	323	1993
K. Unshoo	D/S	501603	868881	2070	121.7	297	65	362	1995
Arata Chufa	D/S	505472	882219	1725	100	279	45	324	1993
Total					522.7	1040	224	1264	

Source: Survey (2021)

The three schemes, K. Fowafowate and K. Genet from the middle, and K.T. Unshoo from downstream (d/s) are three separate schemes that share one abstraction structure from the Ketar river and a commonly managed conveyance system. Each of these schemes has its own secondary and tertiary canals. In addition, each scheme has its own independent water user association and a full governance mandate. Arata Chufa is located on the d/s side of the subbasin on the stream called Chufa river. All the schemes are gravity-fed irrigation systems and are located between 2264 m and 1725m above sea level (a.s.l). The meteorology data were collected from Ogolcho and Kulumsa stations; the average annual rainfall of the study area ranges between 620 -1200mm while the mean daily temperature is between 12.3 – 22.9 °C.

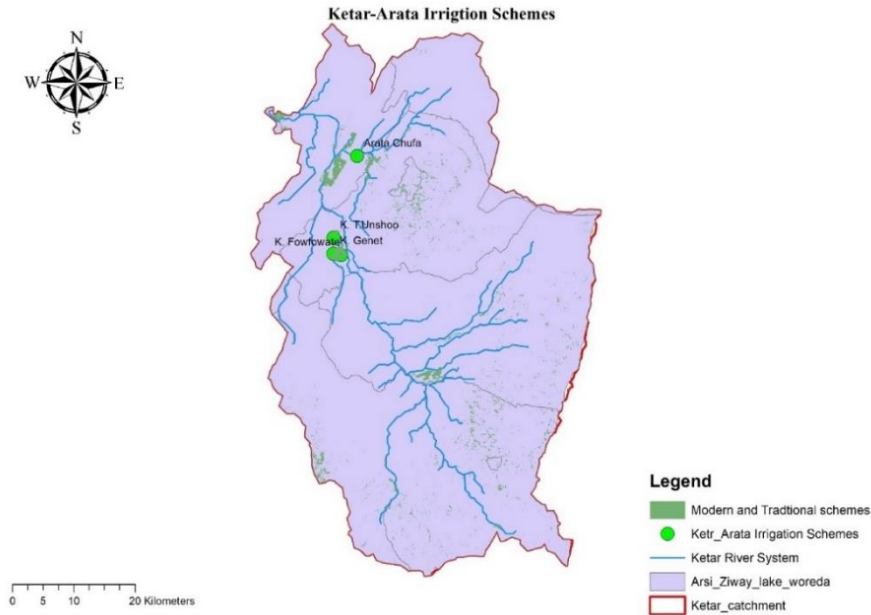


Figure 3-1 Figure 3 1 Study Irrigation schemes and Irrigation coverage in the sub-basin

3.2.2 Data and Method of Analysis

3.2.2.1 MOD13Q1 Image Data

The MOD13Q1 image is 250m resolution composite image data derived from Moderate Resolution Imaging Spectroradiometer (MODIS) observations that describe features of the land, oceans, and atmosphere that can be used for research. It is a composite image for NDVI, using blue, red, and near-infrared reflectance, centered at 469 nanometres, 645 nanometres, and 858 nanometres, respectively, to determine the MODIS daily vegetation indices. MODIS vegetation indices – NDVI -, are a 16-day interval and multiple spatial resolutions that provide a spatial and temporal comparison of vegetation canopy, greenness, a composite property of leaf area, chlorophyll, and canopy structure. The MODIS Vegetation Index (VI) products provide consistent, spatial, and temporal time series global vegetation conditions, gridded VI maps derived at 16-day and monthly intervals. The VIs are produced in multiple spatial resolutions, providing consistent

spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll, and canopy structure (Didan et al., 2015). The NDVI is one of the VI products of MODIS since 1981

A two-irrigation season from Nov -May 2020-22 MOD13Q1 data was downloaded from the MODIS website -<https://ladsweb.modaps.eosdis.nasa.gov>. A total of 18 months of 36 image data were acquired for NDVI processing.

3.2.2.2 Crop data

The primary irrigation crops in the four schemes are onion, potato, tomato, pepper, cabbage, wheat, and maize. However, all schemes have focused on wheat production due to the Ethiopian government's new irrigation wheat production policy. Given the strategic importance for the country in food security, wheat has been selected to measure the irrigation performance of the four schemes.

Four wheat irrigation plots, one from each scheme (K. Fowfowte, K. Genet, K.T.Unshoo, and Arata) were selected based on water availability and the willingness of the farmers. Each plot size, crop type, and flow data during the irrigation (irrigation hour & interval) were collected using handheld GPS, Parshall flume, and direct observation. The wheat yield¹⁰ data is collected from the farmers, development agents, woreda agriculture offices, and the Kulumsa Research Center.

3.2.2.3 Irrigation Water Supplied

The irrigation water data for wheat were collected for November to May 2020/21 as the main irrigation season. The irrigation water supplied (IWS) was measured in two ways; the main canal flow was estimated in manning and verified using the float method while a three-inch Parshall flume was used to measure the water at the farmers' plot level. Besides, the irrigation

¹⁰ Kulumsa Research center was conducting yield estimate in the study area during this study time.

calendar data was collected from the Ziway Dugda woreda irrigation office and Irrigation water users.

3.2.2.4 Soil and Weather data

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 FAO, (2015)soil survey guideline for soil classification and FAO, (2006) field description guideline. Hence, the catchment soil is classified as clay loam in texture with 167mm/m total available soil moisture(MOA, 2018; OWWDSE, 2019). The climate data were collected from the nearby meteorological station, Kulumsa and Ogolcho meteorological stations which are located 32 and 6 km from Ketar and Arata irrigation schemes respectively.

3.2.3 Methods of Data Analysis

The analysis of the four irrigation schemes counts on data from MODIS NDVI, weather, and irrigation data such as irrigation water supply and crop. The MOD13Q1 remote sensing image data is used to extract NDVI values for two irrigation seasons, Feb-May 2021 and 2022, The evapotranspiration is computed based on the weather data from the nearby Ogolcho station. Data on irrigation crops such as crop type, growing period, and yield were collected from Zone and woreda irrigation offices and the Kulumsa research center. The crop coefficient (KC) value was considered from FAO irrigation and drainage paper 24 – Guideline for predicting crop water requirement (Doorenbos & Pruitt, 1977). After having the NDVI value, irrigation water supply, irrigation efficiencies, and crop yield, both intra and inter-scheme comparative performances were conducted (Figure 3-2).

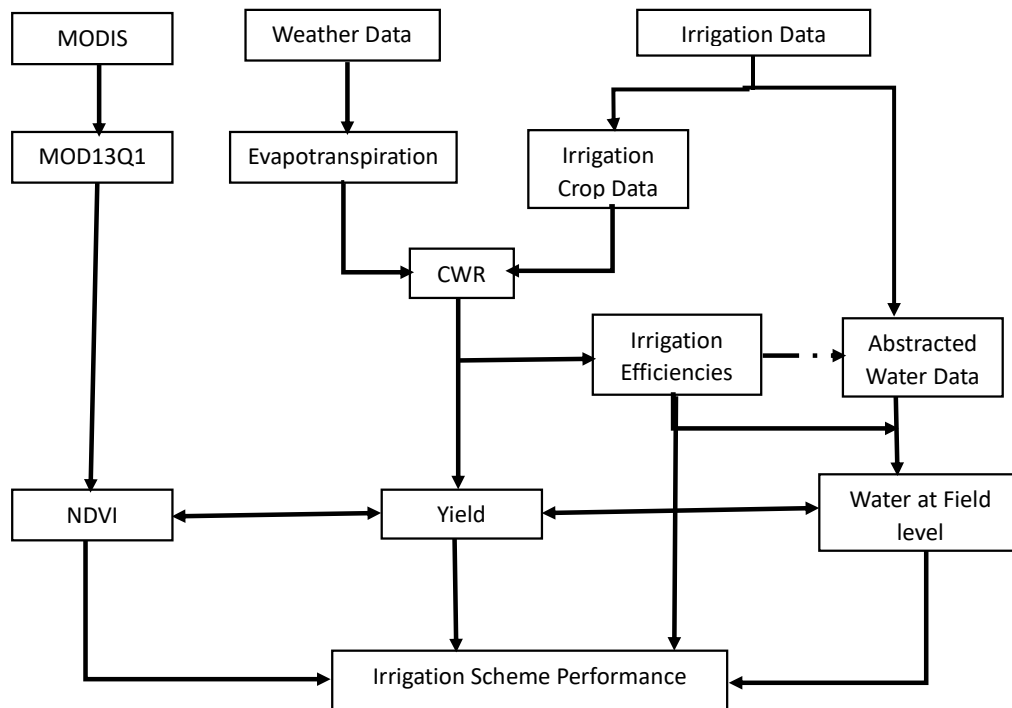


Figure 3-2 Ketar subbasin Irrigation Performance Analysis Framework

3.2.3.1 NDVI

The NDVI is a normalized transform of the NIR to red reflectance ratio designed and commonly expressed as:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} \quad \text{-----(eq-3-1)}$$

The result swings between -1 and 1; -1 and near -1 indicates no or little vegetation while 1 and near 1 value shows dense and green vegetation.

The MOD13Q1 image is composed of 12 subdatatsets numbered from 0 to 11, with subdataset 0 representing NDVI. The raw image is scaled to 0.0001, with pixel value ranging for example like -1999 to 9943 which requires a raster calculation with 0.0001 to adjust the value

between -1 and 1 for the actual NDVI values. Once the scale is adjusted, the MOD13Q1 raster data were prepared for analysis by clipping to the study area, applying appropriate symbology for classification, and reclassifying for NDVI index area analysis.

3.2.3.2 Crop Water Requirement

The Irrigation Water Requirement (IWR) for wheat is estimated using CROPWAT-8.0. The Crop coefficients and root depth data were used from FAO 56 - Irrigation drainage paper for crop evapotranspiration and FAO 24 Irrigation drainage paper for crop water requirement (Allen, 1998; Doorenbos & Pruitt, 1977). The climatological data for Arata and K.T.Unshoo was taken from Ogolcho meteorological station, while Kulumsa meteorological station data was used for K. Fowafowate and K. Genet.

3.2.3.3 Seasonal Irrigation Water Supply (SIWS) Vs Irrigation Water Requirement

The SIWS at the plot level was compared to the estimated IWR. The ratio of SIWS to IWR showed the difference between the supplied and the estimate as excess or deficit. One is the theoretical best result of the ratio.

3.2.3.4 Irrigation Efficiencies

All the conveyance, field, and distribution efficiencies were estimated based on FAO Irrigation drainage paper 24 guidelines for predicting crop water requirements and compared with FAO recommendations (Doorenbos & Pruitt, 1977).

3.2.3.4.1 Conveyance efficiency (ϵ_c):

The conveyance or the main canal efficiency is calculated as the ratio of water delivered from the source (Q_s) to the water reached the end of the main canal or distribution point (Q_d)

(Doorenbos & Pruitt, 1977; Jensen, 2007; ORSON W. ISRAELSEN, 1932). Mathematically the scheme efficiency is explained as :

$$\epsilon_c = Q_s / Q_d * 100 \text{-----(eq-3-2)}$$

3.2.3.4.2 Field canal efficiency (ϵ_f):

The distribution efficiency is calculated based on the FAO guideline for Guidelines for predicting crop water requirements as the ratio of water delivered at the beginning of the secondary canal (Q_d) to the water reached to field point (Q_f) in this research case (Doorenbos & Pruitt, 1977; Jensen, 2007; ORSON W. ISRAELSEN, 1932). Mathematically the distribution efficiency is explained as :

$$\epsilon_f = Q_d / Q_f * 100 \text{-----(eq-3-3)}$$

3.2.3.4.3 Distribution efficiency (ϵ_d)

The distribution efficiency is calculated as the product of the conveyance and field canal efficiency. The ratio of water delivered at the beginning of the distribution point, in this case, the beginning of the secondary canal (Q_d) to the water reached the end of the Secondary canal or field point (Q_f) in this research case (Doorenbos & Pruitt, 1977). Mathematically the distribution efficiency is explained as :

$$\epsilon_d = \epsilon_c * \epsilon_f \text{-----(eq-3-4)}$$

3.2.3.5 Farm Level Water Productivity;

Water productivity is theoretically defined as crop yield per unit volume of water, that is ‘green’ water which is effective rainfall, and ‘blue’ water that is abstracted from water bodies for irrigated areas(Cai & Rosegrant, 2009; Clemmens & Molden, 2007; Molden et al., 2010). However, in this study, only blue water which is supplied at the farm level only is considered for water productivity. It can be termed farm-level water productivity.

the Farm level water productivity (FWP) is the ratio of the yield obtained to the amount of water supplied at the plot level, excluding the conveyance and field canal losses. Mathematically the FWP is explained as;

$$FWP_p = Y_i / Q_p; \text{-----(eq-3-5)}$$

Where FWP_p = water Productivity at plot level (kg/m^3), Y_i yield in kg, Q_p Water delivered at plot level in m^3

Crop yield is directly correlated with high NDVI(Poudel et al., 2021); hence high NDVI values are considered a high yield taking other factors as constant. Other factors such as agricultural inputs, agronomic practices, and other related activities were considered the same for all the schemes taking into account their similar irrigation experience and the same government support. Hence, irrigation water is accounted as the main determinant factor for the performance of the irrigation schemes.

3.3 Results and Discussion

3.3.1.1 NDVI Results of the four Schemes

The minimum NDVI values from K. Fowafowate , K. Genet. K.T.Unsho and Arata for Feb-May 2020/21 irrigation season are 0.2, 0.13, 0.08, and 0.22 respectively while for Jan-Apr 2021/22 are 0.27, 0.28, 0.29, and 0.29 respectively (Table 3-2).

Table 3-2 Min and Max NDVI value of 2020/21 and 2021/22 Irrigation seasons

		2020/21 Irrigation season				2021/22 Irrigation season				
NDVI Date		K.F	K.G	K.T.U	AR	NDVI Date	K.F	K.G	K.T.U	AR
17/01/21	Min	0.21	0.20	0.26	0.22	1/1/2022	0.23	0.21	0.23	0.23
	Max	0.50	0.57	0.42	0.39		0.59	0.67	0.68	0.48
2/2/2021	Min	0.21	0.19	0.22	0.24	17/01/22	0.22	0.22	0.23	0.15
	Max	0.69	0.60	0.52	0.41		0.41	0.40	0.39	0.24
18/02/21	Min	0.20	0.23	0.24	0.23	2/2/2022	0.23	0.20	0.24	0.22
	Max	0.60	0.67	0.55	0.42		0.77	0.77	0.64	0.38
6/3/2021	Min	0.20	0.20	0.24	0.24	18/02/22	0.22	0.20	0.24	0.25
	Max	0.69	0.64	0.52	0.43		0.41	0.48	0.39	0.42
22/3/21	Min	0.20	0.20	0.23	0.22	6/3/2022	0.23	0.20	0.25	0.35
	Max	0.70	0.64	0.51	0.35		0.78	0.79	0.64	0.23
7/4/2021	Min	0.23	0.20	0.21	0.22	22/3/22	0.21	0.20	0.26	0.25
	Max	0.63	0.56	0.40	0.32		0.78	0.78	0.60	0.42
23/04/21	Min	0.24	0.17	0.07	0.25	7/4/2022	0.25	0.20	0.26	0.46
	Max	0.49	0.90	0.58	0.32		0.63	0.65	0.51	0.25
9/5/2021	Min	0.29	0.13	0.08	0.45	23/04/22	0.24	0.23	0.27	0.32
	Max	0.55	0.77	0.62	0.66		0.49	0.58	0.49	0.58
25/05/21	Min	0.31	0.29	0.39	0.50	9/5/2022	0.26	0.23	0.25	0.52
	Max	0.49	0.57	0.43	0.60		0.50	0.58	0.61	0.54

*K.F – K. Fowafowate; K.G – K. Genet ; K.T.U – K.T.Unshoo; AR - Arata

The maximum NDVI values recorded for Ketar Fowafowate, Ketar Genet, K.T.Unshoo, and Arata for Feb-May 2020/21 irrigation season are 0.7, 0.9, 0.62, and 0.66 respectively while for Jan - Apr 2021/22, the NDVI values are 0.78, 0.79, 0.68, and 0.58 respectively (Tab.2). The minimum NDVI values recorded for the same schemes for Feb-May 2020/21 irrigation season are 0.2, 0.13, 0.07, and 0.22 respectively while for Jan - Apr 2021/22, the NDVI values are 0.21, 0.2, 0.23, and 0.15 respectively (Tab.2).

The average NDVI values of wheat during its growth stages across the four schemes during Jan-May 2021 and 22 irrigation seasons didn't follow the growing stage Kc pattern (Figure.3-3 & 3-4). For instance, Arata NDVI value in 2021 from developing to late stage was not following the Kc value pattern – decreasing during the development and mid stage while increasing at late stage. While in 2022 all schemes' wheat NDVI values, except for Arata, fell two times to 0.3 between development and mid stages, while it was expected parallel to the Kc value. Both irrigation seasons, 2021 and 22, showed similar performances across the four irrigation schemes; K. Fowfowate recorded an average NDVI value 0.41 for both years, K.Genet 0.43 and 0.42 for 2021 and 2022 respectively, K.T. Unshoo, with 0.36 and 0.39, and Arata with 0.36 & 0.33 in 2021 and 2022 respectively.

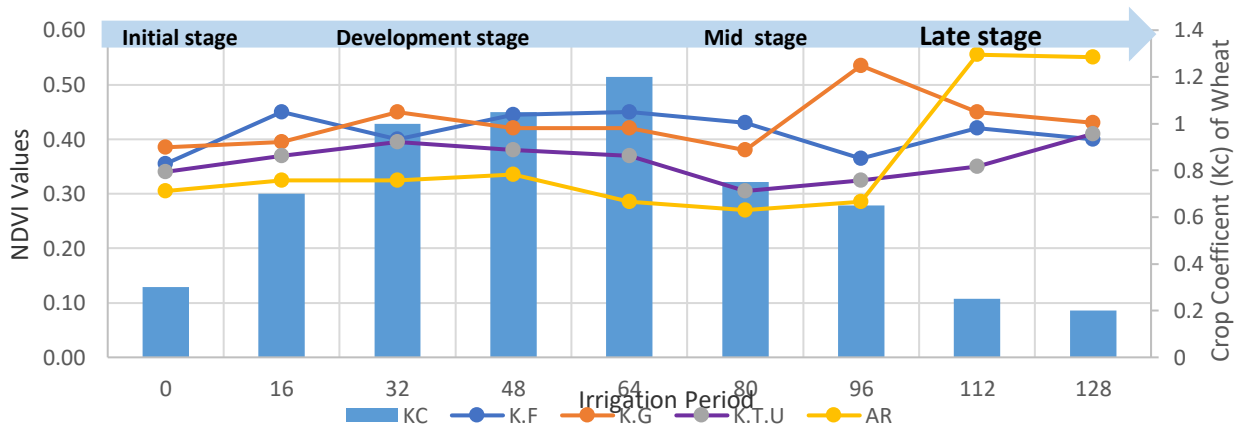


Figure 3-3 Wheat NDVI value of 2020/21 Irrigation season based on the growing stage

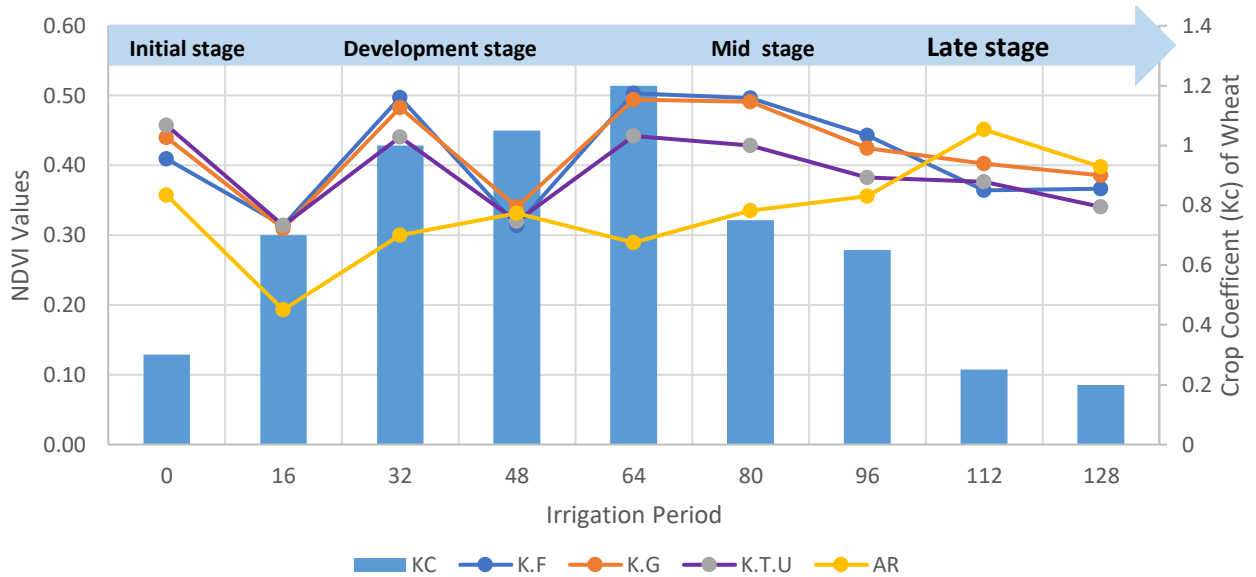


Figure 3-4 Wheat NDVI value of 2021/22 Irrigation season based on the growing stage

3.3.1.2 NDVI Results for Head, Middle, and Tail within each scheme

The greenness within the command areas of K. Fowafowate, K. Genet, K.T. Unsho, and Arata Irrigation scheme during the Feb-May 2020/21 irrigation season revealed anomalies (Figure 3-5 & 3-6). The NDVI values of this irrigation season for all the schemes fell from 0.13-0.9; K.Fowafowate's NDVI ranged between 0.21-0.69, K. Genet ranged from 0.1-0.78 (with an outlier plot of 0.9 NDVI value), K.T.Unsho's NDVI ranging from 0.2-0.65(with an outlier plot having an NDVI of 0.07) and Arata Irrigation scheme's falling between 0.21-0.6.

The NDVI value of each scheme downstream irrigation area is the lowest while the upstream areas enjoy the highest NDVI value. Unirrigated areas were present in all irrigation systems, particularly towards the downstream of each scheme. The NDVI values for each scheme downstream irrigation area improved as the irrigation months advanced.

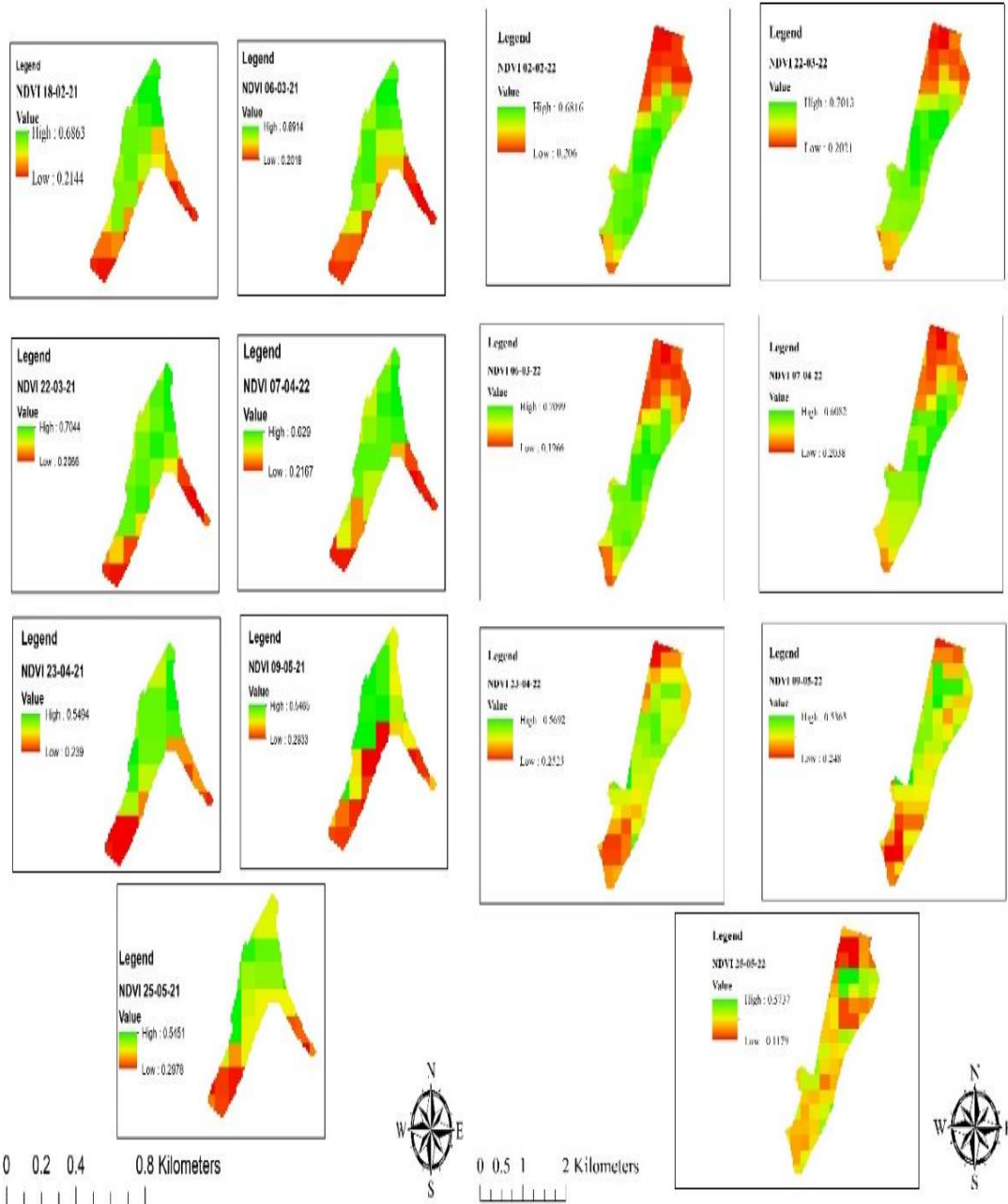


Figure 3-5 K. Fowafowate, K. Genet, (from left to right) NDVI value for the 2020/21 irrigation season

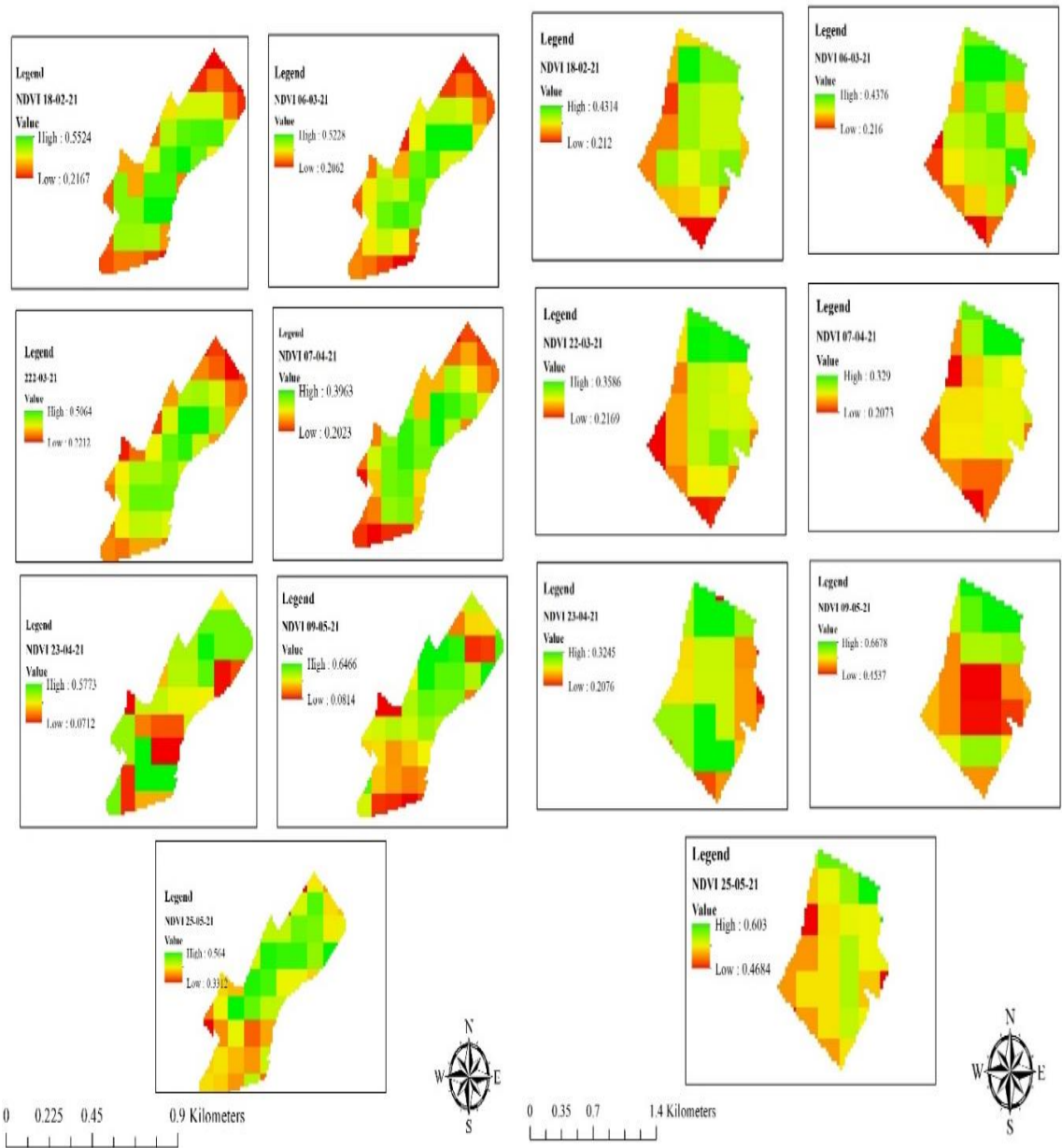


Figure 3-6 K.T. Unshoo, and Arata Schemes (from left to right) NDVI value for the 2020/21 irrigation season

The Feb-May 2021/22 (Figure 3-7 & 3-8) irrigation season NDVI values ranged between 0.1-0.7 for K. Fowafowate and K. Genet while the NDVI for K.T.Unsho and Arata ranged from 0.2-0.7 and 0.2-0.5 respectively. The NDVI values for all schemes except Arata increased as the number of irrigation days increased and decreased close to the end of the irrigation season. However, the NDVI value for Arata continued to increase throughout the irrigation season, albeit slightly. Similar to the Feb-May 2021 irrigation, each downstream irrigation area has the lowest NDVI value and unirrigated land.

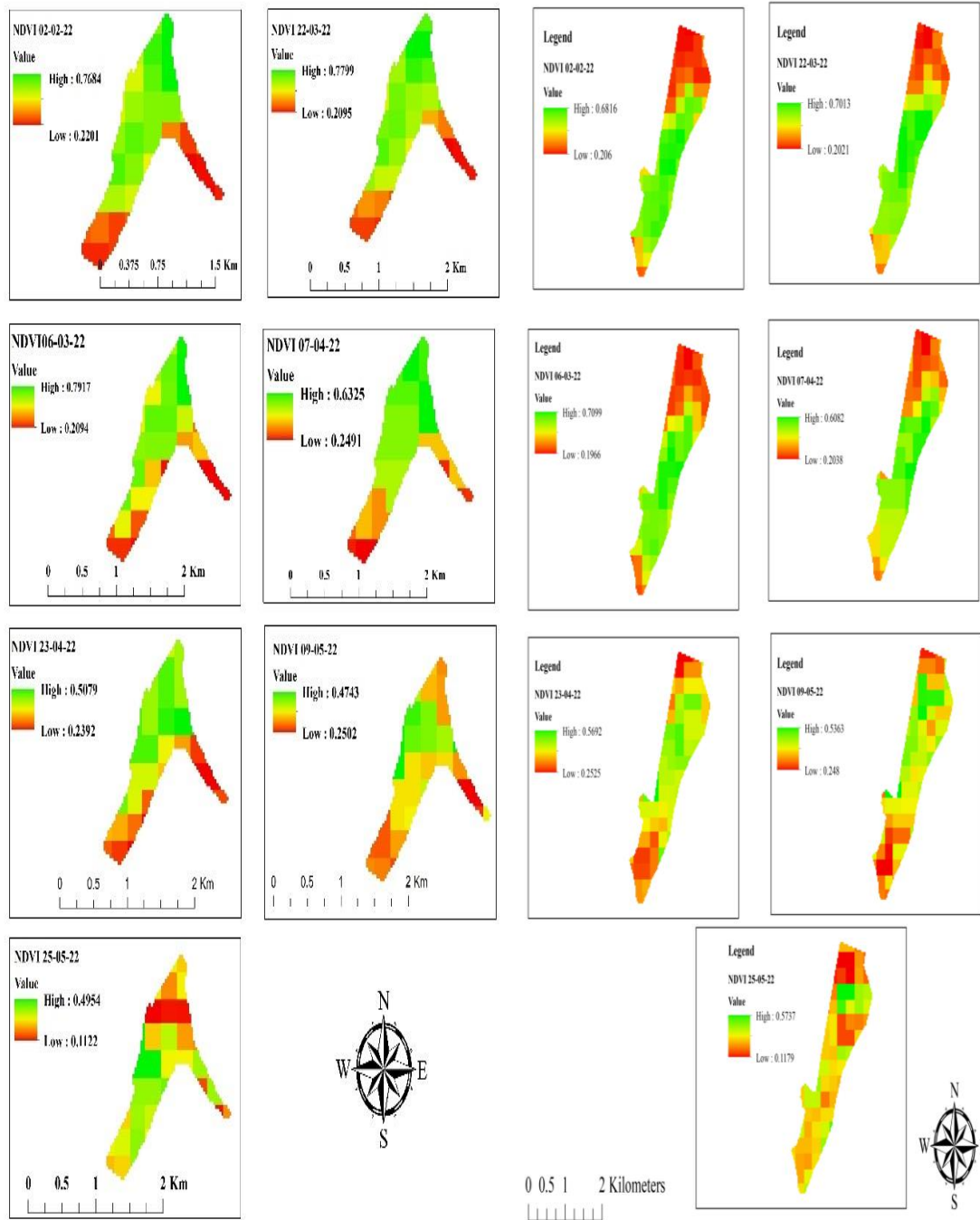


Figure 3-7 K. Fowafowate, K. Genet, K.T. (from left to right) NDVI value for the 2021/22 irrigation season

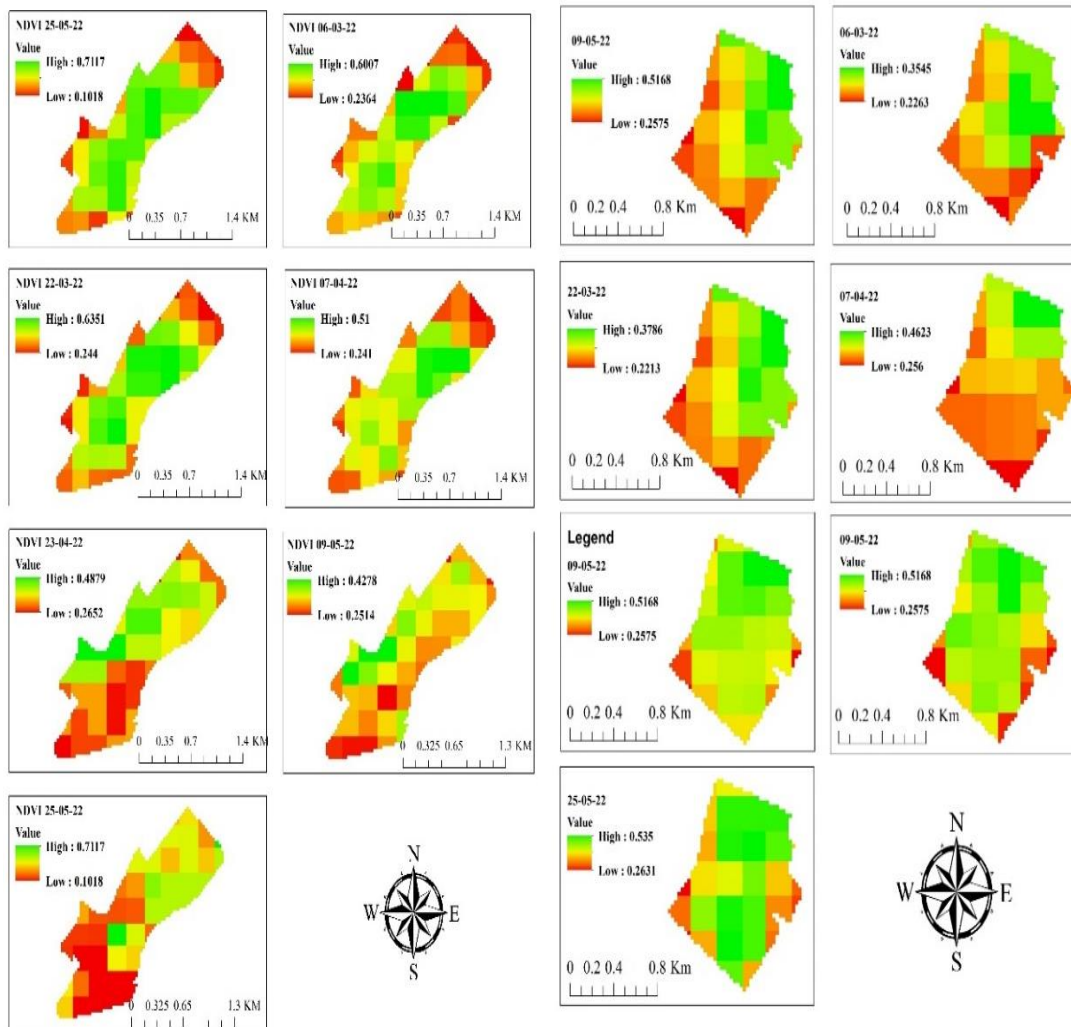


Figure 3-8 K.T. Unshoo, and Arata Schemes (from left to right) NDVI value for the 2021/22 irrigation season

3.3.1.3 Conveyance efficiency

The conveyance efficiency of the four schemes was calculated starting from the aqueduct outlet for K. Fowafowate, K. Genet, and K.T. Unshoo up to their respective main canal and conveyance canal end. Besides, K.T. Unshoo's main canal efficiency is considered from the night storage outlet up to the end of the canal. Arata conveyance efficiency is calculated considering both main canals, the main canal (1) and the main canal (2) at left and right respectively. The main canal (1) takes water from the night storage of the scheme while the main canal (2) gets water directly from the diversion structure.

Table 3-3 Conveyance Canal efficiencies of the four schemes

Scheme	Canal beginning	Q at aqueduct (m ³ /sec)	Length (km)	Q at the end (m ³ /sec)	Conveyance efficiency (%)
K. Fowafowate MC	Aqueduct outlet	0.875	6.5	0.69	79
K. Genet MC	Aqueduct outlet	0.875	11.1	0.513	59
K.T. Unshoo	Aqueduct outlet	0.875	16.2	0.428	49
Conveyance					
K.T. Unshoo MC	Night Storage	0.51	1.5	0.4	80
Arata Chufa MC (1)	Weir Intake	0.55	1.3	0.45	82
Arata Chufa MC(2)	Night Storage	0.63	1.1	0.49	78

Q – discharge in m³/sec

The conveyance efficiency for K. Fowafowate, K. Genet, and K.T. Unshoo is decreasing while the canal length is increasing (Table 3-3). The water loss per kilometer decreased from 0.11 m³/sec at K. Fowafowate to 0.04 m³/sec at K. Genet and 0.03 m³/ sec at K.T. Unshoo. On the other hand, the water loss of the Arata main canal(1) and the main canal (2) are 0.35 m³/sec and 0.45 m³/sec per kilometer respectively.

3.3.1.4 Distribution and Field Canal efficiency

The field canal efficiency of each scheme is found to be 62%, 64%, 73%, and 76% for K. Fowafowate, K. Genet, K.T. Unshoo, and Arata chufa respectively. The distribution efficiency which is the product of the conveyance and field canal efficiency of the four schemes is found at 49%, 48%, 57%, and 59% K. Fowafowate, K. Genet, K.T. Unshoo, and Arata chufa respectively.

3.3.1.5 Crop Water Requirement

The crop water requirement of wheat, from November to March 2020/21, was computed with cropwat 8.0 using Ogolcho and Kulumsa Metrological station data (Figure 3-6 & 3-9).

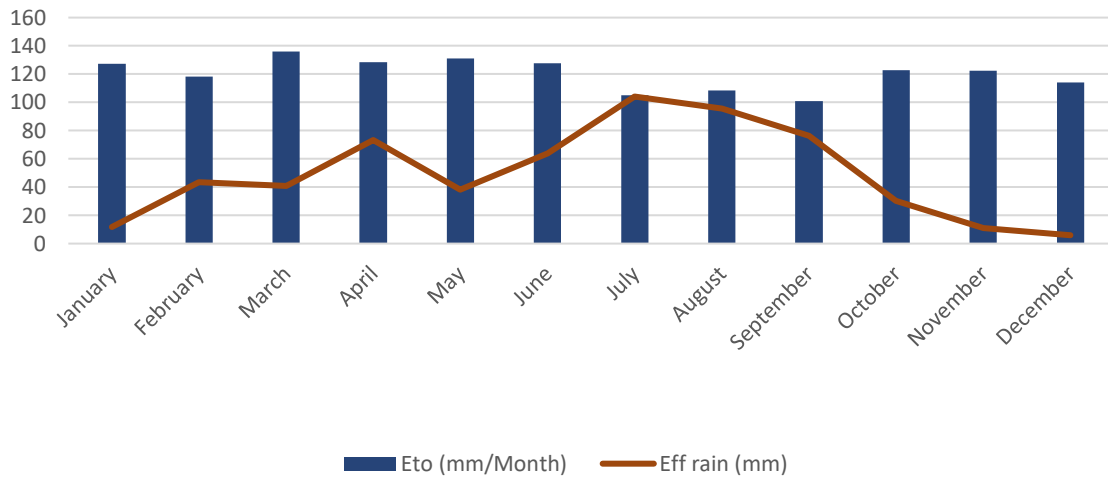


Figure 3-9 K.T. Unshoo & Arata Chufa Eto (Abura Station)

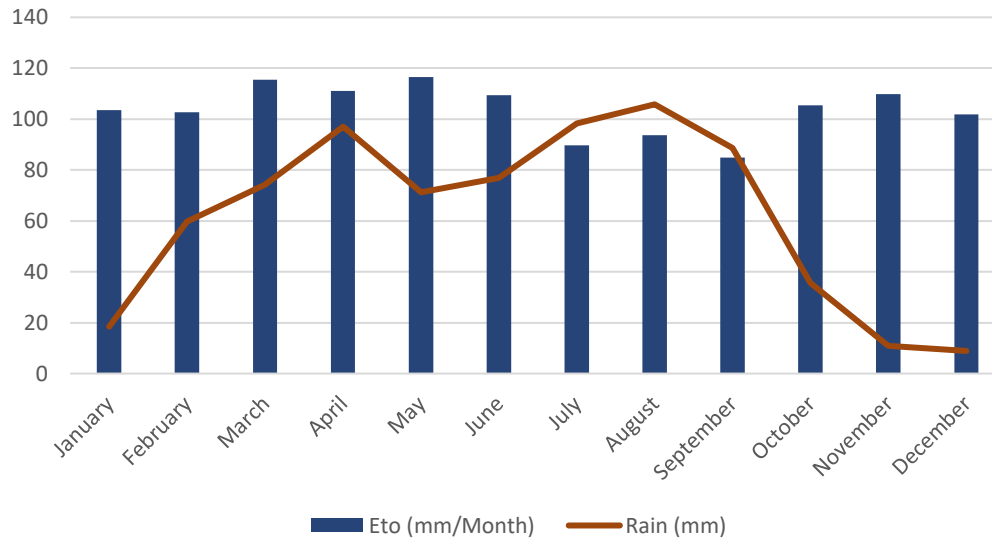


Figure 3-10 K. Fowafowte & K. Genet Eto (Kulumsa Station)

The Irrigation water requirement at U/S schemes(K. Fowafowate and K. Genet) for wheat is 362mm, while d/s schemes (K.T.Unshoo and Arata Chufa) wheat requires 396.3 mm (Table 3-4).

Table 3-4 Crpwat Results of Wheat

Crop	Wheat (mm)	
	CWR	IWR
K. Fowafowate	393	362
K. Genet	393	362
K.T. Unshoo	427.2	396.3
Arata Chufa	427.2	396.3

3.3.1.6 Seasonal Irrigation Water Supply (SIWS)

The SIWS per unit area(ha) at field level was compared to the Cropwat 8.0 estimated IWR (Table 3-5). The irrigation water supply of each unit area was expected to follow the Cropwat 8.0 analysis result. The result showed that the ratio of SIWS to IWR at K. Fowafowate, K. Genet, K.T.Unshoo, and Arata for the year 2020/21 are 0.85, 0.89, 0.81, and 0.66 respectively. It should

be noted that this result only shows at field level where water was measured at farmers plot level. It may vary, if irrigation efficiencies at conveyance, and distribution system were considered.

Table 3-5 IWS Vs IWR ratio result

Crop	Wheat 2020/21		
	SIWS (m ³) ¹¹	IWR (m ³)	Ratio
K. Fowafowate	4032	3620	1.11
K. Genet	4320	3620	1.19
K.T. Unshoo	3360	3963	0.85
Arata Chufa	3500	3963	0.88

* Ratio - SIWS/CWR

3.3.1.7 Farm Level Water and Economic Productivity

The FWP of the four schemes for Wheat, Potato, and Onion taking water supplied at plot level was analyzed. Accordingly The result showed that the wheat water productivity for K.T Unshoo, K. Genet, K.T.Unshoo, and Arata are 0.74 kg/m³, 0.69 kg/m³, 0.86 kg/m³ and 0.8 kg/m³ respectively (Table 3-6). Price-wise¹², the average water productivity of wheat in US dollars, which Ethiopia is importing in large volume is \$0.78/m³ (figure 3-11).

Table 3-6 Water Productivity of Wheat, potato, and Onion

Crop	Wheat			Potato			Onion		
	V (m ³)	Y (kg)	(kg/m ³)	V (m ³)	Y (kg)	FWP (kg/m ³)	V (m ³)	Y (kg)	FWP (kg/m ³)
K.Fofowate	4032	3000	0.74	4032	32000	7.9	4666	24000	5.1
K.Genet	4320	3000	0.69	3629	29000	8.0	3888	25000	6.4
K.T. Unshoo	3360	2900	0.86	4200	27800	6.6	3672	20000	5.4
Arata Chufa	3500	2800	0.8	4320	30000	6.9	3341	24000	7.2

¹¹ The SIWS is the water supply measured at plot level only.

¹² The prices are taken from Ethiopian market and converted to USD in regular Bank rate (1 USD – ETB 53.21)

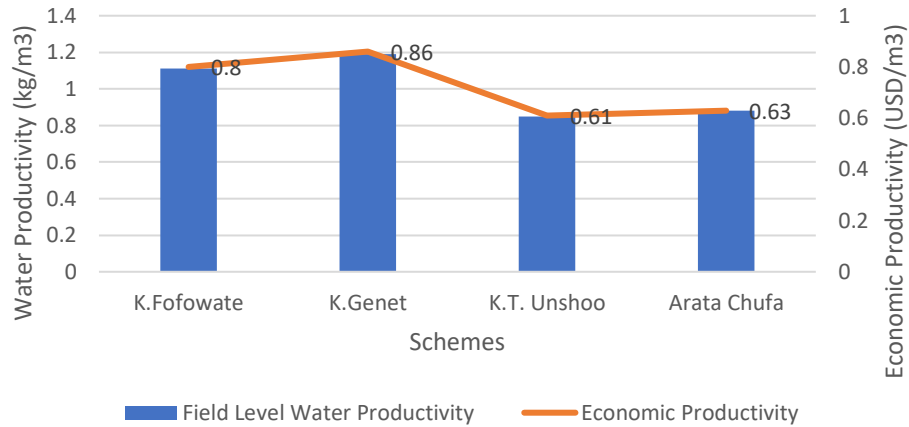


Figure 3-11 Average Water and Economic productivity of wheat

3.3.1.8 Discussion

The study endeavored to engage two irrigation seasons NDVI Jan -May 2021 and 2022 index as an irrigation performance assessment indicator with 2021 irrigation season efficiencies and irrigation water crop productivity. The NDVI value extracted for these two seasons from MOD13Q1 image data was used to assess the performance of the four small-scale irrigation schemes and inter-scheme water distribution.

Based on the average NDVI values of each scheme, it was found that there was no significant difference in irrigation performance across the four irrigation schemes(K. Fowafowate and K. Genet and K.T. Unshoo and Arata) between the two years (2021 & 22). The NDVI values for K. Fowafowate were 0.41 for both years, while K. Genet had 0.43 and 0.42 for year 2021 and 2022, respectively. K. T. Unshoo had 0.36 and 0.39, for Arata 0.36 and 0.32 for both years, respectively. The schemes located near to the water source had higher NDVI values as it is shown in the K. Fowafowate and K. Genet and K.T. Unshoo, which are listed in order of proximity to the

water source. However, the Arata NDVI value was small due to the illegal water abstraction at upstream rather than being proximate to the water source as indicated by study conducted by Geleta et al. (2023).. In addition, the NDVI values that is based on wheat irrigation growth stage showed that the NDVI values of the four schemes were not following the wheat growing stages Kc value pattern (increasing or decreasing with Kc value) and were not also satisfying the minimum NDVI for good yield at each stage. Sometime the NDVI value fell while expected to increase with Kc value and vice versal. According to various studies, a wheat crop with an average NDVI value of 0.3 during the initial stage, increasing to 0.6 during maturity, and then declining to 0.5 during the harvesting stage, can be an indication of a relatively good yield, assuming other factors are normal (Adamala et al., 2016; Aranguren et al., 2020).

The assessment of intra- irrigation scheme performance across the four irrigation schemes showed that the head irrigation areas were the primary beneficiary of the irrigation. The highest NDVI values were consistently observed throughout the irrigation months at the head of each irrigation scheme, as demonstrated by the NDVI observed data 0.7, 0.9, 0.6, and 0.7 recorded for K. Fowafowate , K. Genet, K. T. Unshoo, and Arata head plots respectively, during the 2020/21 irrigation season. Contrary to the head plots, significantly lower NDVI values of 0.2, 0.1, 0.01, and 0.2 NDVI values were observed for tail plots.

The 2021/22 NDVI recorded values also witnessed similar patterns with 2020/21 irrigation season of high NDVI values such as 0.7 for K. Fowafowate and K. Genet; 0.6 and 0.5 for K. T. Unshoo and Arata head plots respectively. The lowest NDVI values were 0.2 for K. Fowafowate and K. Genet and Arata, and 0.1 for K. T. Unshoo tail plots. This finding was triangulated with the Key informants and field observation. Accordingly, the poor water distribution indicated by the NDVI values were caused due to the weak water distribution management of each irrigation water user association and irrigation infrastructure deficiencies like lack of maintenance, earthen canal seepage, water theft by the up streamers, and other. The findings regarding the water distribution within the scheme are similar to other studies conducted in the project area (Fufa, 2017; Geleta, B, & A.Engdawork, 2022).

The irrigation efficiencies consisting of the conveyance, field, and distribution efficiencies analyzed for the four schemes showed that Arata Chufa's main canal efficiency was found better than the other schemes, including the finding of Fufa (2017). According to FAO for a small scheme less than 1000 ha with rotational irrigation water supply and communication problems and predetermined schedule conveyance efficiency of 70% is recommended (Doorenbos and Pruitt, 1977). Out of the four schemes, only K. Fowafowate and Arata Chufa had a conveyance efficiency greater than 70%, while K. Genet and K.T.Unshoo are significantly lower. The results of the main canal efficiency for K. Fowafowate, K.T.Unshoo, and Arata were either similar to or better than those studies conducted in Sub-Saharan African countries like Burundi (Prosper et al., 2022). The primary reason for this poor performance is that the conveyance canals pass through many villages where there is less control and high water theft, long earthen canals that contributed to high seepage, and direct uncontrolled livestock and domestic use.

The two downstream irrigation schemes, K.T.Unshoo and Arata Chufa have higher field canal efficiency 73% and 76% respectively, compared to K. Fowafowate(62%) and K. Genet(64%). However, these results are below 86% the result reported in other parts of Ethiopia (Alebachew and Ing, 2018) but are within the acceptable range of the FAO unlined canals for blocks up to 20 ha which is 70% (Doorenbos and Pruitt, 1977). These results indicate that downstream schemes have better field water management than upstream schemes. Similarly, the distribution efficiency of K.T.Unshoo and Arata is better than those of K. Fowafowate and K. Genet. The former two irrigation schemes' distribution efficiency, 0.7 and 0.59 respectively concur with FAO recommendations that is for rotational irrigation water supply in sufficient water management and communication that is between 0.55-0.65. In contrast, K. Fowafowate and K. Genet distribution efficiencies of 0.49 and 0.48, respectively is below the above FAO recommendation but agree with schemes with insufficient water management and communication efficiency value that is between 0.4 and 0.55 (Doorenbos and Pruitt, 1977). K. Fowafowate and K. Genet are located at u/s where water availability is relatively ample and efficient use is not as critical as in the downstream schemes. In general, the over-exploitation and the deficit irrigation water supply in all the schemes

are attributed to the lack of irrigation water management by users, irrigation water user associations, and nearby irrigation experts.

The productivity of wheat, which covered more than 90% of the irrigation area of the selected schemes, at the field level was observed to be 0.74kg/m³, 0.69kg/m³, 0.86kg/m³, and 0.8 kg/m³ for K. Fowafowate, K. Genet, K.T.Unshoo, and Arata respectively. These results fall within the productivity range of medium-latitude countries, which is 0.75-1.1 kg/m³ (Foley et al., 2020) and are nearly similar to the findings of Hordofa et al., (2022) and it is less than Egypt water productivity -1.08 kg/m³ but greater than Tunisia -0.36 kg/m³ (Zwart, Bastiaanssen, Fraiture, & Molden, 2010). The better water productivity results of downstream schemes such as K.T.Unshoo and Arata Chufa, as compared to K. Fowafowate and K. Genet revealed that the availability of water alone is not the only determinant for water productivity. Other irrigation agronomic practices must be considered.

Generally, the analysis of NDVI values showed that the performance schemes and command areas within an irrigation system are closely tied to their proximity to water. However, when water productivity is overlaid on the NDVI result, it adds the effective water management variable role at both scheme and plot levels. Additionally, the irrigation efficiency result indicates downstream irrigation schemes' relative awareness of irrigation water management.

3.4 Conclusion and Recommendation

The study findings revealed that the performance assessment results of the irrigation schemes varied across different indicators. The NDVI values indicated that irrigation schemes and command areas near the water source performed better, the conveyance efficiency indicator showed that the u/s schemes are well, while the distribution efficiency result disclosed that d/s schemes were preferable. The on-field efficiency indicator demonstrated that all schemes fell within the FAO efficiency range for unlined, insufficient water management and communication schemes. Looking at each scheme from the perspectives of water productivity and water use

indicators, the result displayed different water use and water productivity outcomes. These different results can be attributed to water availability, farmers' awareness of irrigation water management, and agronomic practices.

This study concludes, that measuring and comparing irrigation schemes based on various parameters, particularly by incorporating remote sensing data such as NDVI mainly correlating with yield productivity (even if this study only limited the greenness), alongside water delivery capacity, water use ratio, and water productivity, shows the strength and weaknesses of irrigation schemes. Such comprehensive study can support a sound intervention for improvement.

Hence, the study recommends the academic arena and the water and irrigation sector of the sub-Saharan countries to encourage the inclusion of remote sensing data such as NDVI correlating it with yield a standard approach for assessing irrigation scheme performance, encompassing multidimensional but achievable objective-based scheme evaluation criteria for better irrigation performance. This type of evaluation supports policymakers in scheme-specific intervention and policy orientation.

PART FOUR - ENVIRONMENTAL FLOW

4 MAPPING COMMUNITY PERCEPTION, SYNERGIZE, AND TRADE-OFF OF MULTIPLE WATER VALUES IN THE CENTRAL RIFT VALLEY WATER SYSTEM OF ETHIOPIA

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Abstract

Individuals and communities use and value water in multiple and complex ways. In Sub-Saharan Africa (SSA), the pluralistic nature of water values is poorly documented and the existing and potential value trade-offs unidentified. This study was undertaken in the Central Rift Valley (CRV) of Ethiopia to understand how people with different backgrounds value water and to identify the major water value conflicts. Integrated assessment methods, combining bio-physical and social methods, were applied. The results show 24 community-perceived and articulated water values that are diverse but interconnected including values of water, landscapes, the river system, and downstream water bodies. Connections between people and landscape structures are articulated.. In terms of priority water values, the overall results reflect the primary but basic need of water for food security. The results further illustrate the pluralistic nature of water values and the dichotomy of preferences by people of different backgrounds. The scenario-based Environmental Flow (EF) assessment exercise integrated into community value preferences and the event calendar that was used shows that the river systems in CRV (Ketar, Kulumsa, and Gusha-Temela) have different ecological and socio-cultural flow requirements and that there are marked water values trade-offs. The conclusions of the study suggest that overlapping governance structures are affecting people's perceptions of water and the way they articulate water values. Policy directions and decision-making need to recognise and acknowledge the multiple water values and competing uses of water in the CRV as a starting point to reconcile trade-offs that will then improve water security. Findings suggest that EF estimation and decision support tools can be customized to local ecological requirements through engaging local stakeholders in the assessment process.

Keywords: Multiple water values, integrated assessment, sociocultural values, shared water value, water value conflict, central rift valley

4.1 Introduction

Ethiopia is often described as the water tower of Africa reflecting its large water resources endowment: 122 billion cubic meters (BCM) of river water, 70 BCM of lake water, and 36 BCM of groundwater across 12 river basins [1]. However, the growing economy and rapidly growing population of over 100 million people is exerting unprecedented pressure on water security through increased and competitive water consumption and encroachment into ecologically sensitive ecosystems (e.g. land use/land cover change)

The Rift Valley Basin (RVB) of Ethiopia is an important eco-region hosting National Parks and significant, often endemic, flora and fauna. It includes approximately four BCM of annual average flow into its lake system and is commonly divided into three interdependent sub-basins: i) The Central Rift Valley (CRV) (also known as Ziway-Shala) sub-basin (14,000 km²); ii) The Hawasa sub-basin (1,400 km²); iii) and the Abaya-Chamo-Chew Bahir sub-basin (37,000 km²).

The CRV, where this study focuses, is noted as ecologically the most sensitive and overused system and is primarily under pressure from anthropogenic impacts. Major freshwater flows to the CRV basin from rivers Meki (180 Mm³yr⁻¹) and Ketar (396 Mm³yr⁻¹). These two major rivers originate from the elevated East (Mount Chilalao, Galama and Kubas) and West (Mount Gurage) sides of the CRV and flow in a southerly direction into the terminal lakes: Ziway, Shala and Abjata and Langano [2,3]. The CRV basin is a hydrologically closed system (endorheic), with no surface outflow from lakes. This means that any alteration of river system structure in the major water suppliers (Ketar, Meki, other small streams) would affect the CRV water system and thus could lead to the loss of the multiple water values held by communities that rely on the system.

Agriculture, both smallholder and commercial, in the RVB is intensifying, thanks to the RVB's proximity to infrastructure, settlement centres, and markets – including international air freight – and easy access to water resources. Supported by the government, donors, and the private sector, agro-processing industries are developing rapidly, including Bulbula agro-industrial park,

the beef processing industry, wineries, textile industries (in Hawassa), and a booming floriculture sector.

While these investment efforts are opportunities to improve overall economic growth in the country and support livelihood transformation for local populations, they also pose daunting challenges to multiple water values and sustainable water resources management. Understanding the pluralistic and diverse nature of water values is understood to be a core foundation for sustainable water management [4].

Valuing water has been identified as gauging the importance, worth, desirability, and trade-off strength between different water values [4]. Values are identified through biophysical, economical, and sociocultural indicators [5]. Water valuation is commonly carried out through economic, monetary, and single-unit focused methods [6–10]. This valuation overlooks other important sociocultural values which have been described as intrinsic, instrumental, and relational which cannot be expressed in monetary terms [11–13]. Sociocultural water values include intangible values which can be understood by examining spiritual, emotional, recreational, intrinsic, and aesthetic values expressed by both individuals and communities. Such values develop through the social experience, satisfaction, pursuit, and benefits of society's spiritual and moral characteristics [8,14,15]. Such water values reflect the relationship between places and people; they reflect individual and community behaviours and may be related to time [16]. Hence, understanding water values should be carried out on a multidimensional basis including ecological, economic, and sociocultural assessments, using multiple disciplinary approaches, methods, and scales [15,17]. The multidimensionality of water values requires a transformation from the single valuation approach to the emergence of an integrated and pluralistic valuation approach [17,18]. This study considers economic, cultural, and environmental indicators to develop multi-dimensional valuation using engineering and social science methods [18].

In Sub-Saharan Africa, identifying water values has been a challenging task for many researchers and development experts, due at least in part to limited baseline historical data[19].

Researchers studying water values have focused mainly on using monetary methods such as the actual price paid or the willingness to pay from the consumer's point of view by adopting contingent valuation methods [20,21]. Also, many studies valuing water in Sub-Saharan Africa have mostly focused on domestic water use rather than a more holistic approach to thinking about water [19]. Ethiopian water policy tends to focus more toward the economic value of water leaving a microscopic space for social and environmental values[22].

This study is based around the hypothesis that making the different values of water evident, as well as identifying the actors who define them in a multi-stakeholder engagement process will provide the basis for more transparent and accountable decision-making that acknowledges competing uses of water and aims to reconcile trade-offs between different water users and different uses. Against this background, the main objectives of this study were: i) to document the diversity and priority water values and advancing threats to the values; ii) to investigate major value conflicts

4.2 Materials and methods

4.2.1 Conceptual framework

Different people will place different values on the same water even if they are of the same culture. Someone might want to use it for irrigation, someone for watering their animals, and someone for drinking it themselves. Water has the characteristics of consumption rivalry and thus very often uses of water will be impossible to reconcile. Hailelassie et al., (2020) emphasize that water values are context-specific, and contexts can be explained through the mapping of water systems and sub-systems and the different water users and use within them.

System mapping can identify options, scenarios, and their potential trade-offs which could inform decisions on modification or changing systems to achieve higher levels of performance and examine the effects of other external factors (e.g., climate change). This helps to target and contextualize water value principles and enable synergies and complementarities to be built and

for the system to move in the desired direction. Against this background, Hailelassie et al., (2020) synthesized a water system as a system with defined structures (natural and manmade), functions (supporting, provisioning, regulating, and cultural services), with direct and indirect interactions among its diverse components. It is key to envisage water systems as inherently unstable, undergoing change across time and space physically, but also as new forms of institutional governance arise from formal (e.g., policy change) to informal (e.g., shifts in norms). We adopt this conceptualization to construct the conceptual framework for this study as depicted in Figure 4-1.

The framework begins with a review of water policies and strategies to understand water systems where a threat to multiple water values is at stake in Ethiopia (MoWR 1999). As presented by Mekuria et al., (2021), and Jansen et al., (2007), the central rift valley (CRV) water system ecosystem service value is deteriorating.

The CRV system lakes are fed by Ketar and Meki River systems flowing from Aris and Gurage highlands respectively. The growing interest in food production is putting more and more water under irrigation in Meki and Ketar rivers. This with the water that is directly pumped from Lake Ziway substantially affects the sustainability of the water ecosystem services in CRV. Thus, this study attempts to explore the diversity of and threat to multiple water values across scales (nesting Ketar water system into CRV (Figure 4-2) and presents and discusses the result interactively.

The second step, as depicted in the conceptual framework, is CRV and Ketar water systems and value characterization. We followed the suggestion by Hailelassie et al., (2020) and disentangle methods that highlight water system structures and functions and its governance and methods to capture multiple values of locals. Temporal and spatial mapping of multiple water values, based on information gathered during the second step completed. This allows us to identify spots for overlaps and competing water values and to synthesize information into global experiences in terms of how understanding multiple values, nurturing synergies, and managing

tradeoffs following the valuing water principles suggested by HLPW, (2017) can ensure better water security.

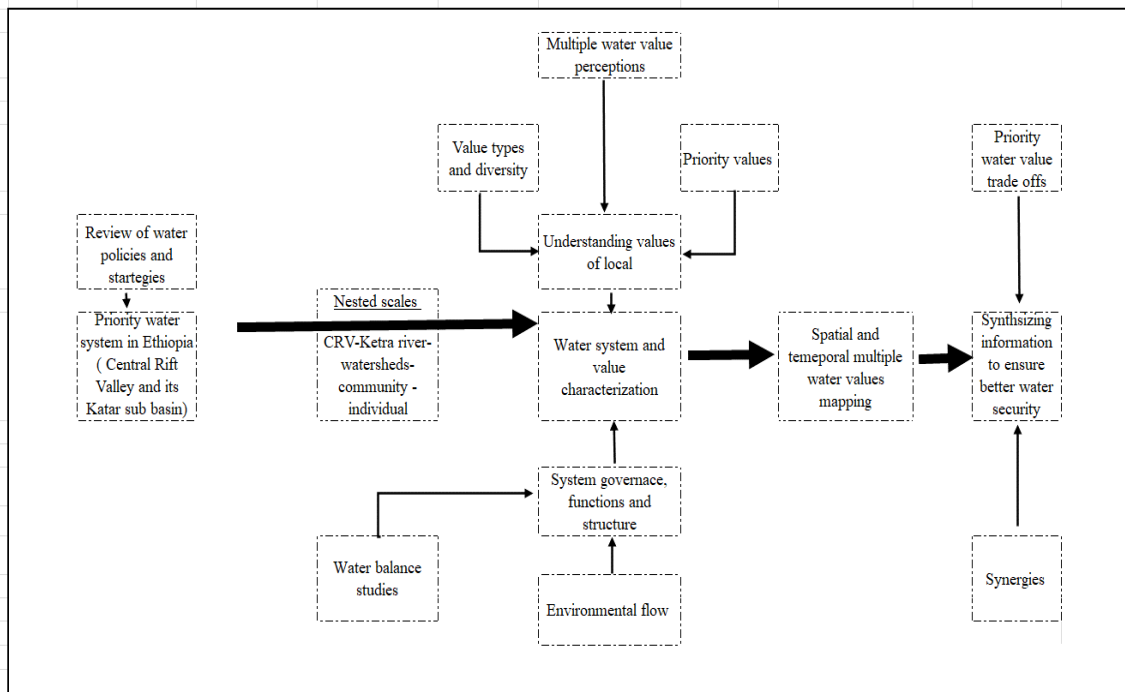


Figure 4-1 Figure 4 1 Conceptual framework for understanding synergies and trade-offs of multiple water values in the Ketar basin of the Central Rift Valley water system in Ethiopia.

4.2.2 Functions and structure of the Central Rift Valley and Ketar water systems

4.2.2.1 The Central Rift Valley

Central Rift Valley (CRV) is found in the central lowland part of the country located in two regional states: Oromia and the Southern Nations, Nationalities and Peoples’ Region [SNNPR (Ayenew, 2009)]. The elevation of the basin ranges from 500 m.a.s.l. to more than 4000 m.a.s.l. (Ethiopian Panel on Climate Change, 2015). The CRV is also a center of biodiversity, acting as a

migration corridor for critical bird species as well as an important system to ameliorate the effects of drought and protein shortage for the population in the region.

The mean annual rainfall of the basin varies between 500mm near the Lakes and 1,200mm around the highlands. Overall, the total precipitation is estimated at 12.95 BCM of surface water resources and the average minimum temperature is 10.5°C, while the average maximum temperature is 24.3°C (Gadissa et al., 2019). In addition to the lakes, the river systems which feed fresh water to the lakes make up an important structure of the CRV water system.

There are several perennial rivers, including the Meki, Ketar, Bulbula, and Horakelo. Abijata is connected to both Ziway and Langano through Bulbula and Horakelo, respectively, and it is more sensitive to the reduced flows of the Bulbula compared to those of the Horakelo River (Gadissa et al., 2019).

Another key system structure is land use. Among the seven majors identified LULC classes, farmlands, settlements, and bare lands showed positive changes, while forestlands, grasslands, shrublands, and waterbodies showed negative changes over the last 47 years. The expansion of farmlands, for example, has occurred at the expense of grasslands, forestlands, and shrublands (Mekuria et al., 2021). As now it stands agriculture-led livelihoods dominate the CRV. Agricultural practice in the CRV is heavily rain-fed like the rest of the country. Given this, it accounts for more than 90% of water consumption and it is important to pay attention to how transformations now – and in the future – might take place in the smallholder system and how this affects multiple water values.

While all the sub-basins are important in their context the Ministry of Water Irrigation and Electricity and the River Basin Development office put major emphasis on the CRV. This is mainly related to the economic importance and ecological sensitivities of this sub-basin. Given the amount of literature and as verified during focus group discussion, the CRV sub-basin has faced multiple challenges including water level reduction, land degradation, and water overutilization.

Overconsumption of surface water without a reserve storage facility is currently posing a threat to the lake water system of the basin. According to stakeholder consultation participants during the last three to four decades, many smallholder farmers, as well as large agribusiness, have been increasingly abstracting a considerable amount of water for irrigation from Lake Ziway and its feeder rivers Meki and Katar. This is causing the water-level reduction of Lake Abijata, which connects with Lake Ziway through the Bulbula River.

Reflecting multiple values inherent in this resource base, the lakes in the rift valley are used for multiple purposes including irrigation, fishing, domestic water supply, transportation, and recreation (Hirpo, 2016) also during religious and cultural festivals. The sharing of an interconnected water system between these different administration units has several implications. A multitude of users and a lack of proper coordination systems can introduce environmental externalities with respective regional states striving to maximize economic benefit at the expense of environmental and socio-cultural water values. During the FGD these were major points of debate.

The interconnectivity of the water system structure in CRV suggests the need for holistic recognition and stewardship of multiple values of water. An example in this regard is the over-extraction of Lake Ziway which impacts the level of salinity of Lake Abijata(Goshime et al., 2021), arguably leading to biodiversity degradation and therefore challenging the multiple water values inherent in the system. In particular, the two neighbouring lakes, Abijata and Shalla, in CRV are of special importance to wildlife by providing feeding and breeding grounds for a rich bird fauna of over 360 species including both resident and migratory birds. The two lakes have been enclosed as part of a national park since the 1970s(Kebede et al., 1994), and changes in levels of salinity might affect the diversity of species residing and the habitat quality of the lakes.

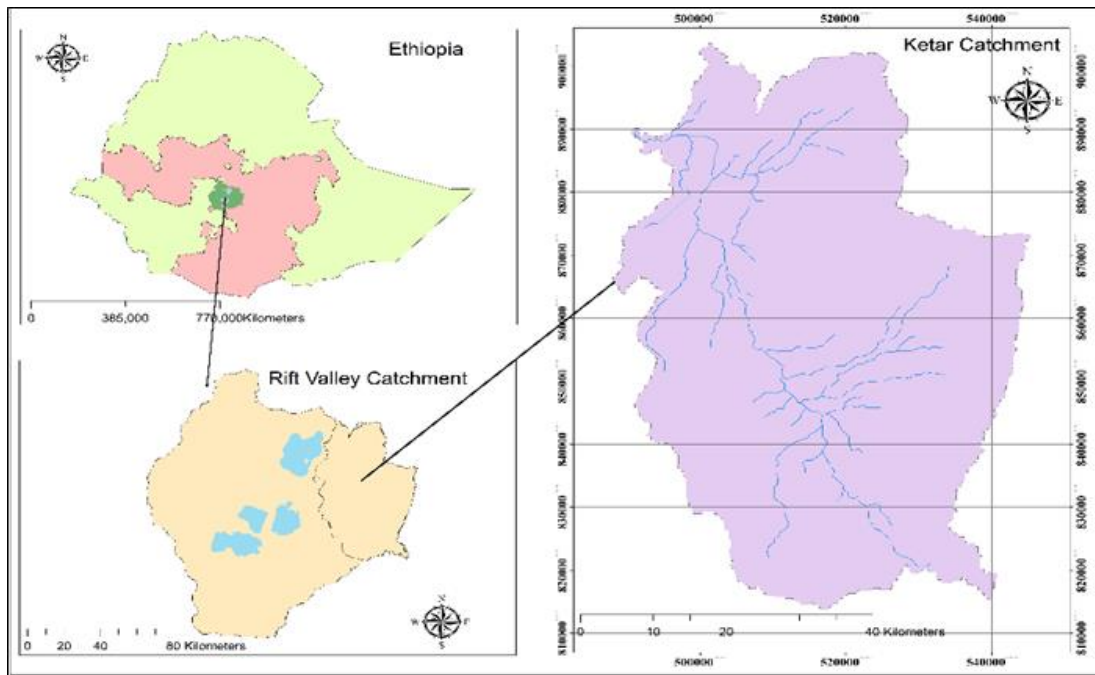


Figure 4-2 Location of the study areas (central rift valley and Ketar River water system)

Although comprehensive and reliable data is hard to find on water use Goshime et al., (2021) reported that the actual storage and outflow of Lake Ziway are significantly impacted by the existing water withdrawal. Implementation of future development plans (2029–2038) annual water withdrawal for irrigation will be about 95 Mm³ and the subsequence is a drop in lake level by the magnitude of 0.94 m or 38 km² reductions in the lake surface area or loss of 26.5% of its actual storage volume compared to the observed storage between 1986 and 2000. This will impact lake Abjata and Bulbula rivers.

Elias et al., (2019) work on CRV substantiate the suggestion of Goshime et al., (2021), and accordingly, lakes in CRV are experiencing decreasing trend. In this regard, the authors demonstrated the case of Lake Abjiata which is shrinking at an annual rate of 12.07%. The authors accounted for the lake size reduction for by to investment policies. The use of river Bulbula, which

connects Abijata and Ziway, for irrigation and factories has caused the river to dry up, contributing to the shrinkage of Lake Abjiata. Now the question is how this affects water ecosystem services associated values and it is important to understand which and whose water values are most affected and what are the policy implications.

4.2.2.2 *Ketar river water system*

Ketar basin is a sub-system of the CRV as indicated in Figure 4-2 and with a drainage area of 327,160 hectares and a 103.1 km long river course. It arises from the slopes of Mount Kaka and Mount Baddain the Arsi Zone. The gradient of the river is generally steep and the Ketar river flows through rugged terrain with steep slopes and high sediment movement is a major occurrence. Ketar river system supports more than 675,000 households' livelihoods that mainly rely on smallholders farming and serves 1.6 million livestock.

The Ketar water system encompasses 55% of six woredas¹³; Tiyo and Digalu fi Tijo woredas fully, Lemmu fi Bilbilo, Munesa, Hetosa, and Enkolo Wabe woredas partially. The Ketar subbasin is divided into 105 kebeles. According to Ethiopian Central Statistics Agency (CSA), the Ketar subbasin woredas year 2022 projected population data is 836,544 of which 45.4% and 54.6% are Male and Female respectively(CSA, 2022). The religious composition of the woreda population is 47.4% Christian, 52.1% Muslim, and the rest indigenous religion and others (CSA, 2007). Ketar is characterized by wider altitude ranges (4188-1667m.a.s. l.). Based on the agroecological classification by (Hurni, 1998), the Ketar river system altitude range is used as a proxy indicator to define agroecology, namely Wurch, Dega (Highland), Woyna-Dega (Midland) (see Table 4-1). The largest area is covered by Woyna- Dega followed by Dega and Wurch (Table 4-1).

¹³ Federal, Region, Zone, woreda, and Kebele are Ethiopian governmental administration structures from top to bottom.

The overall climate of Ketar is indicated in Figure 3. The climatic conditions characterizing the rift floor, the escarpment, and the highlands differ greatly. The mean annual rainfall over the entire basin is around 900 mm. There are high spatial variations in Ketar with 700 mm/year and as high as 1200 mm/year in the rift floor and highlands respectively.

Table 4-1 Table 1. Agroecological classification on Hurni, (1998) classes.

Landscape positions	Traditional agroecology	Elevations (altitude Masl)	Major crop type
Highland	Wurch (e.g surrounding mount kaka)	>3200	Main crop: Barley Vegetation: degraded Erica Soils: Mainly black poorly drained
	Dega	2300–3200	Main crops: Barley, Wheat, Pulses Vegetation: Juniperus, Hagenia, Coffee, Podocarpus Soils: Mainly brown clay
Midland	Weyna Dega	1500–2300	Main crops: Wheat, teff, rarely Maize, Niger seed, Coffee depending on the level of moisture Vegetation: Cordia, Acacia major Soils: Mainly well drained deeply weathered red brown

There is also temporal variability of total rainfall and about 59% occurs during the rainy season (June–September), the remaining 28%, and 13% fall during months of Match–May and October–February respectively (Pascual-Ferrer et al. 2014). The mean annual temperature is about 15° C in the highlands and around 20° C in the rift and actual ET varies from around 900 mm/year in the rift to 650 mm/year in the highlands. The climate is humid to sub-humid in the highlands and semi-arid in the rift floor. The hydrology of the region is characterized by seasonal variations. Since precipitation is the only input of water that is available for ET, surface runoff, recharge to groundwater, and interflow, and in turn, it determines stream flow that mostly feeds the lakes

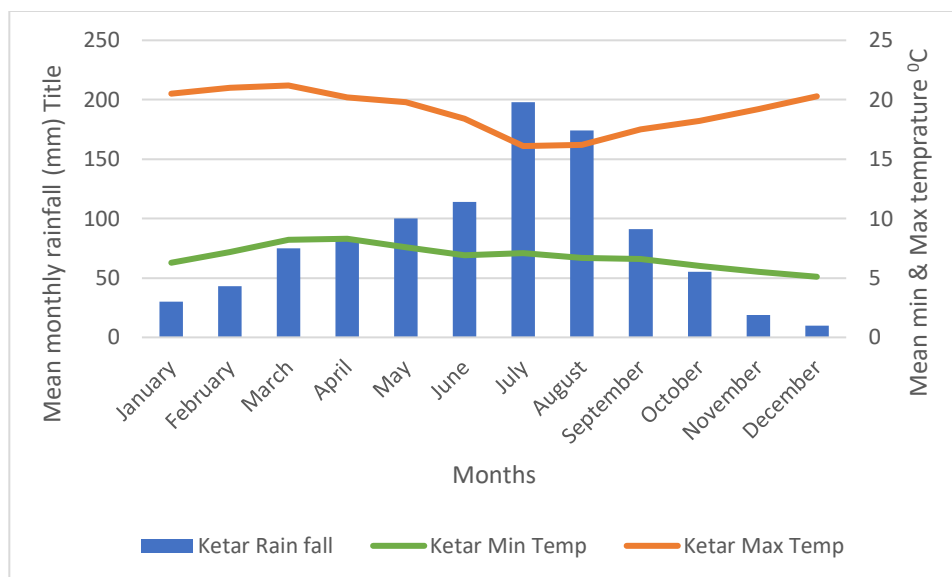


Figure 4-3 Climatic pattern of the Ketar water system (extracted from Geleta et al., 2023)

In the Ketar river land cover is dominated by cultivated land (64%) and forest (20%). The remaining smaller proportion of land use land cover is shared among grassland, shrubland, and bare land and this influences its climate and hydrological variables and paedogenic process. Erosion and land degradation are one of the major sources of pollution in the Ketar River and threaten access to water (Mekuria et al., 2021).

Tufa et al., (2015) evaluated the SWAT model response to the land-use/land-cover change in Ketar and illustrated that the mean wet monthly flow for 2010 land cover increased by 3.8% compared to the 1986 land cover. On the other hand, the average monthly flow in the dry season decreased by 12.3% in 2010 compared to the 1986 land cover. The authors concluded that due to increasing population, there is a high probability that the existing marginal lands will be converted to agricultural lands, and this affects the health of the hydrological process and ecosystem service values within the watershed and in downstream areas (e.g., Mekuria et al., 2021;).

The Ketar river regulates the lake chemistry and water quantity thus the habitat quality of the lake Ziway-Abjata complex (Eyasu 2019). Ketar contributes 57% of freshwater flowing into

Lake Ziway and overflowing from Lake Ziway through the Bulbula river to Abjata lake. It has a major share in sustaining Lake Abijata and maintaining its water quality. Currently decreasing base flow (Tufa et al., 2015) and increasing use of water for irrigation in the upstream area of Ketar (AZILDO, 2017) are interrupting this natural connectivity and impacting Lake Abjata and Ziway (Eyasu et al., 2019) economic, socio-cultural, and environmental water values. As of now, it stands evidence on **Water value perception, plurality, priorities, and risks** of water values across social and geographic strata; information as to which values are most affected, where, why, and by who is generally limited. Additionally, an informed policy decision to stewardship water values requires systematically organized information on water value conflicts and complementarities between values.

4.2.2.3 Water governance and power relation in Central Rift Valley and Ketar River systems

According to Rogers & Hall, (2003) and Vialatte, et al (2019) water system governance refers to the norms, institutions, and processes that figure out how power and responsibilities over allocation and access to natural resources in the water system are exercised. It is also how decisions are taken, and how all citizens participate in and benefit from the management of water and associated natural resources. The effectiveness and equity of governance processes critically determine the strength of the bond between socio-cultural.

To materialize the general development goal of Ethiopian (as stipulated in the ten-year development plan) goals of national-level organizations' powers and duties were redefined and established (ECoM, 2021; FDRE, 2021). Accordingly, the Ministry of Water and Energy (MoWE), the Ministry of Irrigation and Lowland (MoIL), the Ministry of Agricultura, and the Ethiopian Environmental Protection Authority (EPA) are the key institutions concerning water-resources management.

According to the ECoM, (2021), the MoWE is mandated among others with river basin development and sustainable water resource management, *and* access to safe drinking water and

sanitation, The MoWE is responsible for creating the framework, strategy, strategic plan, and regulations for the nation's water laws along with mobilizing capital for large-scale water initiatives. Besides, water law frameworks, regulation, and enforcement in the nation are the responsibilities of the MoWIE and Basin Development Authority at the basin level (one of the MoWE's departments). MoWE is an important stakeholder with a keen interest and power in water resource development. Instrumental water value is the emphasis of MoWE's water policy and legal frameworks. The water policy, legal structures, and regulations do not give enough consideration to multiple water values, and it emphasizes domestic water uses, water for livestock, and water for agriculture (MoWR 1999)¹⁴.

The MoIL is mandated for quality and sustainable irrigation infrastructure development (ECoM, 2021). The MoIL is recently founded as a ministry (Proclamation NO. 1263/2021) and it was established to bridge the gap that existed between water/energy infrastructures and required agricultural productivity and is responsible for the nation's large and medium-scale irrigation development (ECoM, 2021). Similar to MoWE, MoIL has the influence and a stake in the development of irrigation systems while major gaps exist in managing water use conflict and value trade-offs as a result of the expansion of irrigation. It has a high interest and high power for the economic use of water.

In addition to the MoIL, the MoA is another ministry in Ethiopia that is in charge of small-scale irrigation development, agronomic practices, and overall national irrigation production. MoA is mandated to contribute beyond food and nutrition security to the economic development of the country by making the agricultural sector more productive and competitive in the coming ten years (MOA, 2022). Additionally, the MoA is accountable for fisheries, which have a close relationship to water development. MoA has implemented various agricultural policies and programs such as Sustainable Development and Poverty Reduction Program, Participatory, and

¹⁴ New water resource policy which considers multiple water value is submitted to the Ethiopian government for approval.

Accelerated Sustainable Development to Eradicate Poverty and successive Growth and Transformation Plans I and II to raise productivity in agriculture between 1991 and 2016. All these policy interventions have been implemented to increase agricultural productivity and production which, in turn, reduces poverty and food insecurity. This puts MoA as high interest and high-power institutes for the economic use of water.

Ethiopian Council of Ministers establishing proclamation no 1263/2021 gives power to Ethiopian Environmental Protection Agency (EEPA) to develop environmental policies, strategies, regulations, and standards. In addition, EEPA gives environmental clearance for development activities and audits the environmental assessment results management plan for mitigating negative impacts in the country (ECoM, 2021). One of the major policy goals of the EPA is to promote sustainable social and economic development through the sound management and use of natural, human-made, and cultural resources and the environment as a whole. Under its water sector environmental policy, among others, EPA policy stipulates that it recognizes that natural ecosystems, particularly wetlands, and upstream forests, are fundamental in regulating water quality and quantity and to integrate their rehabilitation and protection into the conservation, development, and management of water resources. Water-resources developments in the country should pass through this process and need to obtain environmental clearance (EEPA, 1997) and this is where the right of different water users could be ensured and the pluralistic nature of water value maintained. However, EEPA lacks the real power to monitor and audit this (e.g., Hailu et al., 2017).

Other national-level entities, such as the Ethiopian Electric and Power Authority and the Ministry of Tourism, have interests in the governance of water. The region's water, agricultural, and irrigation offices and environmental protection agencies are governance structures on the second layer of the nation's water governance hierarchy. The Woreda and Kebele structure adds grass root level of water resources governance layer to the federal and regional levels. There are community-level organizations such as these dealing with watershed management, irrigation water management, and domestic water supply infrastructure management. Some of these (e.g., water

user associations are legal bodies) have functional linkage with government structures(FDRE, 2014).

On the other hand, water, agricultural, and irrigation offices at the regional and woreda levels have authority and interest in water for agriculture and domestic water uses but less interest in environmental, social, and cultural water uses and associated values. The local community has influence over and an interest in water governance. Most of the time, they are exposed to the tragedy of the commons in managing water resources. The community, however, wants water governance that is optimized and addresses all water values. While the community appreciates the economic water values, they do not want to lose the environmental and key socio-cultural values.

In addition to formal governance, social norms are running locally in CRV and Ketar basins. Social norms provide individuals with an expected idea of how to behave in a particular social group or culture. The idea of norms provides a key to the understanding of social influence in general. Socio-cultural norms influence people's perceptions, knowledge, and commitment, therefore, affecting how they use and how communities provide access to water (Heinrichs & Rojas, 2022). There are local community-level institutions (e.g. Churches) that are operating independently by focusing on customary laws (Heinrichs & Rojas, 2022) and safeguarding their environment

As discussed above, the Federal Government is responsible for drawing up general policies pertaining to common interests and benefits while Regional Governments are usually contextualizing and implementing these policies. The key point of interest here would be, how these policies and regulations are cascaded to grass root level implementers (woreda and kebele level governance). Is it aligned with community water management goals? In this regard, Hailu et al., (2017) argue that the policies are not cascaded to the lower level as it was fundamentally top-down. Several stakeholders were not involved in the policy-making process and customary water institutions were undermined. Study on the perception of the local community on available policies and regulations and their enforcement by Desta et al., (2019) most respondents (68%) stated that

they do not know about provisions (nationally or regionally) pertaining to the conservation of water resources. This illustrates the low level of community engagement in its policy formulation.

Besides, the drive for development to escape poverty and mandate overlaps among the institutions are two of the major obstacles to managing water values in an integrated fashion. As an illustration, article 51.11 of the Ethiopian constitution states "It [the federal government] shall determine and administer the utilization of the waters or rivers and lakes linking two or more states or crossing the boundaries of the national territorial jurisdiction," while article 52.1 declares that "All powers not expressly granted to the Federal Government alone, or currently to the Federal Government and the states, are reserved to the states." (FDRE, 1995). Is cited by regional institutions to govern water bodies like Ziway and Hawasa lake, and other bodies of water. Such type of overlaps erodes the power and interest of the organization in water resources management including recognition of its multiple values. In water valuation discourse sometimes conflict between the formal and informal institutions can arise. This can be because local and public institutions water management goals are different. For example, informal institutions may focus on the relational or intrinsic use of water while ignoring the instrumental value or vice versa. Such conditions may lead the one who has the power at the time to enforce its interest value and ignore the high interest of the other party.

In view of the reviewed literature (ECoM, 2021; FDRE, 2021; FDRE, 1995; EEPA, 1997; MoWR 1999; FDRE 2014; Hailu et al., 2017), focus group discussion and key informant interview, it is apparent that the following governance gaps contributed to the current state of the water system structure and functions.

- 1) There are vivid policy gaps in terms of the process policies are developed (top-down approach) and recognition of multiple water values.
- 2) Lack of public policy goals alignment with local community governance goals for water management

- 3) Overlaps of duties and responsibilities among the federal institutions, federal and regional level institutions (e.g., river basin authority and EPA, regional water bureau and MoWE; e.g *Hailu et al.*, 2017)
- 4) Mismatch of institutions power and interest to sustainability managing water

4.2.2.4 Overall approaches, data sources, and acquisition

4.2.2.4.1 Multiple scales: nested approach

Water systems are interconnected (Hailelassie et al., 2020). There is a material flow between systems components and between adjacent systems (Xanthe et al., 2022). This influences use types, value perception, and valuation of water ecosystem services. Therefore, the scale of focus in this work ranges from the CRV water system through sub-watersheds (Ketar water system and its smaller watersheds) to communities and households. Without a better understanding of water uses, values, and connectivity across scales, it is difficult to capture risks and opportunities (Xanthe et al., 2022). Hailelassie et al., (2020) suggested that the values that people hold can be multidimensional (ecological, economic, and sociocultural) or “plural.” People may also hold multiple different values. Capturing all these values and value tradeoffs at a single scale does not give a full insight into values in a systemic manner. Looking at the intersectionality of social, including indigenous, constructs of value, economic value, and political value (who’s water is valued and by whom) and of the *intrinsic*, or ecological value, is a core foundation for sustainable water management (Hailelassie et al., 2020). Making the different values of water visible, as well as the actors who define them will allow for a multi-stakeholder engagement process, and ultimately decision making, that acknowledges competing uses of water, that is transparent and accountable and that aims to reconcile trade-offs between different waters, different users, and different uses.

This justifies the need for a nested approach in constructing water value-related solutions on an understanding of the multi-institution, multi-scale, multi-stakeholder mosaic of interests

surrounding water values in CRV. This approach allows a better understanding of the short-term and long-term impacts of water management decisions on ecosystems and social groups, as well as an explicit cause of unsustainable practices (Hailelassie et al., 2020). Against this background, for the current study, we did an overall water system assessment and water value mapping at the CRV scale. Then we zoomed into the Ketar river sub-system and its smaller catchments and communities to understand conflicting water values. The results are presented interchangeably among scales and when needed for specific scales.

4.2.2.4.2 Data sources and acquisition

Data sourcing for this study follows value quantification; local ecological knowledge and deliberation (Peck & Khirfan, 2021). For each of these data sourcing techniques detail is provided in the following sections (also Figure 4).

Water value perception, plurality, priorities, and risks: to understand the diversity of local water value a household survey was conducted in the CRV water system in January 2021. About 128 farm households representing different community segments (religion, culture, level of education, etc.) and gender were selected randomly. A questionnaire covering priority water values, values at risk, value complementarity, and conflict was developed and pretested. The pretested questionnaire was implemented in 4 Woredas (Adami-Tulu; Ziway, Arsi Negele) covering 42 kebeles in CRV and Ketar river system and its sub-catchment. In this part, our methods focus on the implementation of local ecological knowledge and deliberation as suggested by Peck and Kirfan (2021) to undertake the pragmatic socio-cultural value of water. The household survey was supported by Focus Group Discussion (FGD) and Key Informants Interview (KII) at CRV, Ketar, and its catchments. Topics for FGD and KII cover issues on trends of ecosystem services for triangulation of literature and the household survey results and water value perception and associated plurality, priorities, and risks. Information regarding the water-related events calendar (irrigation, scenery, Thanksgiving Day ; orthodox church epiphany, holy water use, etc...) was collected through FGD and KII. The information generated from the household survey, FGD, and

KI was integrated into the WEAP model results (detail provided below), and a comparison was made between the economic use of water vis a vis environmental water flow and socio-cultural demand..

Estimation of water flow: To estimate water discharge at the Ketar water system level, flow data of Ketar river gauges from the year 1972 to 2016 was collected from the Ministry of Water and Energy (MoWE). The flow of ungauged rivers which are sub-catchments in the Ketar rivers (*Kulumsa and Gusha- Temela*) were estimated using the catchment area ratio method as illustrated by Equation 1 (Geleta et al., 2023).

$$Q_{sd} = \frac{A_{sd}}{A_g} \times Q_g \text{ ----- EQ 1}$$

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 in this case), and Q_g the discharge of the gauged river. These data were checked for quality; missed and outlier values. Missed data were filled in using an arithmetic mean (Geleta et al., 2023).

Estimation of major water demand: the demand side, as illustrated in Figure 4, considers the consumptive use of water for irrigation and livestock which makes up the largest consumptive water use in sub-Saharan Africa (Descheemaeker et al. 2010). Irrigation crop water demand was estimated using FAO CropWat 8.0. Climate data input was collected from the nearby Ogolcho and Asela metrological stations representing the midland and the highland areas.

Data from the district agricultural office indicates that the dominant irrigated crops in Ketar catchments and its sub-basin are Tomato, Potato, Onion, and Wheat. The area coverage of these crops in the catchment varies yearly based on crop rotation, market, and seed availability and thus we considered 2020/21 as the base year. The past three years (2018/19 - 2020/21) irrigation area coverage was considered for the crop water demand estimation both at Ketar and its subbasin. Hence, in this study, the irrigation water demand of wheat covering 50%, potato 25%, tomato 10%,

and onion 15% of the irrigation area in the catchment was considered. We adopted Doorenbos and Pruitt, (1977) and Van Halsema et al., (2011) suggestion of 55% of overall irrigation efficiency for the catchment irrigation water requirement.

Livestock is an important water consumer. But estimating the total water requirement needs data on animal physiology and activity. Currently, this is lacking in Ethiopia and therefore we applied an average livestock water requirement of 14.4 liters per day per head as suggested by Sileshi et al., (2003). Data on livestock population was collected from the Woreda Agriculture offices in the study area.

Estimation of environmental flow: environmental flow (EF) is one of the disputed areas of water balance estimation in many studies in Ethiopia. Traditionally engineers use 15% of the base flow but there is neither standard at the national level nor efforts to customize EF estimation to the local context. 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., 2017; Reitberger and McCartney, 2011; Tharme, 2003). Each methodology can be used as a decision tool to identify failure in EF 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, we adopted a scenario-based approach to estimate EF. In the scenario *I* we used the Tennant method, Scenario *II* Q95, and scenario *III* was a local thumb rule (e.g., Geleta 2023). We estimated EF for the Ketar river and two selected sub-catchments to understand scale effects and competing water demand between environment, economy, and socio-cultural water needs. Methodological details for each of the EF scenarios are presented below (Geleta et al., 2023 Sedighkia et al., 2021).

- 1) 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 (Geleta et al., 2023).
- 2) The Q95 is estimated as EF using flow duration curves (FDC). The FDC was plotted by arranging the statistical flow data in descending order against the percentage of exceedance (M. Acreman et al., 2008; Hart & Chan, 2011).
- 3) 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 EF (Sedighkia et al., 2021).

The results of the three methods were compared against the water abstraction for agriculture and overlaid on the community-selected event calendar of sociocultural water requirements.

Water balance computation: WEAP tool was selected to analyze the water balance and EF of the Ketar and sub-catchments. WEAP was developed by the Stockholm Environment Institute [SEI (Sieber & Purkey, 2015)]. The tool places the demand side on equal footing with the supply side. WEAP simulates different scenarios between demand and supply, considering different development options and environments (Sieber & Purkey, 2015). The tool was calibrated based on farmers' experience, identifying the water conflict period between *upstream* and downstream users, and the irrigation area management practice. The result was verified at the field level through observation and FGD with irrigation farmers and the local irrigation office.

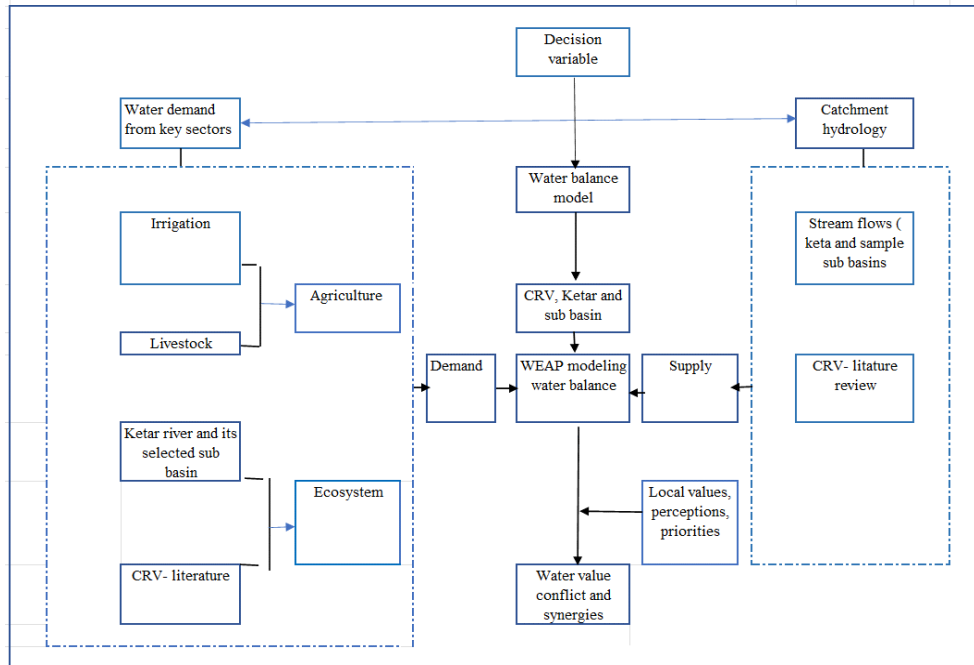


Figure 4-4 A framework showing integration value quantification; local ecological knowledge and deliberation followed (Peck and Kirfhan 2021).

4.3 Results and discussion

4.3.1 *Plurality of water values in the central rift valley water system*

Figure 4-1 presents household survey results on priority water uses and associated values as perceived by diverse water users in CRV of Ethiopia. About 24 perceived values were identified. Respondents were given the option to choose more than one use type or values and accordingly the result indicates that the highest number of mentions was recorded for domestic water use related values (97) followed by agriculture and livestock (92 each). The smallest number of mentions of the water use types by the household survey respondents were on water as a commodity (27) and water as sources of energy (8). Based on the identified use types of multiple water value is apparent. The *instrumental* value type is dominating the top and bottom of Figure

5. The middle layer is mainly dominated by the *relational* water value examples. The least preference was recorded for uses related to *intrinsic*.

Whilst the term ‘value’ and the process of ‘valuation’ are well defined, there are several different views and perspectives of what ‘value’ specifically means to various user groups and stakeholders (UNESCO 2021). Figure 4-6 depicts the pluralistic nature of water value based on the educational background of the household survey participants (illiterate, primary and secondary school, and high school and above) in CRV. Accordingly, while preference for *instrumental* (domestic and agricultural water uses), as the most preferred value, is shared among all the participants, *relational* values (e.g., aesthetic benefits) are important value attributes for respondents who were above secondary schools. Pluralistic and multiple nature of water value is depicted in Table 4-2 as deduced from the focus group discussion in the Ketar river system.

The overall result reflects the basic needs for food and water security. It is in line with the former Ethiopian government water policy (MoWR 1999)¹⁵ which prioritizes domestic water uses, and water for livestock in that order of magnitude and without detailing other water use and values including environmental flow. The food security value of water is high but rarely quantified– and it is often a political imperative irrespective of other values (UNESCO 2021). The finding is substantiated by findings of Houston et al., (2002) who suggested that the best way to determine how people value water is to determine how people use water.

Agriculture uses the major share (>75%) of developing countries freshwater resources (UNESCO 2021). Global demand for food and other agricultural products is projected to increase by 50% between 2012 and 2050, driven by population growth (UNESCO 2021). Similarly, food security has long been a challenge for human societies in this part of Africa and will become an increasingly pressing issue over the coming years given the increasing population.

¹⁵ In the recent water and agricultural policy reform by government of Federal Democratic Republic of Ethiopia considers multiple value

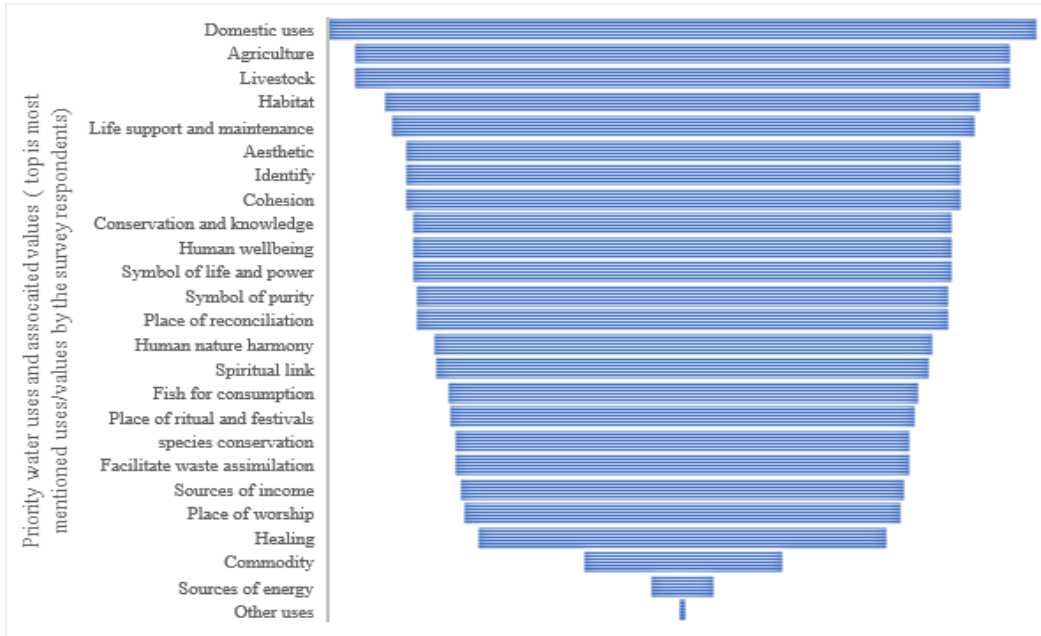


Figure 4-5: Diversity of water use and values in Central Rift Valley water system (unit - number of the mention of value domains respondents)

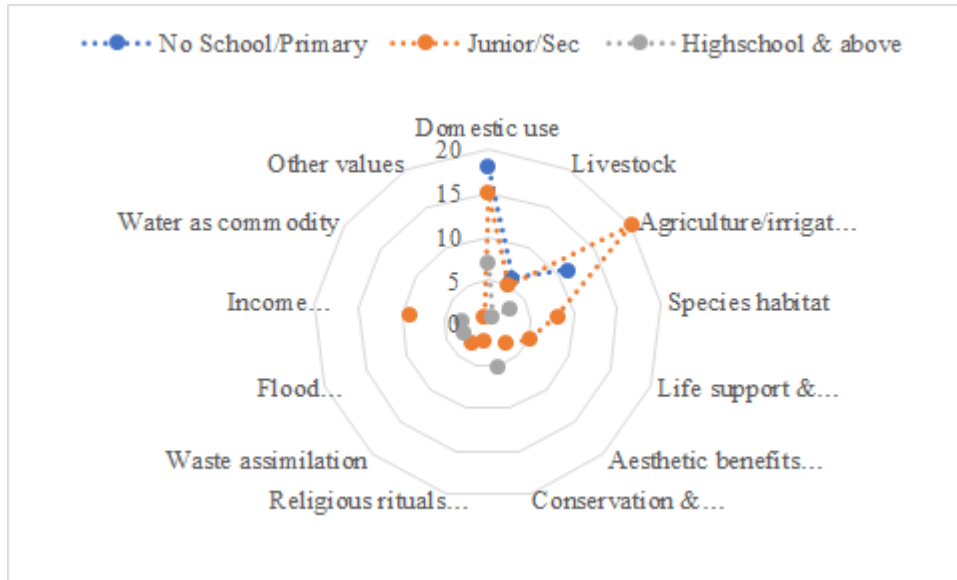


Figure 4-6 Pluralistic nature of water value and dichotomy of preference by people of different educational backgrounds in the central rift valley

Additionally, Mekuria et al., (2021) reported that in many parts of CRV, increasing demand for water for food production is a major driver of dwindling ecosystem service values. Environmental degradation, including depletion of aquifers, reduction of river flows, degradation of wildlife habitats, and pollution (Teklu et al., 2022; UNESCO 2021), probably additionally explains the reason for the highest policy prioritization of agriculture and domestic water values.

While Figure 5 presents individual value level preference Figure 7 shows the attribution of plural values (i.e., *intrinsic*, *relational*, and *instrumental*) to the water systems of the Ketar River (Arias-Arévalo et al., 2017). Particularly, *relational* values were the most frequently mentioned value. About 43% of the water values identified were *relational*, 36% *instrumental* and 20% under *intrinsic*. In this relation, *intrinsic* values (i.e., earth life dependency on water, concerns toward plants and animals), *relational* values (i.e., health and quality of life), and *instrumental* values (i.e., economic., dependency on water and associated landscape) were conceptualized as elaborated in Arias-Arévalo et al., (2017). The result in Figure 6 contrasts with Figure 7 but substantiate the findings by Arévalo et al., (2017) where *relational* value ecosystem services for urban and rural

community received the highest score. However, Arévalo et al., (2017) and the current studies vary by the order of magnitude of preference for *Intrinsic* and *Instrumental* value. *Instrumental* value is the second highest preference in CRV while it is the last in Arévalo et al., (2017) study.

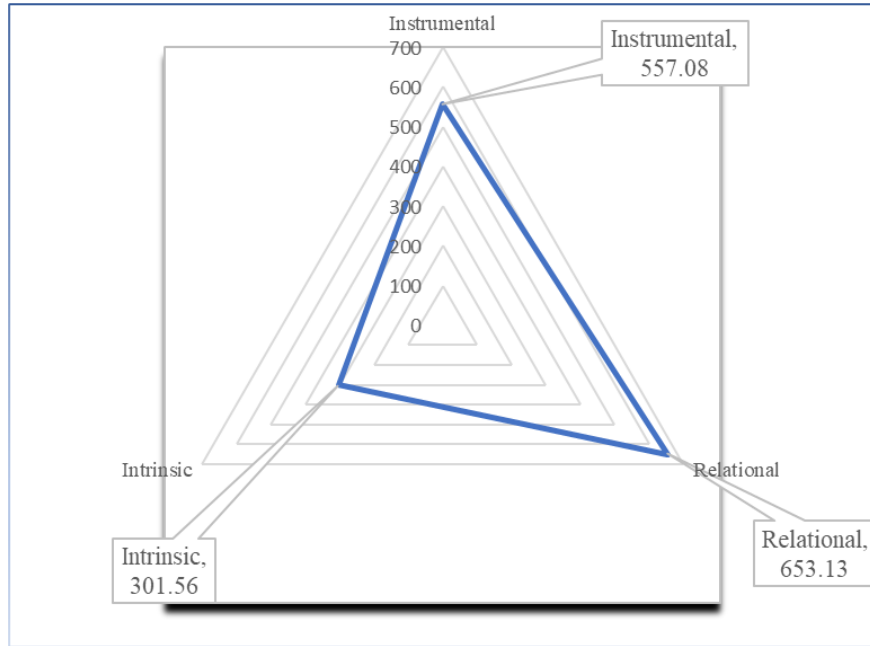


Figure 4-7 Aggregated water values priority in central rift valley water system (values are the number of times the survey respondents mentioned specific water use and associated values)

In of the is living from livestock, other natural related

CRV most population agricultural, fishing, and resources-activities.

The level of dependence on natural resources and livelihood associated therein explains the dichotomy in priority between *intrinsic* and *instrumental* values for the community in CRV. The reason behind the highest number of scores for *relational* value is due to the diversity of water use in *relational* value compared to the *instrumental* values. The fact that values are interdependent relational values is critical to ensure sustained water ecosystem services and access to water for food security and economic activities (*instrumental*).

The status of water resources in CRV highlights the need for improved water resource management. Recognizing, measuring, and expressing water's worth, and incorporating it into decision-making, are fundamental to achieving sustainable and equitable water resources management and the Sustainable Development Goals (SDGs) of the United Nations' 2030 Agenda

for Sustainable Development (UNESCO 2021). The question is as to whether the integrations of collective values or individual values are fundamental in policy decision-making.

4.3.2 Shared values and value articulation: an example from the Ketar river water system

There are several different views and perspectives of what ‘value’ specifically means to various user groups and stakeholders (UNESCO 2021). Information in Tables 2 and 3 were generated from FGD and KII and it depicts how different community segments (individuals, public and religious) have their own priority values and shared values. Accordingly, all the priority water uses, and associated values listed in Table 2 are shared among the private, public, and religious groups. Specific to the public interest, only these related to *instrumental* value got the stronger endorsement. Although different *relational* values attract the stronger interest of the public (e.g., environmental flow and maintaining biodiversity) the *instrumental* values outweigh when it comes to actual implementation. Particularly failure to implement small-scale irrigation development studies which often recommend the allocation of 15% of the annual flow to environmental flow is caused by a lack of standard methods and policy enforcement. In this regard, McClain et al., (2013) concluded that the implementation of environmental flow faces multiple challenges generally in Africa ranging from a lack of will on the part of water authorities to a lack of technical capacity.

Addressing these challenges will require continued cooperation between the multiple stakeholders in the process. Community segments connected to Christens and Muslim religion were more in the category of thanksgiving days and holy water and Ethiopian Orthodox Christian Epiphany though they demonstrated their interest also to other values.

At a policy level, water policy decisions are driven by the country's economic and legal systems values, such as economic efficiency, justice, equity, development, and others. At community levels, water choices and decisions are motivated by shared plural water values within a community but are always limited to the existing structures, such as water use practices, infrastructure, legal use frames, and others. At micro levels, in people’s everyday life, values do

not underpin decisions or choices related to water, at least when understood as people’s values. Individuals perform practices, a routinized and socially shared type of behavior that possess their own logic and values. Therefore, most of the time, the value of water does not lie in the individual, but in the practice. An important question for sustainable management of water is how to reconcile these different practices, and interests.

According to Euzen and Morehouse, (2011) how water value is defined depends on who is doing the definition, the context, and the entities involved. Thus, water may be considered as a symbolic element, a resource, a commercial product, or a service. Each perspective will attribute different kinds of values to the water and articulate it differently, but there will also be many interconnections between the perspective and the values attributed to the water in question. The interconnections established, in turn, serve to build norms and references that influence decisions made from individuals to higher levels of social organization. Considered as a resource for life, water thus becomes an object enfolding a multiplicity of interests and a broad diversity of values. These interests and values vary and change across cultures, communities, states, space, and time (Euzen and Morehouse, 2011).

Accordingly, the value articulation in Table 4-3 was developed from consensus-based group discussion and it illustrates that diverse but also interconnected water value. Articulations were not just limited to water *per se*. There are cases where water and landscapes, the river system and downstream water bodies, and the connection between human beings are valued and articulated connectively. This supports one of the water value principles which suggests conserving value at its sources in connection with the landscape which it is generated from (HLPW, 2017)

Table 4-2 Plurality and priority of values (FGD and KII sessions, 1 is the most and 5 is the least preferred values)

Water value category	Examples of Value	Examples of use type	Popularity and priority of values				
			Shared	Christian	Muslim	Private	Public

<i>Relational</i>	Cultural heritage	Waterfalls	X	4	4	4	3
	Sacredness, religious value	Holy water, thanksgiving sites	X	1	1	2	4
	Symbolic value		X	4	4	4	2
	Social cohesion		X	3	3	3	4
	Environmental justice	Environmental flows – maintain biodiversity	X	4	4	5	1
	Aesthetic	Waterfalls,	X	4	4	4	3
	Recreation, leisure	Swimming	X	4	4	3	4
	Nature-based tourism	Waterfalls	X	5	5	3	2
	Education and cognitive development	Research, studies, parenthood	X	4	4	3	1
	<i>Instrumental</i>	Monetary benefits	Irrigation, livestock drinking	X	3	3	1
Economic development		Irrigation, livestock drinking	X	3	3	1	1
Life-sustaining			X	2	2	3	3
<i>Intrinsic</i>	Moral duties to other organisms and ecosystems	Survival of birds, important tree species	X	2	2	3	2

This implies connectivity between system functions and structures in valuing water. For example, the focus group discussant mentioned the Ketar river landscape diversity ranging from the highland (4200m) m a.s.l to the lowland 1600 (m a.s.l) and how it gives opportunities for learning different livelihood, culture, and ecosystem functions and structure and how this relates to enjoyment. In this regard, (Euzen and Morehouse, 2011) argued that when people talk about the water they talk about a specific idea that they associate with a vital need, a memory, a daily action, a belief, or a landscape. The omnipresence of water, paradoxically revealed by its absence, has encouraged people, from ancient times to attribute to it one or more specific values that become hierarchized and evolved overtime.

Focus group discussion also emphasized that the boundary of water uses, and associated values are loose, and an example provided in this regard is that the pastoralist from the Fentale area who are traveling about 100km with their camels to Ketar wetland called Sheetamaataa to feed their camels. Sheetamaataa is a wetland that is 1793 ha- 30km in circumference formed due to the inundation of Ketar River before joining lake Ziway. A similar perception was reflected in the use of hot springs and holy waters.

Table 4-3 Articulated water values of Ketar catchment (generated from group discussion on consensus base).

Value category	Examples	Water values articulation in Keta water systems
<i>Relational</i>	Cultural heritage	The Ketar river system is blood vein of lake Ziway; its beautiful fall is a national heritage
	Sacredness, religious value	The Ketar catchment river is a God-given water resource; we made holy celebrations like thanksgiving and epiphany once per year. Also, a local expression like “የውሃ ቆሻሻ እና የ እናት መጥፎ የለውም” - “Haadha fi bishaan xurree ykn yartuu hin qabuu” -meaning there is no bad water and no bad mother... implying how sacred water is.
	Symbolic value	The Ketar river is an emblem of the Arsi zone administrative area and nearby community.
	Social cohesion	It gives sentimental cohesion “የ ወንዜ ልጅ”“laga tokkoo waraabannaa/ obaafnaa – bishaan lagga tokko dhugnaa ...” - in Amharic meaning my fellow village inhabitant or native. Also “ሚስትና ባል ከአንድ ወንዝ ይቀዳሉ” jaarsaaf jaartiin madda tokko waraabuu ” - meaning husband and wife are coupled from the same river....
	Environmental justice	There is a water permit policy but not enforced. Locals or lessee from individuals can pump water without a formal permit.
	Aesthetic	The Ketar river landscape from the highland (4200m) a.s.l to the lowland 1600 (a.s.l) gives different travel and psychological enjoyment.

Value category	Examples	Water values articulation in Keta water systems
	Recreation, leisure	The Ketar river gives a recreational experience with its waterfall for a wedding ceremony.
	Nature-based tourism	It has the potential to attract tourists starting from the end of the rain season (September – November) for its waterfall
	Education and cognitive development	The Ketar river is one of a learning and research place for higher education and scientific study. Farmers share their experiences about the river's nature and development.
<i>Instrumental</i>	Monetary benefits & economic development.	The Ketar river is a water feeder for 6811 ha of land that produces Wheat, potato, onion, cabbage, and other vegetables for a living. If not environmentally properly managed, the life of many farmers will be endangered.
		Pastoralists from Fentale who are traveling about 100km with their camels to Ketar wetland called Sheetamaataa to feed their camels will be affected if the Ketar river is not inundating this Sheetamaataa wetland which is 1793 ha- 30km circumference before joining lake Ziway.
<i>Intrinsic</i>	Life	The Ketar river watershed should be conserved specially to maintain the life of the people at downstream, livestock, fish in the lake Ziway, and other animals.
	Moral duties to other organisms and ecosystems	Conserving the Ketar watershed makes it a suitable place for birds, wildlife, and fish in the Ziway lake and different trees.

4.3.3 Water value conflict and trade-off: an example from the Ketar river water system

Water values are contested as different stakeholders have different interests and policymakers prioritize their policy goals. Given the diversity in culture, religion, livelihood, and environment people live in, water has multiple values and there is value conflict and trade-offs.

Understanding and the managing tradeoff is one of the multiple water valuing principles (HLPW 2017). Water is a pillar of life: it cleans, heals, and quenches. Results of selected water values representing the economic, environmental, and socio-cultural aspects are presented in Figure 8, Tables 4,5, and 6 and interpreted in relation to the event calendar presented in Figure 9.

As demonstrated in Tables 4,5, and 6 the results of scenario-based analysis for water balance and environmental flow estimation show different results across scale (larger rivers, smaller rivers) and across scenarios. For example, at a larger scale (Ketar river system) in December, January, and February the environmental flow of the Ketar river according to the scenario I [Tennant a minimum 10% Annual Average Flow (AAF)] and scenario II [Flow Duration Curve (FDC) Q95] is negative while under scenario III (Local thumb rule of 15%) the river satisfies the minimum requirement. For the smaller river in Ketar (Kulumsa- Table 5) similar trends with Ketar was observed except for more deficit months for scenario III. In a similar pattern, the third example, the Gusha river (located upstream of the Ketar catchment) EF observation showed December, January, and February under deficit for all scenario except for December which satisfies the Local thumb rule of the January 15% of the river.

The lesson we can draw from this scenario-based EF assessment exercise proofs the concept of “one size does not fit all”. The different river system has different ecological and socio-cultural flow requirement. Ecological flow estimation and decision support tools such as those we used for scenario analysis must be context-specific and this is lacking in the Ethiopian context. Regardless of the difference in magnitude of the estimated EF results share one common future: value conflict between water for the environment and the economy.

As suggested by MacClain et al., (2013) environmental flow assessment refers to a science-based process for determining the amount of flow to be allocated in a river reach to meet specific management objectives. Within the framework of integrated water resources management under most African water laws, the primary environmental objective is to maintain the vitality of ecosystems and the services they provide. Objectives may be further refined to specify the level of

ecological condition or health desired. MacClain et al., (2013) provided South Africa’s ecological management classification system as an example of such objective refinement whereby Class A rivers are assigned the highest level of protection, and environmental flows are established to maintain natural ecological conditions. Subsequent classes allow for greater levels of alteration, as increasing priority is given to water abstractions and the use of rivers for other purposes (e.g., hydropower production). Such a customized approach also facilitates policy enforcement.

Comparing the water balance tables along with the water use event calendar developed in consultation with the community gives a complete insight into spatial and temporal details of water value trade-offs. Figure 8 illustrates that some relational values are throughout the year (e.g., aesthetic, holly water) while others concentrate in October and January (e.g., spiritual, and cultural values) and in these months the water availability is already deficit for environmental flow under some of the scenarios considered and validations from focus group discussion.

As these cultural and spiritual events are non-consumptive water use there are arguments that maintaining environmental flow is sufficient to meet the socio-cultural needs. But as elaborated earlier, under different scenarios and different scales, the environmental flow has already suffered a shortage. Nevertheless, the different values of water need to be reconciled, and the trade-offs between them resolved and incorporated into systematic and inclusive planning and decision-making processes (HLPW 2017). The way forward, therefore, will be to further develop common approaches to valuation where feasible but also to prioritize improved approaches to compare, contrast and merge different values, and to incorporate fair and equitable conclusions into improved policy and planning.

Table 4-4: Effects of agricultural water demand on Ketar river system environmental flow (000 liter /second)

Description	Jan	Feb	Ma	Apr	My	Jun	Jul	Aug	Sep	Oct	No	De
Ketar flow	1.8	2.2	3.3	5.0	6.2	5.4	16.4	48.5	32.4	13.0	3.7	1.9
Ketar agricultural water demand	1.3	1.5	0.9	0.9	0.7	0.1	0.0	0.0	0.2	0.3	0.7	0.9
Ketar balance	0.53	0.78	2.35	4.12	5.5	5.3	16.7	48.5	32.2	12.7	2.9	1.0

Description	Jan	Feb	Ma	Apr	My	Jun	Jul	Aug	Sep	Oct	No	De
Environmental flow												
Scenario I: Tennant												1.4
10% AAF	1.4*	1.4*	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	*
												1.5
Scenario II: FDC-Q95	1.5*	1.5*	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	*
		0.27	0.27	0.27	0.3	0.2	0.27	0.27	0.27	0.27	0.2	0.2
Scenario III: LTR	0.27					7					7	7

*Is for deficit months

Table 4-5 Effects of agricultural water demand on Kulumsa river system (smaller catchment in Ketar) system environmental flow (000 liter /second)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Kulumsa flow	0.13	0.17	0.25	0.37	0.45	0.40	1.21	3.61	2.40	0.96	0.28	0.15
Kulumsa demand	0.18	0.24	0.16	0.16	0.08	0.02	0.00	0.00	0.06	0.06	0.09	0.16
Kulumsa balance	-	-	0.09	0.21	0.37	0.38	1.21	3.61	2.34	0.90	0.18	-
	0.05	0.07										0.01
Environmental flow												
Scenario I:	0.06	0.07	0.06	0.07	0.06	0.07	0.06	0.06	0.07	0.06	0.07	0.06
Tennant 10% AAF	*	*										*
Scenario II:	0.07*		0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.07
FDC-Q95			*	7	7	7	7	7	7	7	7	*
Scenario III:	0.02*		0.03	0.0	0.0	0.0	0.0	0.1	0.5	0.3	0.1	0.0
LTR			*	4	5	7	6	8	4	6	4	4
												*

*Is for deficit months

Table 4-6 Effects of agricultural water demand on the Gusha- Temela river system (smaller catchment in Ketar) system environmental flow (000 liter /second)

Description	Jan	Feb	Mar	Apr	Ma	Jun	Jul	Aug	Sep	Oct	Nov	Dec
					y							
Gusha- Temela flow	0.1 6	0.2 0	0.3 0	0.45	0.5 6	0.4 9	1.4 9	4.4 2	2.9 5	1.1 8	0.3 3	0.18
Gusha- Temela demand	0.3 4	0.3 7	0.2 0	0.14	0.1 4	0.0 0	0.0 0	0.0 0	0.0 0	0.0 0	0.0 7	0.14
Gusha- Temela balance	- 0.1 8	- 0.1 7	0.1 0	0.31	0.4 2	0.4 9	1.4 9	4.4 2	2.9 5	1.1 8	0.2 6	0.04
Environmental flow												
Scenario I: Tennant 10% AAF	0.1 3	0.1 3	0.1 3	0.13	0.1 3	0.1 3	0.1 3	0.1 3	0.1 3	0.1 3	0.1 3	0.13
Scenario II: FDC-Q95	0.1 4	0.1 4	0.1 4	0.14	0.1 4	0.1 4	0.1 4	0.1 4	0.1 4	0.1 4	0.1 4	0.14
Scenario III: LTR	0.0 2	0.0 2	0.0 2	0.02	0.0 2	0.0 2	0.0 2	0.0 2	0.0 2	0.0 2	0.0 2	0.02

*Is for deficit months

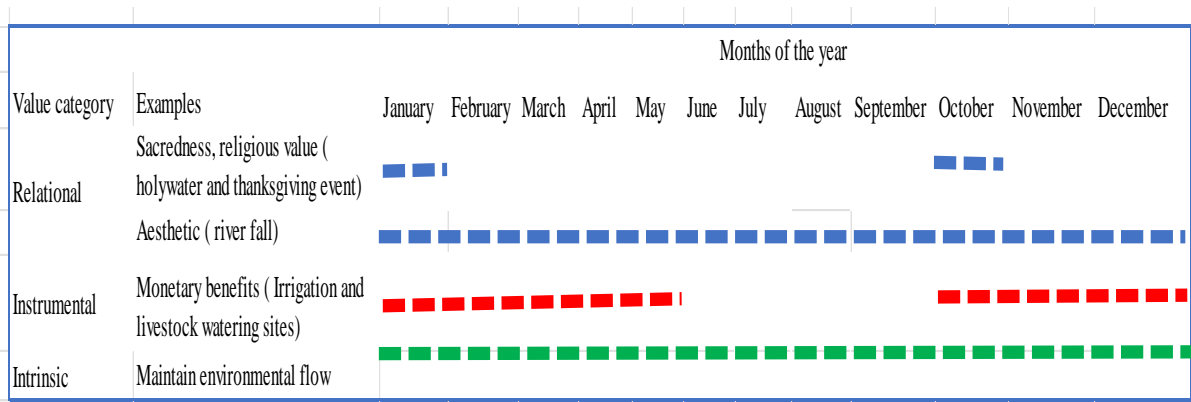


Figure 4-8: Calendar of different water use-related events for Ketar river system

4.3.4 Water-related risks and threat to multiple water values as perceived by local communities

Freshwater is essential for human survival, agriculture, and the survival of our planet’s plants and animals. In addition to the trade-offs illustrated earlier pollution, climate change, water-related disease, and the destruction of our natural world all threaten the purity and availability of our most precious resource.

The current household survey community in CRV and Ketar water system underscored about 7 different types but in many cases, interrelated water risks communities are confronted with (Figure4-9)¹⁶.

. Among the mentioned risks, the prevalence of water born disease and poor water quality hit the greatest score. In this regard, Desta et al., (2020) investigated the public perception of water quality and the major cause. Their results suggest that the water quality and water level of Lake Ziway have been decreasing due to anthropogenic factors. The main causes are attributed to uncontrolled water abstraction from the lake, discharge reduction from feeder rivers, siltation due

¹⁶ values are the number of times the survey respondents mentioned specific water risks associated with use and values

to deforestation-induced soil erosion in the watershed, and effluent discharges from floriculture industries as well as agrochemical runoff. Similarly, physicochemical water quality parameters assessment in two relatively freshwater lakes (Ziway and Hawassa) by Hailesilassie and Tegaye,(2019) substantiate the local community perception we reported here. According to these authors, the mean value of most water quality parameters they investigated shows clear deterioration over the last few decades. The status of water quality affects the already low level of water supply in the central rift valley. Gleick (2003) suggests that access to a basic water requirement is a fundamental human right implicitly and explicitly supported by international law, declarations, and State practice. The likely factors are rapid urbanization, sedimentation, excessive use of fertilizers, and industrialization in towns established along their shorelines.

The second group of water-related risks, as perceived by the local community, involves increasing invasive weed species (e.g water hyacinth) and ecosystem degradation (e.g Mekuria et al., 2020; Elias et al., 2019) in CRV. Traditional rainfed agriculture is challenged by rainfall uncertainty and land degradation across generations. Highlands flanking the valley are prone to land degradation and are the major source of sediments, while valley floors and lakes (Lake Ziway for example) act as sediment sinks. While deposition of fertile topsoil can have positive effects (e.g., nutrient inputs), deposition into lake beds negatively impacts water chemistry and this compounded with the over-abstraction of water reduces reservoir volume (Elias 2019). This has a detrimental effect on how and why people use water and how they value it.

To guide the delivery of SDG6, the High-Level Panel on Water (HLPW) identified five principles of valuing water (HLPW, 2017). There are deep interconnections between human needs, social and economic well-being, spiritual beliefs, and the viability of ecosystems that need to be considered, inferring multiple values of water. The first principle refers to recognizing and embracing water's multiple values and HLPW (2017) suggests identifying, understanding, and considering the multiple and diverse values of water to different groups and interests in all decisions affecting water. Given limited information on diversity of water values in SSA and

specifically in CRV information generated by this study is a breakthrough, but more work is needed as water system evolves due to mounting population and climate change pressure.

The second principle is about reconciling these values and building trust between different users - the upstream, downstream, urban, rural, private, public, etc. Here reconciling, according to HLPW (2017), refers to equitable, transparent, and inclusive ways of managing and sharing resources. Trade-offs are inevitable, particularly in water-scarce areas such as CRV, where diverse use and users have different interests, priorities, and norms and therefore value water differently. In view of HLPW (2017) suggestion delays in planning and managing trade-offs may have costs in CRV. These processes need to be adaptive in the face of speedy system changes.

Protecting water sources is the third principle in valuing water. This is about the maintenance and restoration of water systems [e.g., structure, function (Haileslassie et al., 2016)]. HLPW (2017) emphasizes that all sources of water in a water system, including rivers, aquifers, and associated ecosystem services, and return flows of water must be protected. There is growing urgency to protect sources (erosion in mountain areas of CRV), control and prevent pollution (in lowland intensive crop production and vegetable/flower farms) and address other pressures across multiple scales in CRV.

Fourth, HLPW calls for educating and empowering people. Our result illustrated difference in perception among these household survey respondents going to school and not. Educating and empowering people includes promoting education and public awareness about the interdependence of the different water values its essential role in all aspects of life and sustainability of water ecosystem services. This will support broader participation, water system-wise decisions.

Finally, the fifth principle of valuing water is its investment and innovation. This is the pathway towards realizing the many different benefits derived from water to reduce risks. Investment can take the form of investment in institutions, infrastructure, information, and innovation and these are not mutually exclusive. It should be emphasized that this is a key driver

that spurs the effectiveness of the four principles above and thus it requires concerted action and institutional coherence.

Figure 4-10 illustrates the perception of the local community on the threat to multiple water values. It shows the number of times the respondents mentioned and demonstrates values that are most affected (agricultural water value). This implies community concerns about water security for food production (food security value of water). An almost similar magnitude of threat was also assigned to values such as astatic and habitat for species. Water is a critical input for agricultural production and plays an important role in food security. The growing population in CRV, as in other parts of Ethiopia, is putting more demand and thus more extraction of water for irrigation (e.g. AZILDO, 2017; Elias et al., 2019; Demelash Wondimagegnehu Goshime, Alemseged Tamiru Haile, Rafik Absi, 2021). Along with this, the compound effects of climate change as suggested by Gadissa et al., (2019) would explain respondents' concerns over the threat food security value of waters in CRV. Livelihood in central rift valley is agriculture based and the threat to water value for agriculture is a threat to food security for the majority. In this regard Houston et al., (2002) discusses interdependency among water uses and the importance of scarcity in determining the value of water.

The fact that public sector policy goals are focusing more on food production (instrumental value) exacerbates the problem(Hailu et al., 2017). In this regard HLPW, (2017) pointed out, in its five principles that there are deep interconnections between human needs, social and economic well-being, spiritual beliefs, and the viability of ecosystems that need to be considered, inferring multiple values of water. This suggests that solution to water security for agriculture lies in recognition of other water values (i.e., intrinsic and relational) and reforming and enforcing policies in this direction

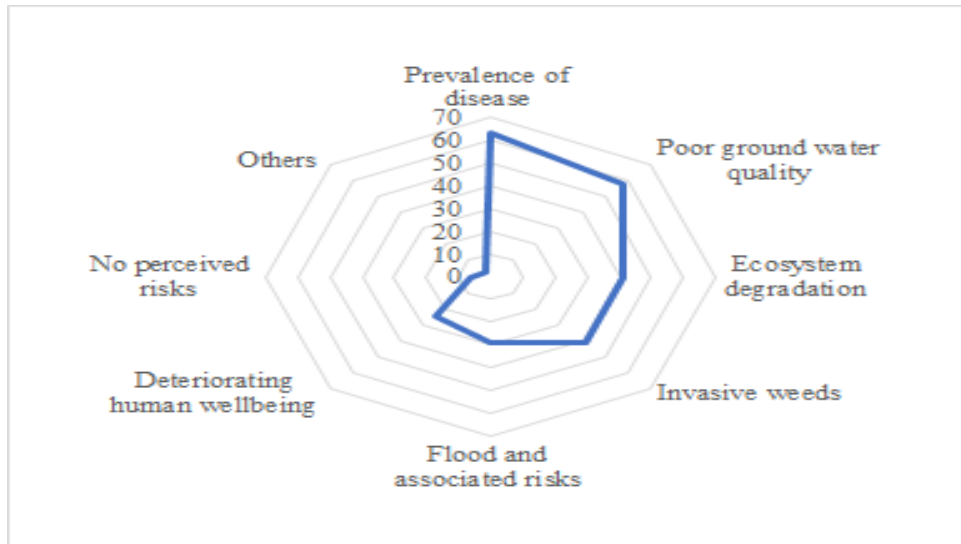


Figure 4-9 Water-related risks

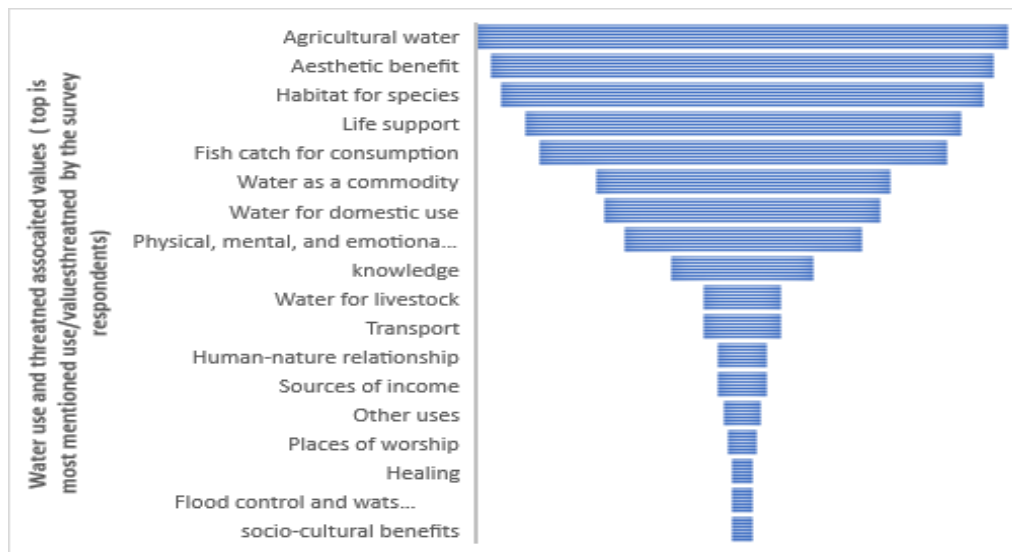


Figure 4-10 : The most treated water values as perceived by the local community in the central rift valley (unit – number of responses)

4.4 Conclusion

Water security is a foundation for sustainable development. In many instances, the pluralistic nature of water values is not documented and there are marked value trade-offs. In the present study, we attempt to map water values, priorities, risks and trade-offs. Given the results we concluded the following: firstly our findings suggest the pluralistic nature of water value in CRV and this concurs with the arguments by several authors (Amare Hailelassie et al., 2020; HLPW, 2017; UNESCO, 2021). But the community in CRV prioritizes water value in relation to their livelihood. Our findings also underscore that farmers prioritization of water for food security is a reflection of dominant public food security-focused policy goals. Here it is important to underscore that understanding of the interconnections between water values provides a helpful entry point into the causes and consequences of water management problems (Loris 2013) . Secondly, there was an apparent water value trade-off triggered by food security (irrigation) focused policies and the application of generic decision support tools (EF tools) to manage value conflict in CRV and in Ethiopia in general and lack of community engagement in public policy and local norms dialog and alignment thus failer to recognize prulaity of water value. Thirdly multiple water value at CRV is at risk. Water value for food security, which is the shared value among the majority of the population in CRV, is most threatened because of water ecosystem service deterioration (polution, climate cnhnage, ecosystem degradation) . Failure to reverse this may lead to the collapse of the food system and worsen the current food insecurity situation in CRV. This suggests that solution to water insecurity for agriculture lies in recognition of other multiple water values. Reforming and enforcing policies in this direction would be an important first step.

5 IMPACTS OF SMALL-SCALE IRRIGATION ON ENVIRONMENTAL FLOW IN
UNGAUGED RIVERS IN AFRICA: EXAMPLE FROM ARATA CATCHMENT,
CENTRAL RIFT VALLEY ETHIOPIA

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Abstract

Failure in Environmental flow in quantity, timing, and quality leads to failure to support ecosystems and human livelihoods and well-being. Irrigation is the main actor 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 on environmental flow in Arata's small ungauged catchment. The study estimated the flow in sub-catchments in the area ratio method, the crop irrigation water requirement using FAO cropwat 8.0, and the water balance in Water Evaluation and Planning System tool. The result showed that the Arata main river yields 77 MCM of water per year. The annual irrigation and livestock water demand are 7 MCM per year which is only 9% of the annual water capital. However, in December, January, and February 59 thousand m³ and 430 thousand m³ of unmet irrigation and environmental flow demand existed. The environmental flow for January and February was found as zero while 21% for December. For the rest of the months, the catchment contributes 91% of its flow to downstream ecosystem services, which is an environmentally sensitive lake Ziway. Given the result, we concluded that meeting the environmental flow of the system requires reducing the current irrigation area by 20% or improving the irrigation efficiency from 55% to 66% by introducing different water-saving technologies. This evidence provides policymakers, practitioners, and the academic world a scientifically supported understanding of small-scale irrigation water use impacts on environmental flow in ungauged catchments in planning and water allocation.

Key Words: water balance, environmental flow, demand, ungauged catchment, water use efficiency

5.1 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 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 & 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 (IUCN, 2003). 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(Boomsma and Herzog, 2008; Maliehe and Mulungu, 2017; McClain et al., 2013; NBI, 2020; Overton et al., 2014; Suresh Babu, Malavika Chauhan, Brij Gopal, Nitin Kaushal, 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.

5.2 Materials and Methods

5.2.1 Location

Arata catchment is located in the central rift valley basin, Oromia region of Ethiopia (Figure.4-1). 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.

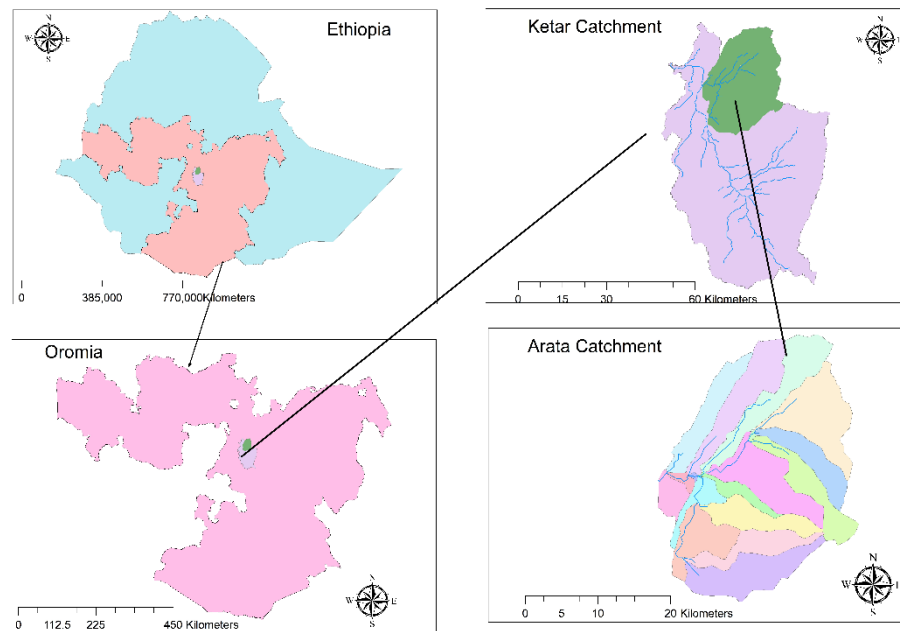


Figure 5-1 Arata Catchment Location Map

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 (Figure 1). Arata river catchment benefits 1960 irrigation user households (HH) with more than seven gravity small-scale irrigations (Table 5-1 & Figure 5-2) and 31,010 different types of livestock, excluding poultry, dogs, and other wildlife, and birds. All the irrigation schemes use furrow irrigation.

Table 5-1 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

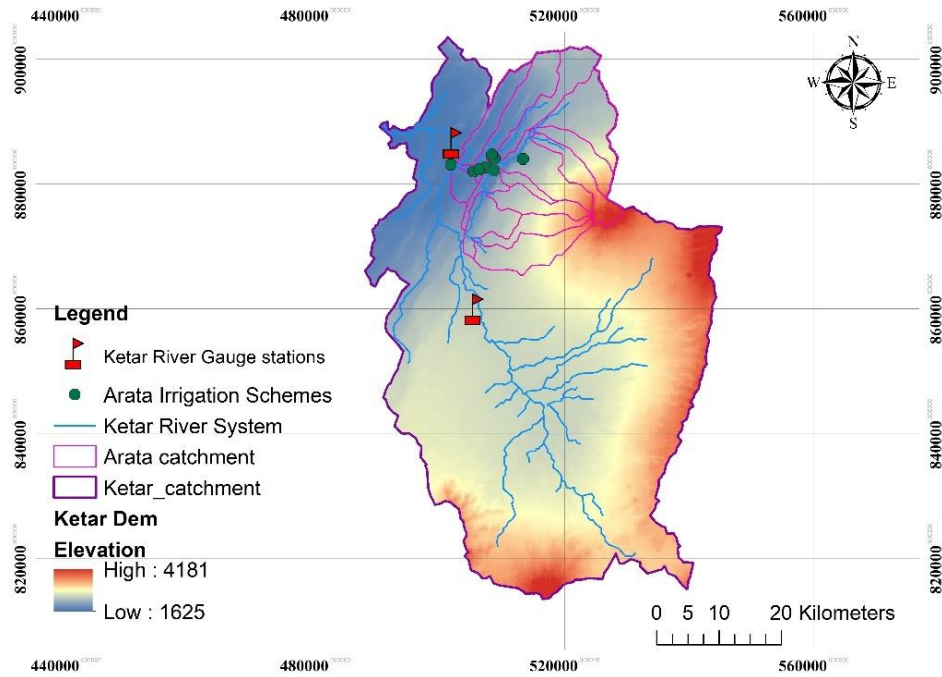


Figure 5-2 Arata _ Ketar Catchment, irrigation schemes, and River gauge stations

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 6km far from Ketar at Abura gauge, while Ketar at Fite gauge is 26km. The Arata catchment and rivers were synthesized from 20m X 20m D.E.M. data. The collected data quality was checked, adjusted, and synthesized to analyze Arata's water balance and environmental flow.

5.2.2 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(Figure.5-3). 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 parshall flume and 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.

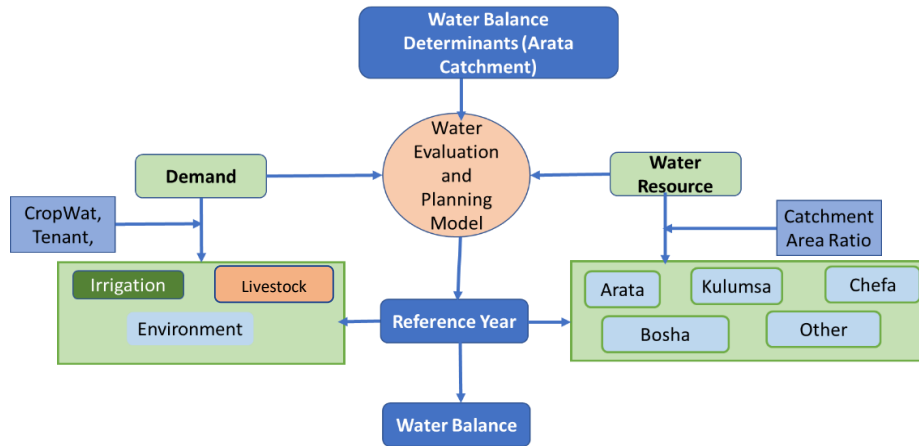


Figure 5-3 Arata Catchment Water Balance Analysis Framework

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

5.2.3 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 & 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(Figure.5-3). 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 & 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.

5.2.4 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 (Jackie King et al., 2003; N. L. R. Poff et al., 2017b; Reitberger & 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 (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 (M. Acreman et al., 2008; Hart & 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.

5.2.5 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 (Figure 5-4 & 5-5). Both catchment's land use and land cover consisted of more than 50% cultivated land and less than 1% woodland (AZILDO, 2017; Gurm, 2017).

Ritzema, Fraiture, Riksen, & Ayana, 2021; Sime & Abebe, 2022). Both catchments have similar drainage classes and fine to medium soil texture.

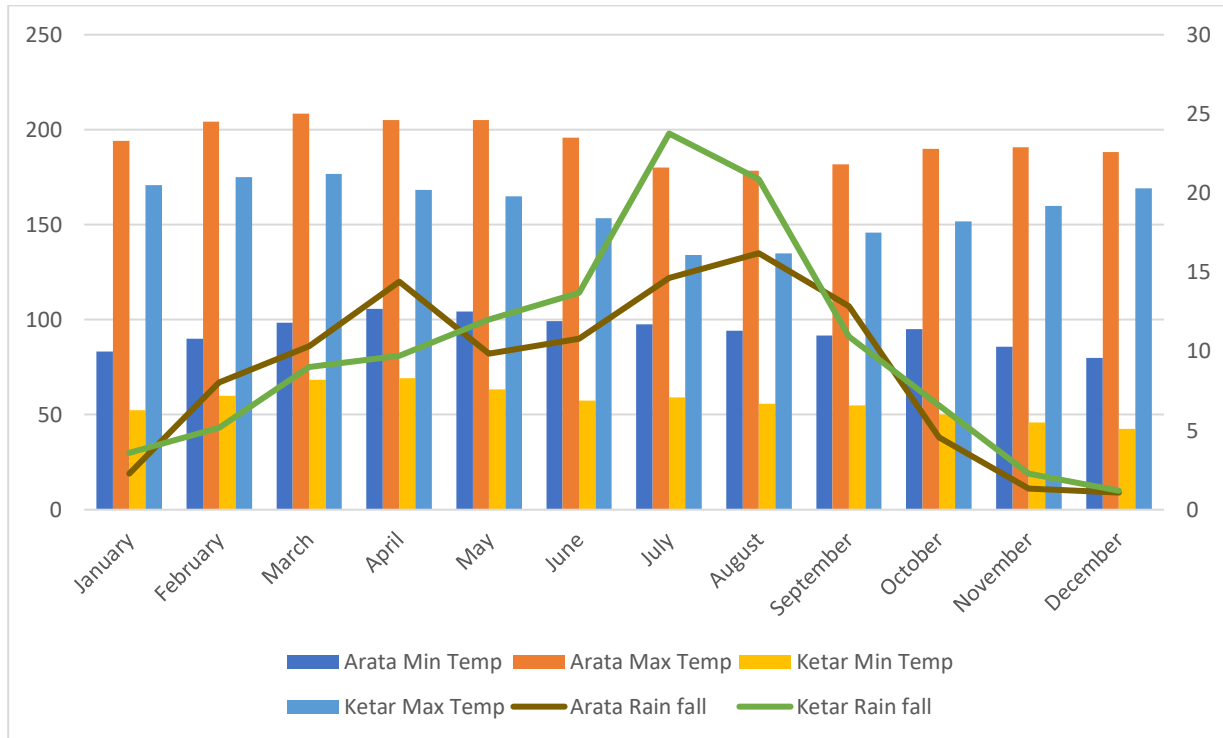


Figure 5-4 Climate Pattern of Arata and the Ketar catchment

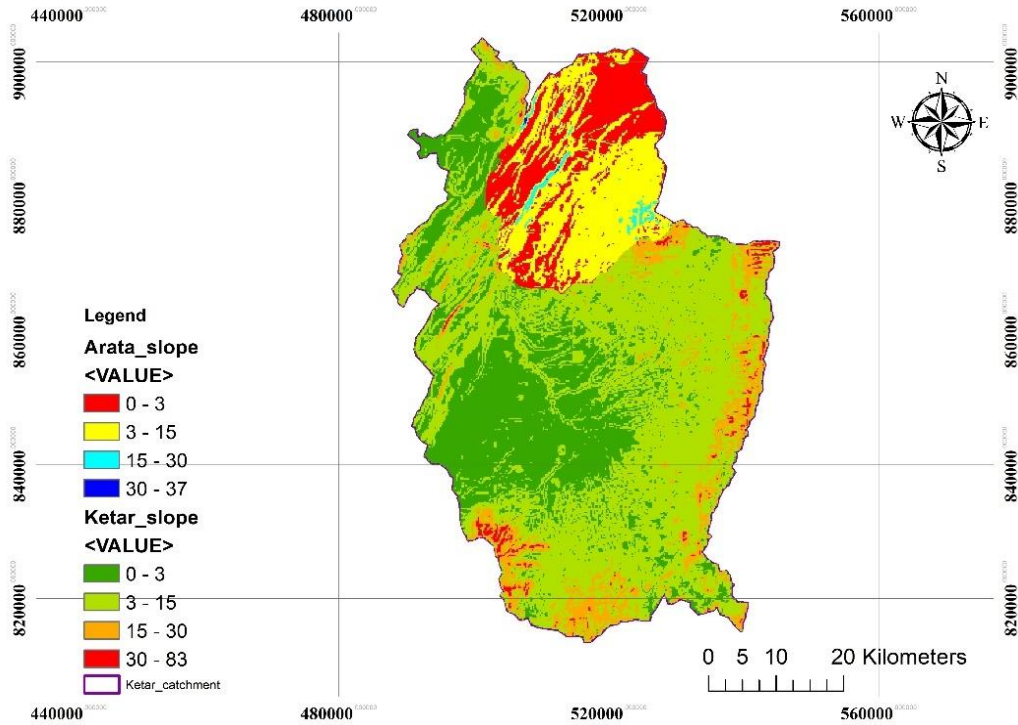


Figure 5-5 Slope pattern of Arata and Ketar catchments

The catchment area ratio method is mathematically expressed as:

$$Q_{sd} = \frac{A_{sd}}{A_g} \times Q_g \text{ ----- EQ 1}$$

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 6.0km 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.

5.2.6 Crop and Livestock Water Demand

5.2.6.1 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 three years (2018/19 - 2020/21) is considered for the water balance analysis. The three-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 & Pruitt, 1977; Ethiopian Ministry of Agriculture, 2018; Van Halsema et al., 2011).

5.2.6.2 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 8km downstream of the Arata¹⁷. The Arata scheme and the Ogolcho metrology stations are 1750m and 1700m altitude above sea level respectively.

¹⁷ The CropWat result was checked with five times measured abstracted flow of the Arata irrigation. The water measurement was conducted using parshall flume and 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 FAO (2014) soil survey guideline for soil classification and FAO (2006) field description guideline. Hence, the catchment soil is classified as clay loam in texture with 167mm/m total available soil moisture(Ethiopian Minstry of Agriculture, 2018; OWWDSE, 2019). Besides, the irrigation calendar data was collected from the Ziway Dugda woreda irrigation office and Irrigation water users.

5.2.6.3 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, Markemann, & Zárata, 2013; Descheemaeker & Tolera, 2011; Sileshi et al., 2003). Accordingly, 14.4 li/day 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.

5.3 Result and Discussion

5.3.1 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 km² yield. The sub-catchments of water resources are presented below (Table.5-2 & Figure 5 -6).

Table 5-2 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 ¹⁸		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

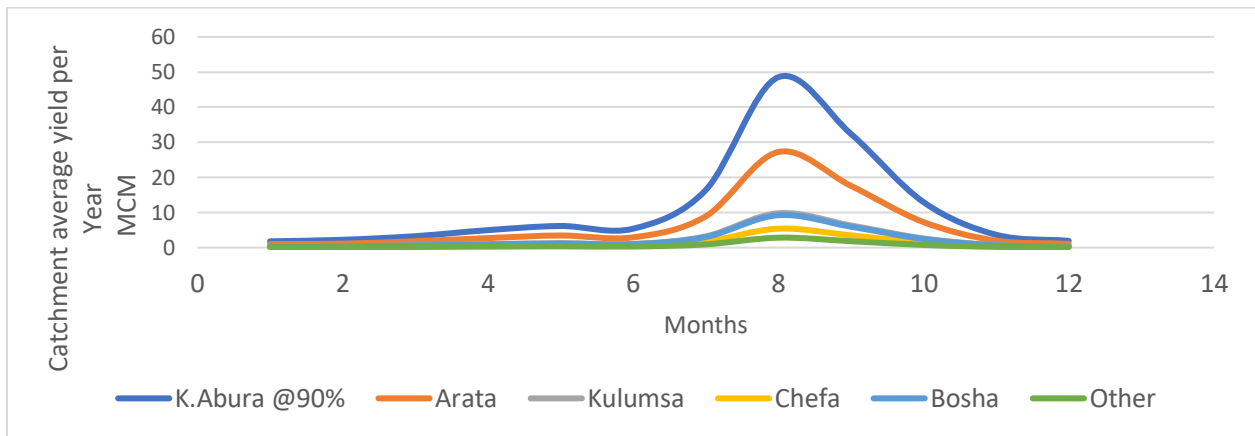


Figure 5-6 Mean Monthly flow of Arata sub-catchments

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.5-3).

¹⁸ 90% dependable flow is considered.

Table 5-3 Sub-catchments monthly average flow (m3/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

5.3.2 Irrigation Demand

The irrigation area of the Arata catchment is 490ha. The catchment has more than seven small-scale irrigations. Wheat is the dominant crop, followed by potato, onion, and tomato (Table 5-4).

Table 5-4 Irrigation Area in Arata Catchment

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

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

Table 5-5 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

The CropWater estimate for the selected crop is presented below (Table 5-6). The Cropwat was calculated by taking Ogolcho meteorological station climate data. The average irrigation water requirement found is 603mm per ha, which is 1206 mm per year including losses which is 12060 m³/ 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 m³. Arata and Bosha irrigations water demands were the first two highest demands in the catchment, 1,8791,400 and 1,687,300m³ 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 5-6 Monthly Irrigation demand per scheme ('000 m3)

Irr.	Jan	Feb	Mar	Apr	May	Jun	Ju	Au	Sep	Oct	Nov	Dec	Sum
							1						
Sch.1	271.4	362	271.4	217.1	90.5	0	0	0	90.5	90.5	126.6	271.4	1791
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	76.8	0	0	84.4	84.4	164.3	176.6	1687
Sch.4	31.3	34.0	23.6	30.0	18.1	7.7	0	0	10.4	10.4	19.2	23.6	208
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
Sch.6	181.0	186.4	126.1	177.7	115	54.8	0	0	60.3	60.3	117.3	126.1	1205
Sch.7	108.6	144.8	108.6	86.9	36.2	0	0	0	36.2	36.2	50.7	108.6	717
Sum	1045	1210	861.4	945.5	531	183.1	0	0	348	348.1	597.3	861.4	6931

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

5.3.3 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 5-7).

Table 5-7 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)

Taking the average of 14.4 li/day of water consumption the total livestock water demand in the catchment was 466.6 m³/year. The livestock water demand of the Kulumsa, Chefa, and Arata outlet areas are 76.5, 163.5, and 226.6 m³/year, respectively.

5.3.4 Seasonal and overall system level annual water balance

In this study, only irrigation and livestock demand were considered (Figure 5-5). 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.

The schematics of the Arata rivers and demand site were organized in the WEAP model (Figure 4-7). The monthly flow amount of each Arata catchment river, 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.

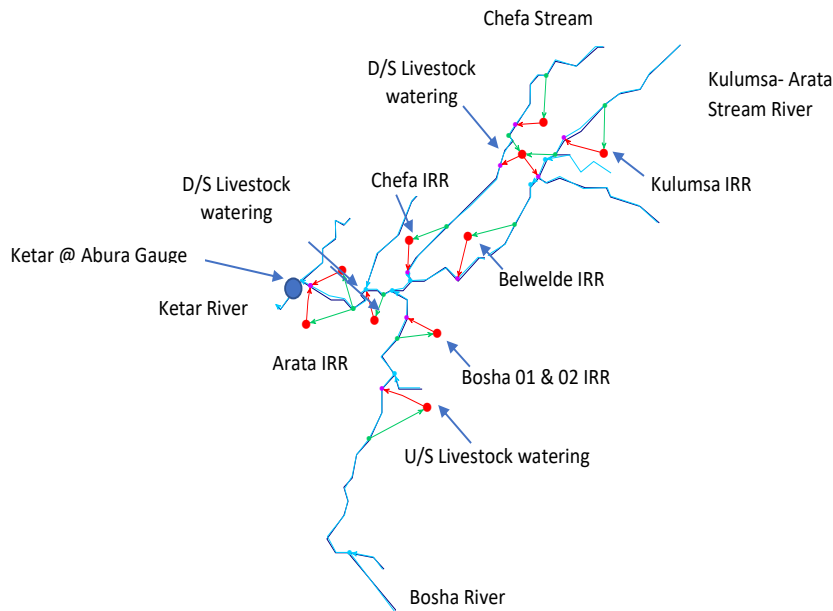


Figure 5-7 Schematics of the Arta River water demand Analysis (WEAP)

The total water capital of the Arata catchment is about 76,966 000 m³ per year (Figure 4-8) which is more than the demand of the catchment for irrigation and livestock(Figure 5-9).

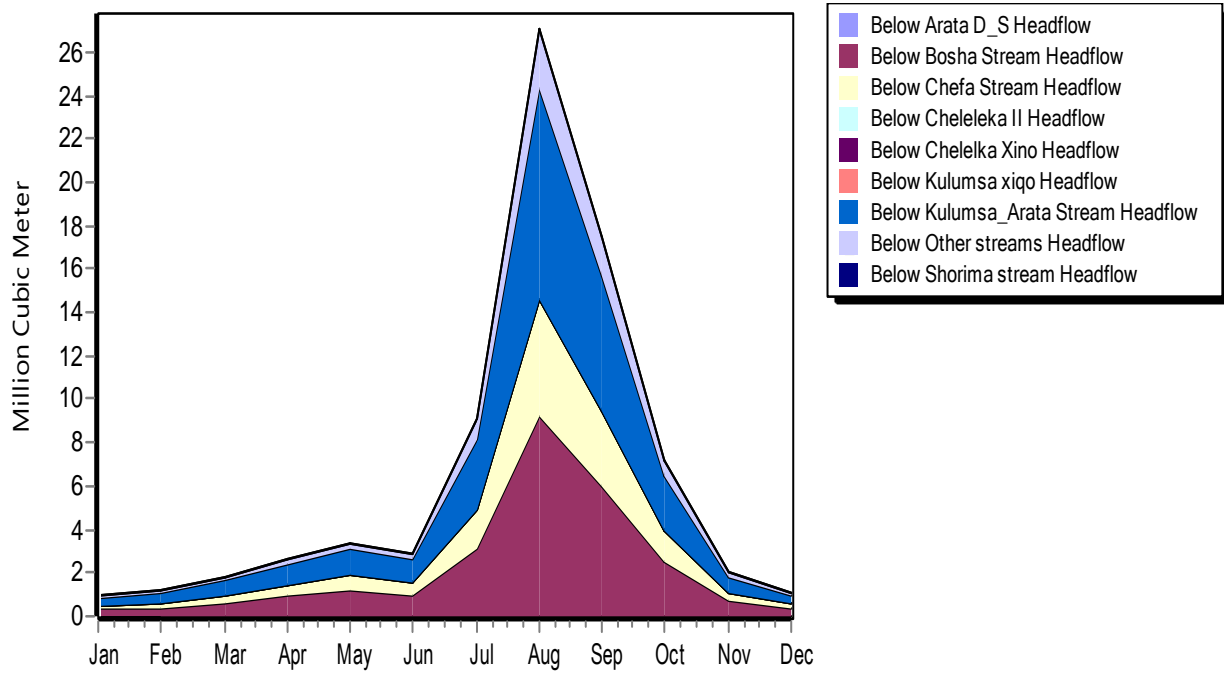


Figure 5-8 Average Inflows of the sub-catchment

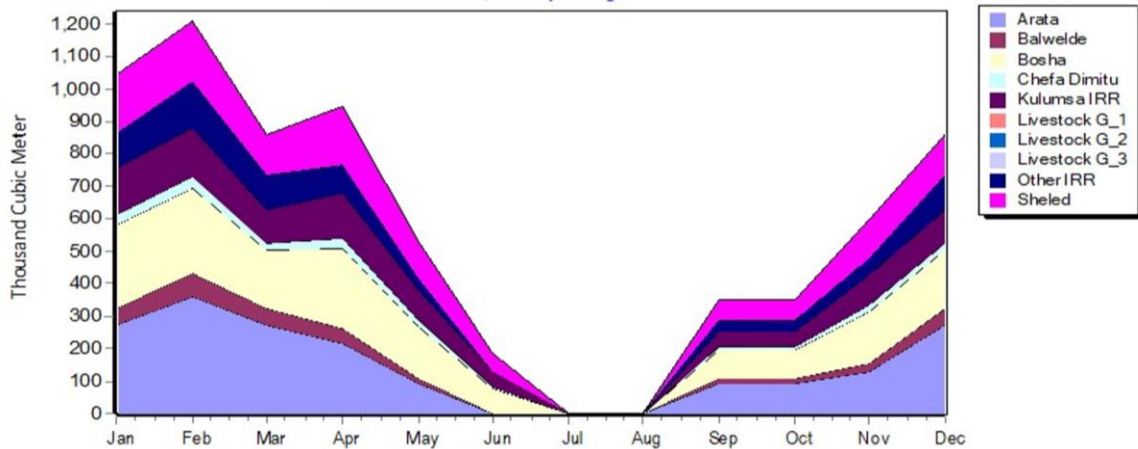


Figure 5-9 Total demand for Arata Catchment (WEAP Result)

The result of the water balance analysis showed that all rivers had a deficit or marginal from December up to March (Tables 5-8, 5-9, 5-10 & 5-11). Kulumsa river had a 172,000 m³ 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 5-8 Monthly water Balance of Kulumsa ('000 m3)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
S. water ¹⁹	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

Table 5-9 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	13907

¹⁹ S. water – Monthly water in the river

Table 5-10 Monthly water Balance Bosha river ('000 m3)

	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	26248
Irrigation Demand in Bosha River													
Sch-3	253	261	177	249	161	77	0	0	84	84	164	177	1,687
Lives.	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	23134

Table 5-11 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

The total unmet demand in the catchment is 58,800 m³(Table 5-12). There is no unmet demand for livestock. The total water capital of the catchment is more than 59,700 000 m³ per year which is more than the demand of the catchment for irrigation and livestock. However, the catchment needs 58,800 m³ of water for January and February to compensate for the deficit (Table 5-12 & Figure 5-10).

Table 5-12 Total unmet demand per scheme per month ('000 m³)

	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

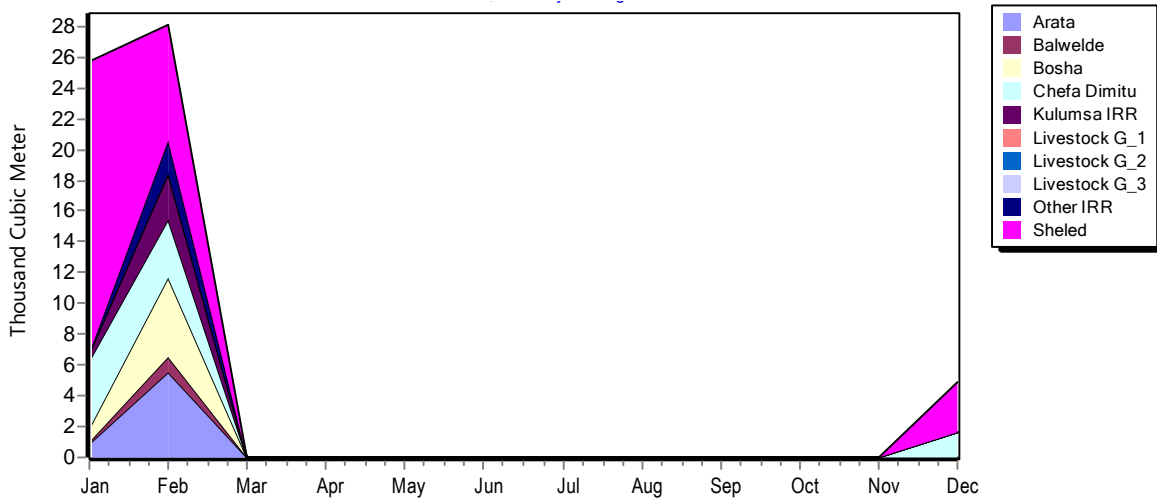


Figure 5-10 Unmet demand of the sub-catchments

5.3.5 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 (Figures 5-11,5-12 &5-13). Based on the yearly analysis, the Tennant and FDC results showed nearly similar results while the thumb rule result is by far the smallest.

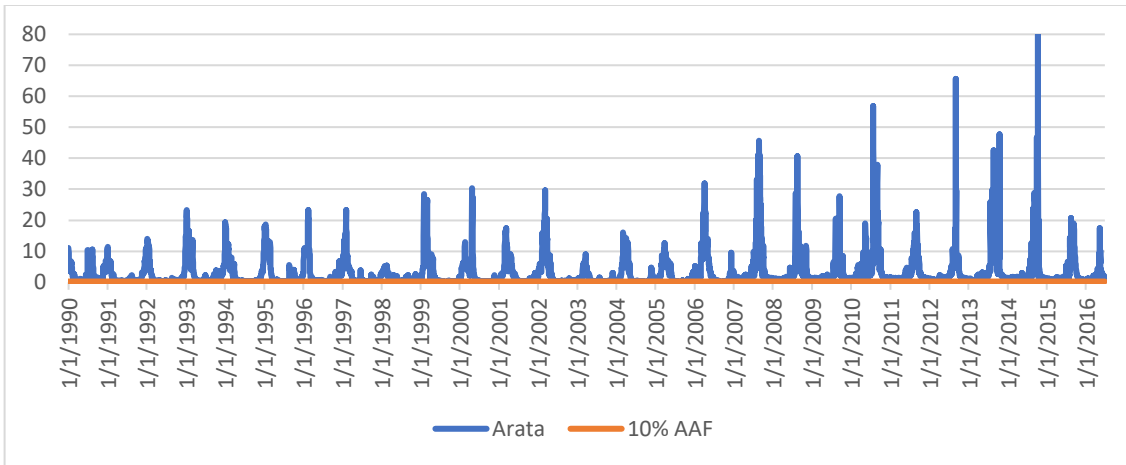


Figure 5-11 Tennant Percent Annual Average Flow of Arata River (m3/sec)

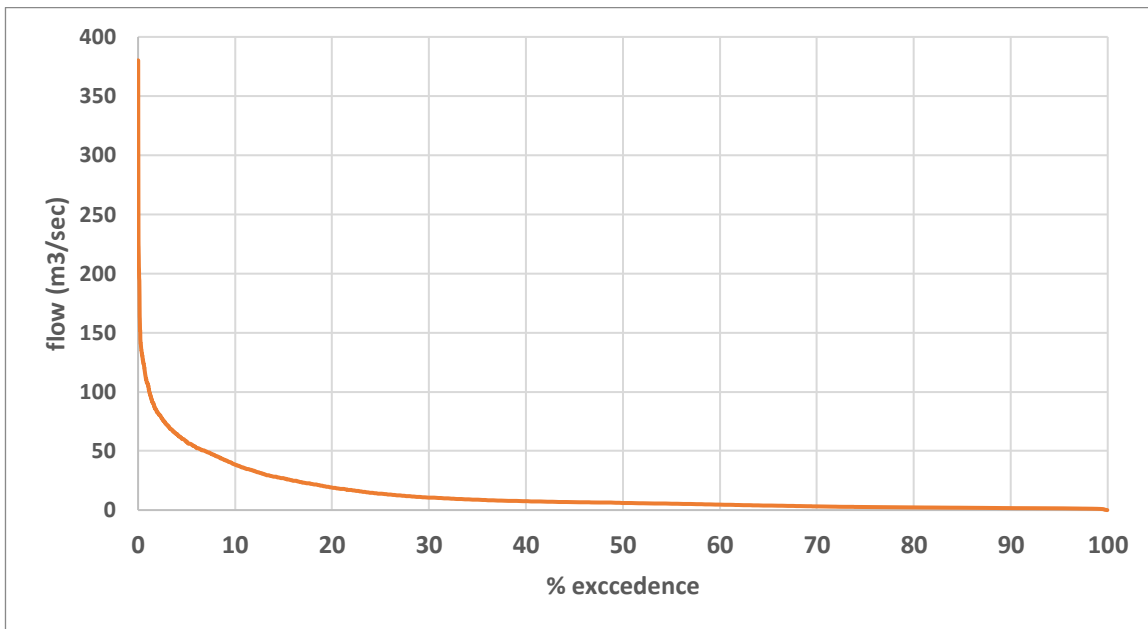


Figure 5-12 Ketar River flow duration curve

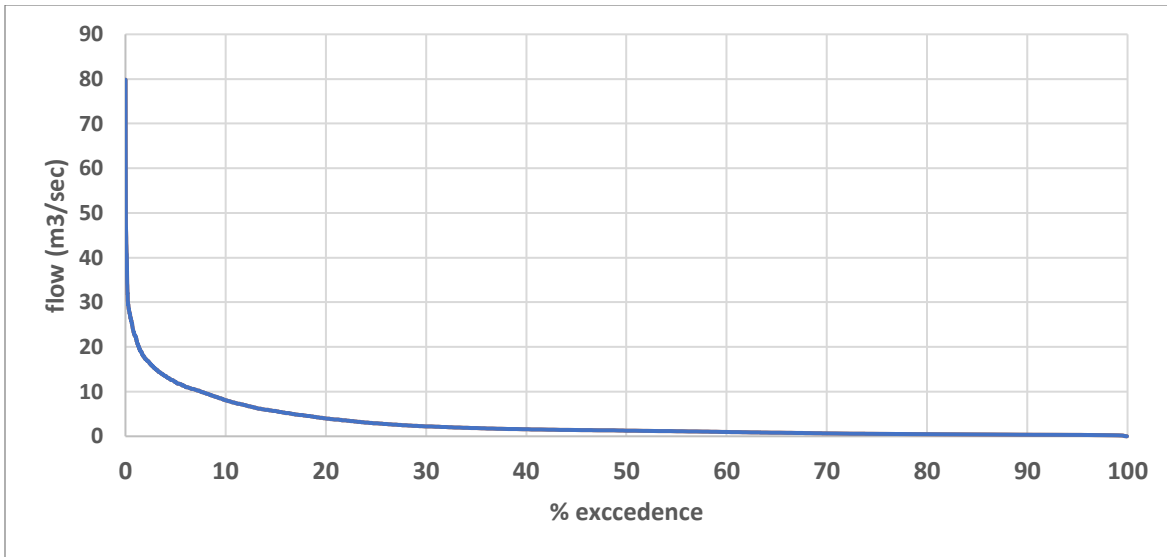


Figure 5-13 Arata River flow duration curve

The WEAP and the environmental analysis result showed zero water balance and environmental flow for January and February (Table 5-13 & Figure 5-14).

Table 5-13 The monthly water Balance and environmental flow of Arata's catchment (m³/sec)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Flow	989	114	182	267	340	290	912	2709	1748	722	198	109	76966
Demand	104	121	861	946	531	183	0	0	348	348	597	861	6931
Balance	-56	-61	959	172	287	272	912	2709	1713	688	139	235	70036
Tennant ENF (%)	290	290	290	290	290	290	290	290	290	290	290	290	
Q95	554	800	570	500	420	320	310	240	230	220	310	440	
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)

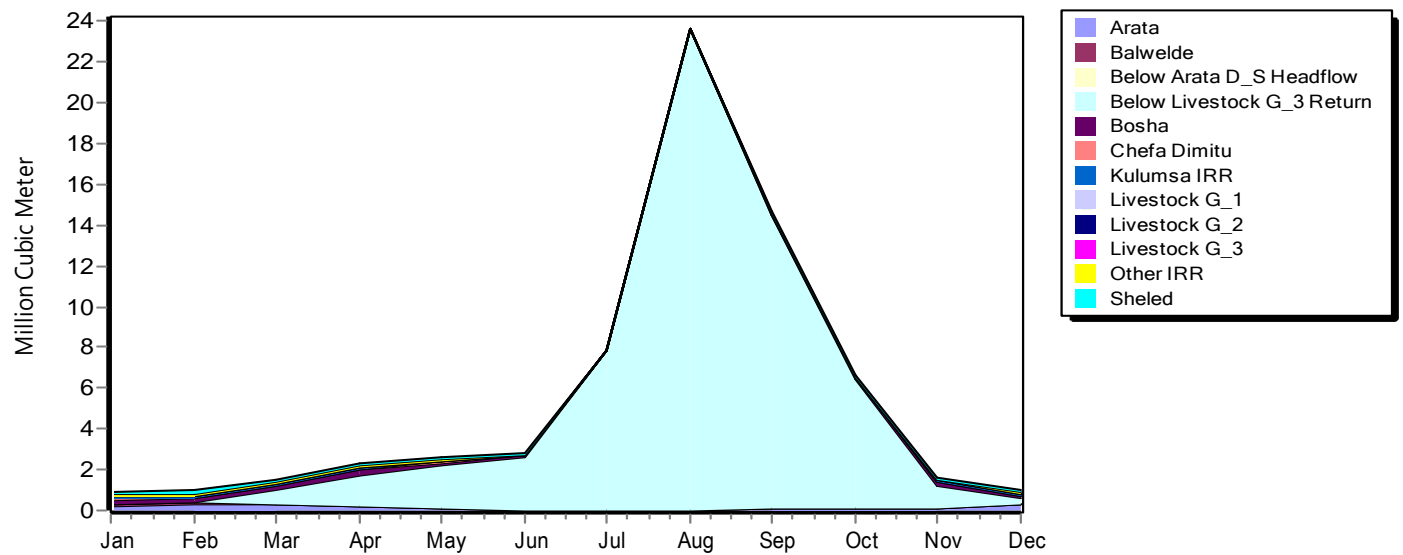


Figure 5-14 Environmental flow in Arata Catchment

5.3.6 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 is similar to most catchments in Ethiopia, like Tekeze, Tana, Rift Valley, and Awash catchments (Gebremicael, Mohamed, Zaag, & Hagos, 2017; Herco Jansen, Huib Hengsdijk, Dagnachew Legesse, Tenalem Ayenew, Petra Hellegers, 2007; Negash, 2011; Seyoum et al., 2015). The flow fluctuation in the rivers over time determines the catchment's water balance 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 flow in January and February. Smakhtin et al.(2004) state that healthy environmental water requirements range from 20-50% 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, Sun, & Yang, 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 two 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.

5.4 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.

6 ENVIRONMENTAL FLOW AND WATER RELIABILITY OF THE KETAR SUBBASIN

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Abstract

In water allocation planning, it is crucial to consider environmental flow in parallel with irrigation water demand. Failure to do so have a negative consequence on the sustainability of irrigation developments at downstream and water reliability. The present study aimed to assess the impact of irrigation water use on environmental flow and learn the current water reliability in the Ketar subbasin, central rift valley, Ethiopia as a baseline. The result showed that Ketar at Abura has an environmental flow of 1.4, 1.5, and 0.27 m³/sec according to Tennant, FDC-Q95, and local thumb rule, respectively. Similarly, Ketar at Fite has an environmental flow of 0.8, 0.9, and 0.28 m³/sec, in the same order of the methods. The total water demand of the subbasin was 27.7 million m³ per year, which is 7% of the mean annual water resource. There was no unmet demand for the water supply and the livestock in the subbasin, however, most of the irrigation schemes in the downstream have unmet demand in December, January, and February. The total unmet demand in the subbasin is 2.7million m³, which is 9.7% of the total demand. The study also depicted that the minimum water reliability in the subbasin was 75%, recorded for Arata, Belwelde, Boshā, Gonde Chefa, and Kulumsa which located downstream. Gusha has 83.3% reliability, while the other irrigation demand sites had 100% reliability. These result suggest that expanding irrigation without giving due attention foe environmental flow could lead to more environmental flow risk and less water reliability. To ensure sustainable irrigation development with high water reliability and sound environmental flow, participatory and implementable water governance policy with tailored technical solutions should come to place.

Key Words: environmental flow, demand, water reliability, Tennant method, flow duration curve, local thumb rule

6.1 Introduction

Even as the planet's endowment of water is expected to remain constant, human appropriation of water, already at 50%, is expected to increase further (Cooley et al., 2013). Though societies benefit from rivers immeasurably, water body ecosystems globally have been suffering from the growing intensity of human use (Knieper & Pahl-Wostl, 2016). This is also affecting the ecosystem service of water bodies as the result of the environmental flow in quantity, quality and time.

The generally accepted belief of the Environmental flow concept set by IUCN is 'Environmental flow is 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' (IUCN, 2003). The current governing theory among most scientists, and which holds the center stage in this study, 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; N. L. R. Poff et al., 2017a). The environmental flow at the basin level should consider three key principles: equity, efficiency, and sustainability (L. Wang et al., 2008).

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). The assessment and application of environmental flows have advanced considerably in the last ten years (Moore, 2004). However, most of the environmental flow studies focused on specific ecosystem services like fish (Bunn & Arthington, 2002; Jacobson et al., 2016; Jager, 2014), reinstating ecological normality and river services (M. C. Acreman & Dunbar, 2004; Tegos et al., 2017) and testing of methodologies (Buchanan et al., 2013; Ge et al., 2018; JM King et al., 2008; Martin et al., 2015; N. L. R. Poff et al., 2017a, 2017b; N. L. Poff et al., 2010). Pieces of literature depict that the USA has been the leading in developing and applying the approaches in

recommending environmental flows (Tharme, 2003), and South Africa is also playing a significant role (JM King et al., 2008; N. L. R. Poff et al., 2017a; Sood et al., 2017).

This study utilized two scientifically known hydrological methods, namely the Tennant method and the Flow Duration Curve method, which employ limited variables for analysis (M. Acreman et al., 2008; Hart & Chan, 2011; Karakoyun et al., 2018; Tegos et al., 2017; Tennant, 1976). The Tennant method employed historical flow data to determine a fixed percentage of the annual average flow (AAF) as the environmental flow, with a recommended minimum of 10% of AAF. The Flow Duration Curve method estimated the environmental flow as Q95, which was plotted by arranging the statistical flow data in descending order against the percentage of exceedance. In addition, Local Thumb Rule (LTR) which is used particularly in the Oromia area of Ethiopia, was used to estimate the environmental flow of the catchments. This approach is based on the dry month flow which considers mostly the 15% January flow. The results obtained from the three methods were compared and synthesized in this study.

Besides, the environmental flow this study examined the reliability of irrigation water resource. The reliability of the water resource for an irrigation system is the timesteps in which a demand site's demand was full satisfied (Sieber & Purkey, 2015). Reliability is explained in percent. The reliability value tells the degree of water satisfaction compared to the time of the expected water satisfaction. Irrigation performance are measured in different indicators like efficiency, adequacy, and water productivity. However, water reliability is another indicator which is more related with the water source, water balance and environmental flow. Reliability is a measure of how actual water delivery performance fits with the expected performance (Abernethy, 1984). Higher reliability pushes farmers irrigation development while the opposite discourages them.

In Ethiopia, water is an economic, social, political, and environmental entity that needs good governance (MOWR, 1999). The population of the country is growing at a 2.83 % rate, currently, it is projected to be 102,998,000 (CSA, 2022). Urbanization is growing at 3.8% and is expected to

be 5.4% by 2030 (WB, 2016). This increases the water withdrawal exponentially. In the next ten years, the main water consumer irrigation is planned to increase from the current two million ha to 4.14 million that is more than 100% (MoWIE, 2018; Worqlul, Collick, Rossiter, Langan, & Steenhuis, 2015). This will project the current irrigation water consumption 16.2 BCM to 23.4 BCM per one irrigation season, in parallel the urbanization demands more water than the current situation. However, the water body of Ethiopia covers only 0.7 percent while the land surface is 1.13 million km²: which is 99.3 percent. This is expected to influence the environmental flow the water bodies of the country which in turn can affect the provisioning ecosystem service. Considering the irrigation growth in the country triggers risk on the the water reliability which can result to higher risk on the environmental flow.

Hence, this study was designed to look in depth the water reliability and the environmental flow status of the Ketar subbasin water bodies to contribute to the limited studies conducted on environmental flow in Ethiopia which have contributed less either to methodology or to defining the river ecosystem.

6.2 Materials and Methods

6.2.1 Study Area

Ketar Subbasin is located in the Ethiopian central rift valley lake basin at 160 km south of the capital city, Addis Ababa, Ethiopia between 38°00'-39°30' East, longitude and 7°00'-8°30' North, latitude. It encompasses five woredas of the Oromia region, of Arsi and East Shoa Zones; Limu fi Bilbilo, Munesa, Digelu fi Tijo, Tiyo, and Ziway Dugda (East Shoa Zone). The subbasin encompasses 55% of six woredas ; Tiyo and Digalu fi Tijo woredas fully, Lemmu fi Bilbilo, Munesa, Hetosa, and Enkolo Wabe woredas partially (Figure1). The Ketar subbasin is divided into 105 kebeles. It is 3350 km² with a 103.1 km long river course called Ketar.

Ketar subbasin is known for its small-scale irrigation and indistinct irrigation water governance (Pascual-ferrer & Candela, 2015; Seyoum, Milewski, & Durham, 2015; Teferra &

Beyene, 2014; Yohannes H, Mohammed A, & Elias E, 2017). Ketar is one of the two main tributaries of Lake Ziway, contributing 396 M m³ of water annually from the eastern portion of the subbasin. 9.8Mm³ /year of water is diverted from Ketar to irrigate 6055ha (Lemi, 2019) in one season, this amount can increase by 50-75% based on the irrigation intensity per year.

The subbasin is gauged only at Ketar river at two points Ketar at Fite 505512.9E 859977N and Ketar at Abura 505509E, 892036.8N. The mean perception of the subbasin is 1075 mm while it is typified by 8.20C and 24.50C mean minimum and maximum temperatures in January and February respectively.

The water balance and environmental flow of Ketar subbasin was analysed using Water Evaluation and Planning System (WEAP), Cropwat 8.0, The Tennant method, Flow duration curves (FDC), and the Local Thumb Rule (LTR). The water balance of small catchments and the Subbasin were analyzed independently and as aggregate. Each river 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 Ketar and Arata river as a main two water courses. Alongside, two economic and sociocultural water services showcases - the Ketar main river and Gonde small river showcases- were qualitatively analyzed to show the status of the subbasin economic and sociocultural water services management.

The water balance and environmental flow mainly considered economic water value specifically expressed in irrigation and livestock. The irrigation demand was estimated based on the irrigation area and season assuming the critical irrigation period. The irrigation demand sites were grouped based on their sub-catchments for the convenience of modeling. Accordingly, the upstream irrigation demands were considered for one irrigation season while two irrigation seasons were assumed for the middle and downstream areas based on the field assessment. Some small supplementary irrigations, (using the seasonal stream as a water source) in the upstream area that the farmers use were not considered in the model.

The livestock population was collected from the woreda Agriculture office and the livestock water requirement was estimated accordingly. 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 sake of the water balance modeling, these points were grouped into convenient points at the upriver part, in the middle, and downstream. The livestock water demand was analyzed by taking the number of livestock in the river catchment and each reach; upriver, middle, and downstream reach.

Both irrigation and livestock demands were given priority 1 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 & McCartney, 2007). The return flow from the irrigation is very small due to the strict control of the irrigation water user associations and the absence of a drainage system. Besides, 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.

6.2.2 WEAP Schematic Arrangement and data input of Ketar subbasin

The WEAP schematic arrangement of the Ketar subbasin was arranged based the demand sites for main catchments of the subbasin (Figure 6-1). The demand sites were located by grouping nearby irrigation schemes that are the part of similar catchment into one. The same approach took place for the livestock; nearby livestock are categorized to the nearby main livestock main water point.

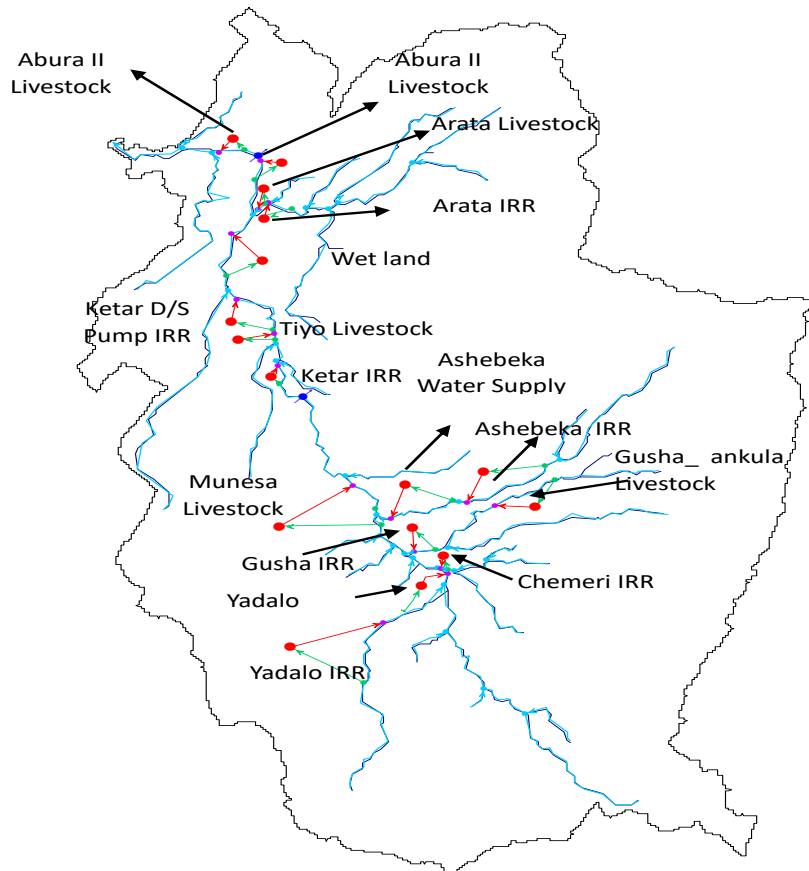


Figure 6-1 Ketar subbasin WEAP schematic map

The annual activity level, the annual water use rate, and the monthly variation, and the monthly consumption were feed for the WEAP model in accordance of the irrigation categorization. The upstream irrigation were considered as a one season irrigation while two season irrigation per year were considered for the down streams . Accordingly, for the upstream 6031m³/ha per year and 12063 m³/ha per year irrigation water requirement were considered for the upstream and downstream irrigations respectively for the WEAP model.

6.2.3 Irrigation Area

The Ketar subbasin has a total of 6627 ha irrigation land out of which 2188 ha is irrigated under modern and traditional full irrigation while the rest is irrigated as supplementary irrigation

with seasonal rivers, by pump from lake Ziway and shallow ground water. The supplementary irrigation is to avoid irrigation crop failure at the end of the rain season. Hence, for the sake of the water balance the full modern and traditional irrigation (2243 ha) demand were considered (Table 6-1). Besides, two irrigation seasons for the downstream schemes and one irrigation season for upstream schemes (Werga, Chemeri, Gusha_Mankula, and Ashebeka) were considered.

Table 6-1 Irrigation area for water demand

Irrigation Schemes	Area (ha)
Yadalo_Hadhaa area irrigations	470
Chemeri area irrigations	333
Gusha_Mankula area irrigations	600
Ashebeka area irrigations	30
Ketar area irrigations	550
Ketar D/S Pump irrigations	50
Arata area irrigations	150
Kulumsa	80
Gonde	50
Belwelde	30
Bosha	140
Sheled	100
Werga	70
Other	60
Total	2243

The main irrigation crops in the subbasin are wheat, potato, tomato, and onion. Wheat is the dominant irrigation crop followed by potato, onion, and tomato. In 2020/21 irrigation season 2874 ha of irrigation land were covered through modern and pump irrigations in the subbasin (Table 6-2).

Table 6-2 Irrigation Crops coverage in 2020/21 for modern and pump irrigations

Description	Area (ha)	Coverage (%)
Wheat	1437	50
Potato	718.5	25
Tomato	287.4	10
Onion	431.1	15
Total Irrigation	2874	100

Source; (AZLPD, 2021)

6.2.4 Assessment Methods

6.2.4.1 Environmental flow Assessments Methods

In this study, the Tennant and Flow duration Curve (FDC) method, the Q95 (Acreman et al., 2008; Hart and Chan, 2011), and a local thumb rule were employed for the analysis. 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 the Ketar river was used to estimate the Ketar subbasin and its catchment environmental flow. Besides, 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. At last, in Ethiopia, specifically the Oromia area, a thumb rule in the ungauged small catchments environmental flow is estimated considering the dry month flow which is estimated by direct measurement in the driest part of a year using the float method. Then, 15% the driest month flow, most of the time the flow of January, is taken as the environmental flow (Geleta, B, & A. Engdawork, 2023). In this study, the results of the three methods were compared and synthesized.

Water Evaluation and Planning System (WEAP) tool was selected for the analysis of the water balance and environmental flow the Ketar subbasin. 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 (Figure 6-2). WEAP simulates different scenarios between demand and supply considering different development options and environments (Sieber & Purkey, 2015).

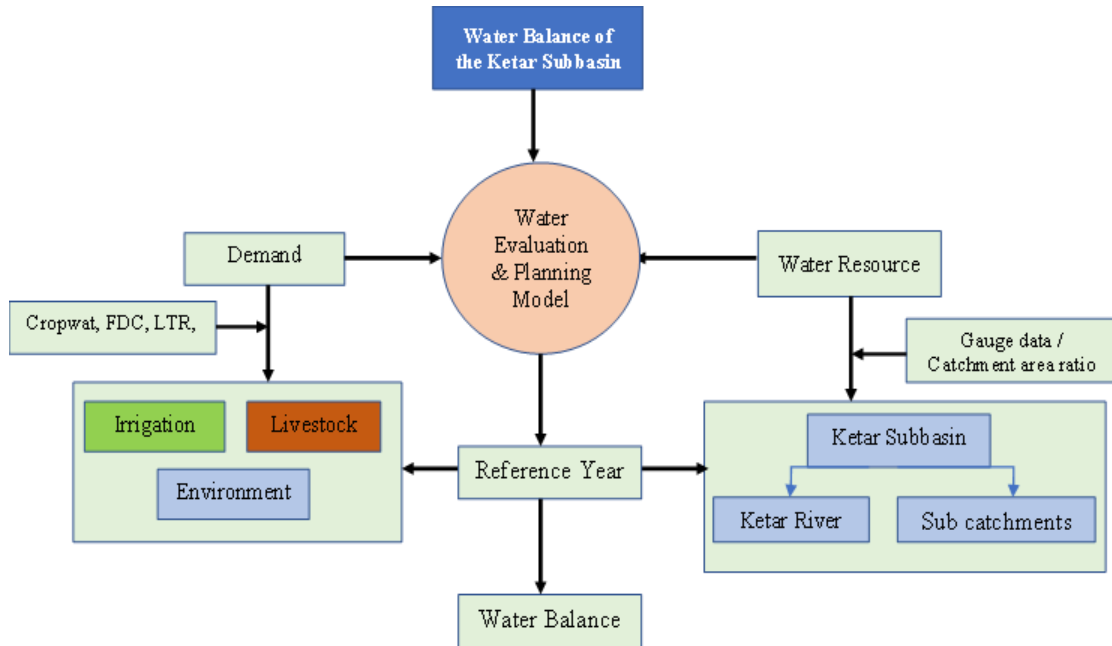


Figure 6-2 Ketar Subbasin water balance analysis framework

6.2.4.2 Reliability of Demand sites on the Water Supply sources

The reliability of the demand sites on their water source is the percent of the timesteps in which a demand site's demand was fully satisfied. It is estimated considering the unmet demand duration (months) compared to the demand met duration. Mathematically it is explained:

$$\text{Reliability} = (\text{Demand met months} - \text{unmet months}) / (\text{Demand met months} + \text{unmet months}) \text{----- eq 5-1}$$

In general, the result found was verified at the field level in observation and FGD with irrigation farmers and Ziway Dugda and Tiyo woreda irrigation office. The validation was based on the existing irrigation farmers' experience, identifying the water conflict period between upriver and downstream users, and the irrigation area management practice of the woreda.

6.3 Results and Discussion

6.3.1 River Flow of the Ketar Subbasin and the ctachments

The water flow of the Ketar subbasin and its sub catchments were conducted using directly the gauged data and the catchment ratio methods. The river daily flow data for from 1972-2016 (for 44 years) were collected from MoWE. Ketar at Abura gauge is used to estimate the Arata catchment flow. The Keatr at Abura river flow data which comprehends all the catchments was used for catchment area ratio method this study. These data were checked for quality; missed and outliers. Only 8.5% were missed. The missed data were filled with the arithmetic mean of the same month values of different years.

The Ketar at Abura river gauge data has a 17% missed data which is filled with simple arithmetic mean of similar months. The river flow data indicated that August and September are with highest flow with 144 and 93.3 MCM respectively while December and January are with small water 5.8 and 5.3 MCM (Tab 6-3).

Table 6-3 Average monthly flow of Ketar at Abura and at Fite (MCM)

Gauge stations	Area Km2	Jan	Feb	Mar	Ap	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
@ Abura	3350	5.3	6.0	9.7	14.3	18.3	15.5	48.7	144	93.3	38.6	10.6	5.8
@ Fitte	1975	1.79	2.23	3.26	4.98	6.16	5.38	16.4	48.5	32.4	13.0	3.66	1.94

The Ketar river at Abura gauge average monthly flow data showed 144 MCM and 5.3 MCM as the highest and the lowest in August and January respectively. Similarly, The Ketar at Fite average monthly flow record indicated 31.8 MCM and 1.2 MCM in similar months as the highest and the lowest record respectively. The daily flow of the Ketar river at both Fite and Abura

recording gauges at the upstream and the downstream shows similar pattern increase and decrease in similar months (Figure6-3).

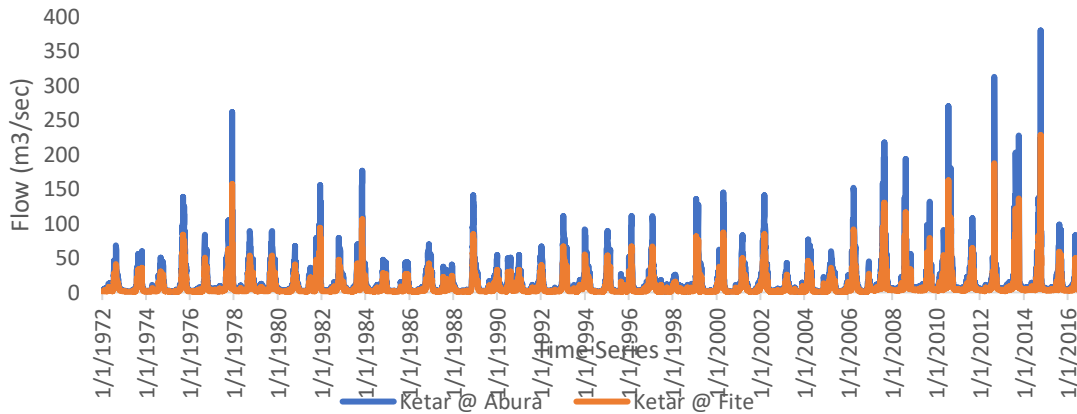


Figure 6-3 Ketar @ Abura and Fite daily flow Pattern

The Ketar subbasin is composed of numerous small catchments which are not gauged. In this study the subbasin is divided into seven stand alone and overlap catchment for the sake of the water balance and environmental flow (Tab 6-4). The catchment as a part of the Ketar subbasin shares the same basic characteristics such as soil, land use and land cover. The characteristics of Ketar and Arata catchments in terms of soil and slope are similar in type and pattern (Figure 6-4).

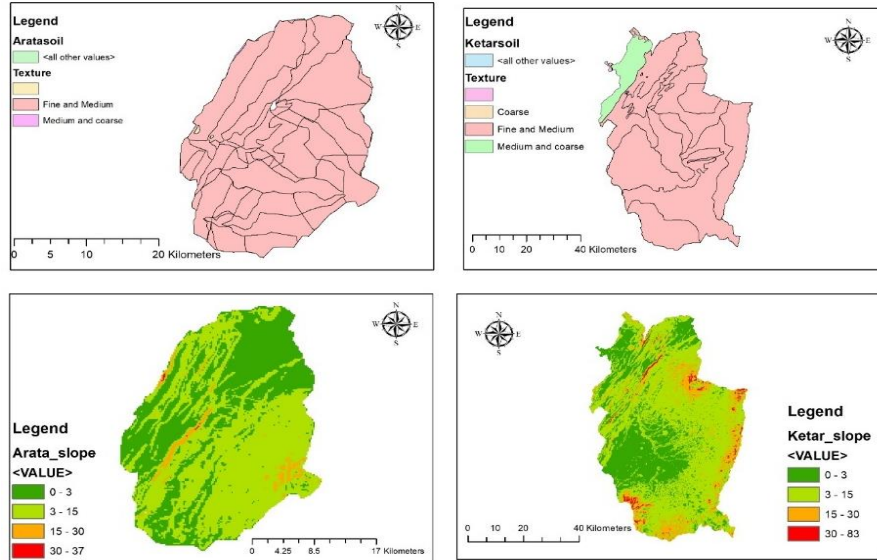


Figure 6-4 Slope and soil characteristics of the Ketar Subbasin and downstream catchments

The 90% dependable flow amount for the Ketar catchments were estimated from the Ketar at Abura catchment area and river gauge (Tab 6-4).

Table 6-4 Ketar subbasin catchments inflow (m3/sec)

Catchments	Chemri	Gusha	Ashebka	Yadola	Hadha	Arata	Kulmsa	Chefa	Bosha
Catchment Area (Km ²)	337	305	350	70	168	702	252	139	238
Catchment Ratio	0.27	0.25	0.28	0.06	0.14	0.21	0.08	0.04	0.07
Jan	0.2	0.18	0.21	0.04	0.1	0.4	0.1	0.1	0.1
Feb	0.25	0.23	0.26	0.05	0.12	0.5	0.2	0.1	0.2
Mar	0.36	0.33	0.38	0.08	0.18	0.7	0.2	0.1	0.2
Apr	0.56	0.5	0.58	0.12	0.28	1.0	0.4	0.2	0.4
May	0.69	0.62	0.71	0.14	0.34	1.3	0.5	0.3	0.4
Jun	0.6	0.54	0.62	0.12	0.3	1.1	0.4	0.2	0.4
Jul	1.83	1.66	1.9	0.38	0.91	3.4	1.2	0.7	1.2
Aug	5.42	4.91	5.63	1.13	2.7	10.2	3.7	2.0	3.4
Sep	3.62	3.28	3.76	0.75	1.81	6.8	2.4	1.3	2.3
Oct	1.45	1.31	1.5	0.3	0.72	2.7	1.0	0.5	0.9
Nov	0.41	0.37	0.43	0.09	0.2	0.8	0.3	0.2	0.3
Dec	0.22	0.2	0.22	0.04	0.11	0.4	0.1	0.1	0.1

6.3.2 Ketar Subbasin Irrigation Water Demand

The Ketar subbasin irrigation water demand is the irrigated crop water requirement in the subbasin. It is dependent on the irrigation area, crop type, climate, soil condition and the irrigation experience of the community. The irrigation demand for the selected crops was estimated using the Cropwat 8.0. The Irrigation water requirement was calculated by taking Ogolcho and Kulumsa meteorological station climate data for downstream stream and upstream irrigations respectively.

The average irrigation water requirement found is 6031 mm per ha per season, which is 12063 m³/ ha/year. Taking into account the crop types, the Cropwat, and the irrigation area. The Ketar subbasin total irrigation water demand is 20.87 million m³ year (Table 6-5). January, February, and March has the biggest irrigation water demand 3.7 , 3.97, and 2.89 million m³ respectively. On the other hand Ketar, Gusha, and Arata gravity irrigation areas are the biggest irrigation demanding areas requiring 6.64, 3.62, and 1.79 million m³ irrigation water respectively.

Table 6-5 Irrigation water demand in Ketar Subbasin

Irrigation Schemes	Irrigation Water Demand in m ³ ('000,000)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Arata	0.27	0.36	0.27	0.22	0.09	0.00	0.00	0.00	0.09	0.09	0.13	0.27	1.79
Ashebeke	0.05	0.05	0.03	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.18
Belewelde	0.05	0.07	0.05	0.04	0.02	0.00	0.00	0.00	0.02	0.02	0.03	0.05	0.36
Bosha	0.25	0.34	0.25	0.20	0.08	0.00	0.00	0.00	0.08	0.08	0.12	0.25	1.67
Chemeria	0.53	0.53	0.32	0.21	0.21	0.00	0.00	0.00	0.00	0.00	0.11	0.21	2.12
Gonde_Chefa	0.09	0.12	0.09	0.07	0.03	0.00	0.00	0.00	0.03	0.03	0.04	0.09	0.60
Gusha	0.90	0.90	0.54	0.36	0.36	0.00	0.00	0.00	0.00	0.00	0.18	0.36	3.62
Keatr gravity	0.93	0.84	0.77	0.72	0.80	0.11	0.00	0.00	0.11	0.40	0.96	1.02	6.64
Ketar Pump	0.08	0.08	0.07	0.07	0.07	0.01	0.00	0.00	0.01	0.04	0.09	0.09	0.60
Klumsa	0.14	0.19	0.14	0.12	0.05	0.00	0.00	0.00	0.05	0.05	0.07	0.14	0.96
Other IRR	0.11	0.14	0.11	0.09	0.04	0.00	0.00	0.00	0.04	0.04	0.05	0.11	0.72

Irrigation Schemes	Irrigation Water Demand in m ³ ('000,000)												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
Sheled IRR	0.18	0.24	0.18	0.14	0.06	0.00	0.00	0.00	0.06	0.06	0.08	0.18	1.19
Warga Irr	0.11	0.11	0.06	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.42
Sum	3.70	3.97	2.89	2.31	1.87	0.12	0.00	0.00	0.48	0.80	1.87	2.85	20.87

6.3.3 Assella Town Water Supply Demand

The Ashebeka river is the only main river that currently serves urban water supply for Assella town. The rest of the towns within the subbasin uses groundwater or small springs for their domestic water demand. Hence, in this study only the Assella water supply is considered. Accordingly, taking the projected population of Assella town as 139,537 (CSA, 2022) the Assella town per capita water demand fall in category II with 80 li/capita/day water demand (MOFED, 2016) the total water demand is 2,415,600 m³ per year.

6.3.4 Livestock Water demand

The livestock demand is analysed considering the type of livestock and quantity at different catchments of the subbasin. The main livestock in the subbasin are cattle, sheep, goat, horse, mule and donkey. The cattle population is the highest livestock population followed by sheep and horse in the Ketar subbasin (Table 6-6). Only 57 % of the livestock population is served from the main rivers of the subbasin. The rest of the livestock population can get water mainly from the Lake Ziway and nearby springs and small streams.

According to the survey and Key informant discussion the Ketar subbasin serves for 57% of the livestock population in the subbasin. The rest of the livestock uses lake Ziway, small lakes in Ziway Dugda, nearby springs and seasonal rivers. For this study, the water demand for 942,523.00 different livestock's categorizing them into seven water points were estimated (Table 6-7). Accordingly, the seven water points are upstream Munesa, Yadalo, Gusha_Mankula, Tiyoo, Arata, Abura I, and Abura II.

Table 6-6 Livestock population and categorised water points

Woreda	T. number of Livestock	Number of Livestock Served by Ketar Subbasin	% Livestock Served by Ketar Subbasin	Assigned Water Point
Digaluuf Tijo	383,400.00	225125	58.72	Gusha_ Mankula
L. Bilbilo	615,500.00	400290	65.03	Yadalo
Munessa	229,300.00	11465	5.00	Munesa
Tiyoo	259,600.00	194700	75.00	Tiyoo
Ziway-Dugdaa	165,800.00	110943	66.91	Abura I & II
Sum	1,653,600.00	942,523.00	57.00	

According to the study made by Sileshi et al.,(2003) the livestock water demand varies according to their difference (Table 19). However, they recommended an average of 14.4 li/day for all types of livestock. Hence this amount is used to estimate the water demand of the livestock population in the subbasin. The water demand of for 942,000 different livestock result showed that 6.8 million m³. The Lemu, Digelu, and Tiyo are the biggest livestock demand area with 2.1, 1.2, and 0.5 million m³ per year respectively (Table 6-7).

Table 6-7 Assella Water Supply and Livestock Demand per catchment

Month	Assella*	Demand ('000) (m ³)								Sum
		Abura I	Abura II	Bosha	Digelu	Klumusa	Lemu	Munesa	Xiyo	
Jan	205.0	2.2	46.0	4.7	97.9	0.2	174.1	5.0	45.2	580.3
Feb	187.0	2.0	42.0	4.3	89.3	0.2	158.8	4.5	41.2	529.3
Mar	205.0	2.2	46.0	4.7	97.9	0.2	174.1	5.0	45.2	580.3
Apr	198.4	2.2	44.5	4.6	94.7	0.2	168.5	4.8	43.7	561.6
May	205.0	2.2	46.0	4.7	97.9	0.2	174.1	5.0	45.2	580.3
Jun	198.4	2.2	44.5	4.6	94.7	0.2	168.5	4.8	43.7	561.6
Jul	205.0	2.2	46.0	4.7	97.9	0.2	174.1	5.0	45.2	580.3
Aug	205.0	2.2	46.0	4.7	97.9	0.2	174.1	5.0	45.2	580.3
Sep	198.4	2.2	44.5	4.6	94.7	0.2	168.5	4.8	43.7	561.6
Oct	205.0	2.2	46.0	4.7	97.9	0.2	174.1	5.0	45.2	580.3
Nov	198.4	2.2	44.5	4.6	94.7	0.2	168.5	4.8	43.7	561.6
Dec	205.0	2.2	46.0	4.7	97.9	0.2	174.1	5.0	45.2	580.3
Sum	2415.6	26.2	542.3	55.9	1153.5	2.4	2051.1	58.7	532.0	6837.8

6.3.5 Ketar subbasin Unmet Demands

The seasonal and overall demand of the Ketar subbasin only considered irrigation, livestock, and Asella water supply. Other demands like wildlife, birds, and sanitation were not included in the analysis due to lack of recorded data and their insignificance in number. Even Fish is not available in the rivers.

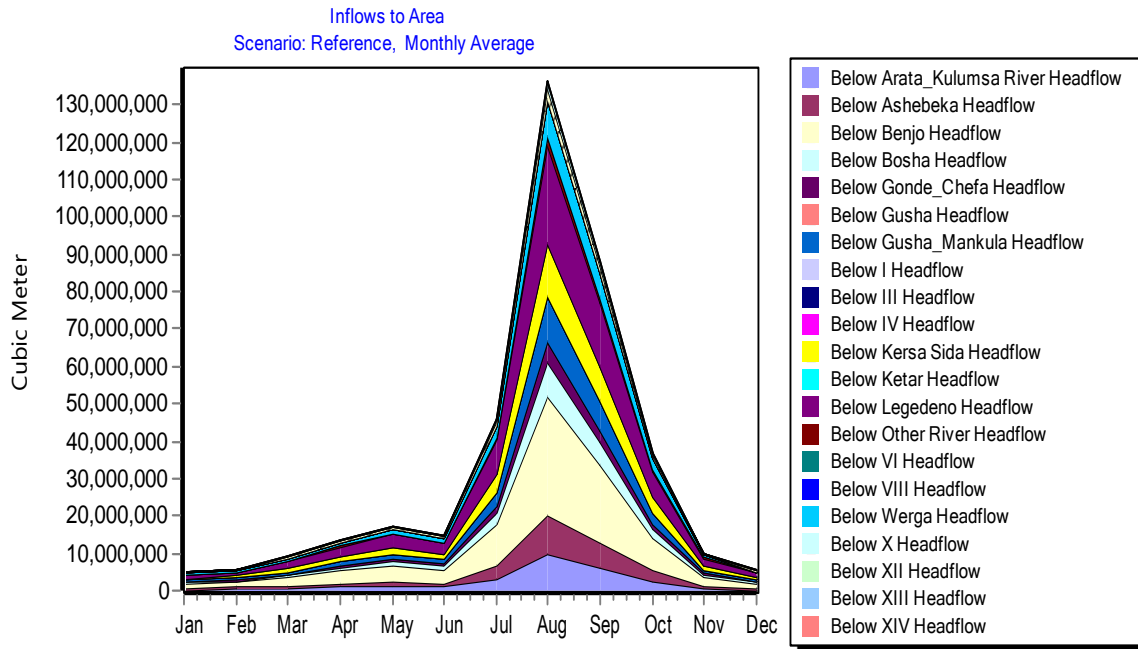


Figure 6-5 Ketar subbasin Catchments inflow

The unmet demand explains the magnitude of demand sites which are not getting full coverage and the amount of each sites requirement that is not met. The unmet demands of the Ketar subbasin considered the inflow of the main rivers in the subbasin (Figure 6-5) and the demand for irrigation, livestock and Asella town. The total water demand of the subbasin for irrigation, Asella Water supply and livestock is 27.7 million m³ per year (Figure 6-5).

According to the WEAP result, there is no unmet demand for Asella water supply and the livestock in the subbasin. However, Arata, Chemeri, Gusha, and Yadalo area irrigations have

unmet demand for December, January, and February. A total of 2, 736,180 m³ water scarcity is found in these three months for the above irrigation areas (Table 6-6). Irrigation areas in upstream such as Ashebeka, Chemri and werga has no un met demand. Similarly, Irrigations on the main course of Ketar river like K. Fofowate, K. Genet, K.T. Unsho and other pump irrigations has no unmet demand throughout the year. However, all irrigations in the downstream and Gusha from upstream has unmet demand.

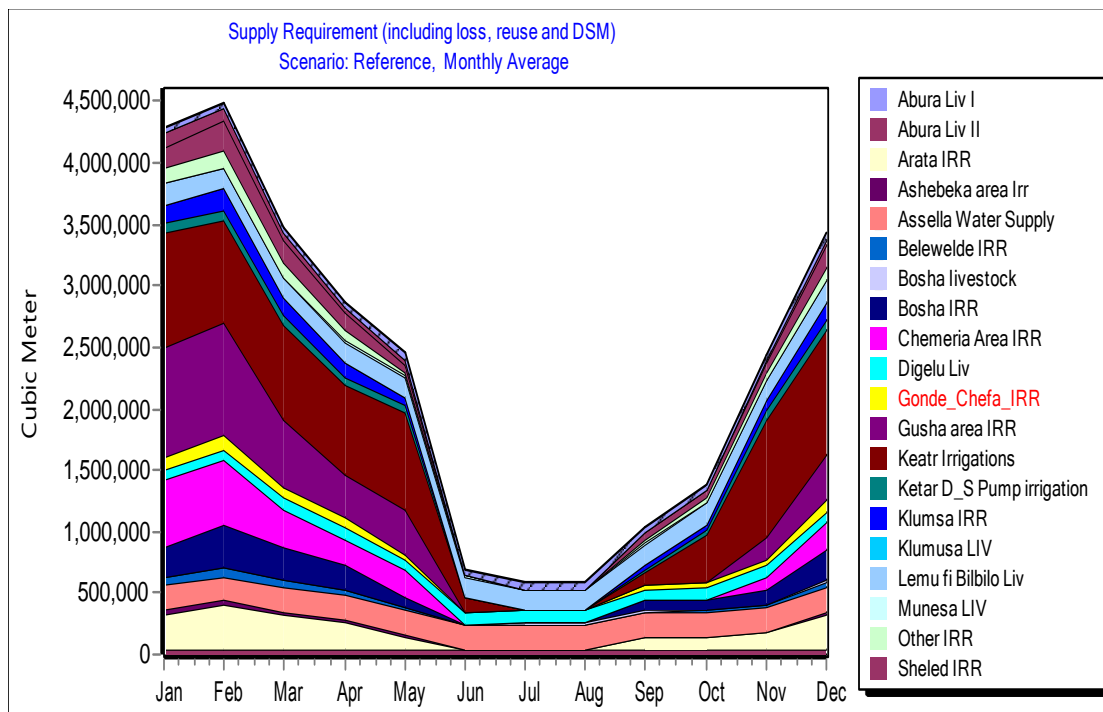


Figure 6-6 The Ketar subbasin total water demand

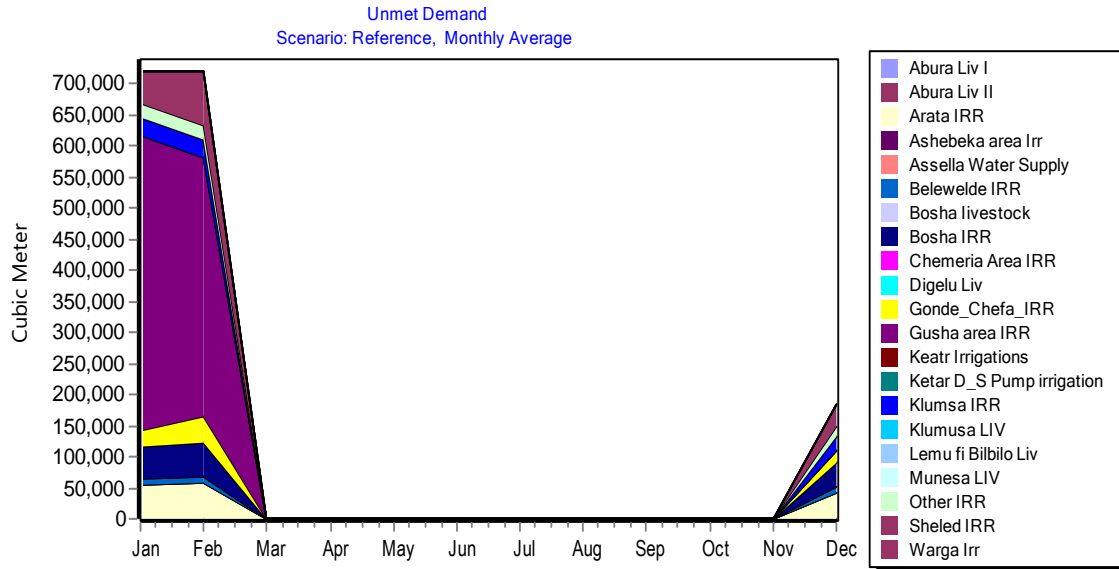


Figure 6-7 Ketar Subbasin catchments unmet demand

The Ketar subbasin catchments has no unmet demand for livestock except for Kulumsa livestock which is insignificant. The Assella town water supply also has no unmet demand for the whole year. However, there is unmet demand for irrigation at different catchments for January, February, and December (Figure 6-7). The Total unmet demand in the sub catchments is 1.6 million m³/year. Gusha, Sheled, Arata, and Boshha have 892, 177, 153, 143 thousands m³/ year unmet demand (Table 6-8).

Table 6-8 Ketar Subbasin Catchments unmet Demand

Irrigation Areas	Unmet Demand ('000) (m ³)			
	Jan	Feb	Dec	Sum
Arata IRR	53.5	56.9	42.2	152.7
Belewelde IRR	10.7	11.4	8.4	30.5
Boshha IRR	50.0	53.2	39.4	142.5
Gonde_Chefa_IRR	26.9	43.6	17.9	88.4
Gusha area IRR	476.1	416.1	0.0	892.2
Klumsa IRR	28.5	30.4	22.5	81.4
Other IRR	21.4	22.8	16.9	61.1
Sheled IRR	53.8	87.3	35.7	176.9
Sum	721.9	722.3	183.7	1627.9

6.3.6 Reliability of the Irrigation Water Supply and Demand site Coverage

The minimum water reliability in the Ketar subbasin specifically for for the Arata, Belwelde, Boshha, Gonde Chefa, Kulumsa, and other irrigation demand sites located at the downstream of the catchments is 75% where as Gusha has 83.3% reliability. Other irrigation demand sites have including the livestock demand sites have 100% reliability(Figure 6-8). January, February, and December are water coverage shortage months in the Ketar subbasin. Arata, Belwelde, Boshha, Kulumsa, and other Ketar downstream irrigations have a 79.9 % only water coverage in January, while Boshha, Gusha, and Shelede have 79.9%, 47.4%, and 70.2% coverage in January. Sheled has 63.2% water coverage in February (Figure 6-9).

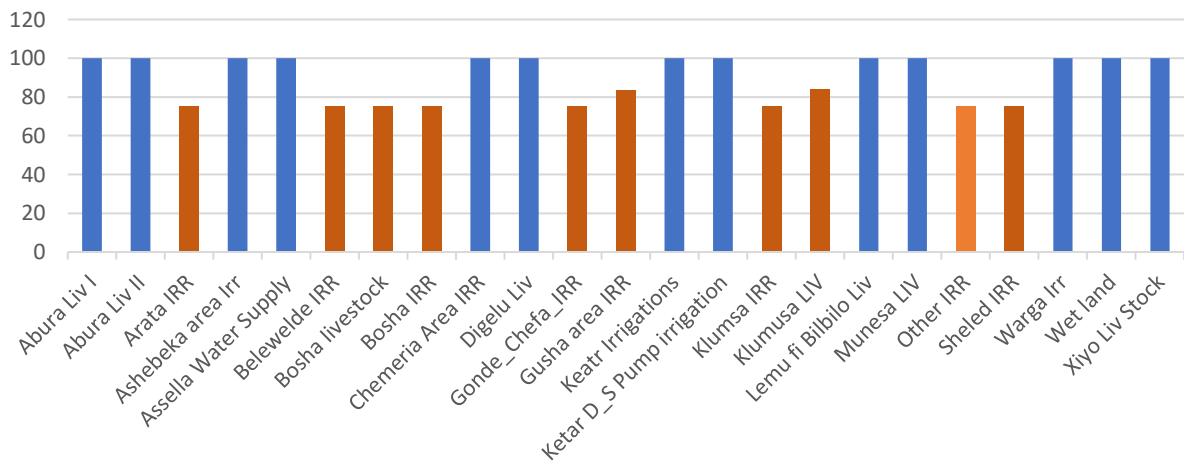


Figure 6-8 Reliability of Water demands on the water source (%)

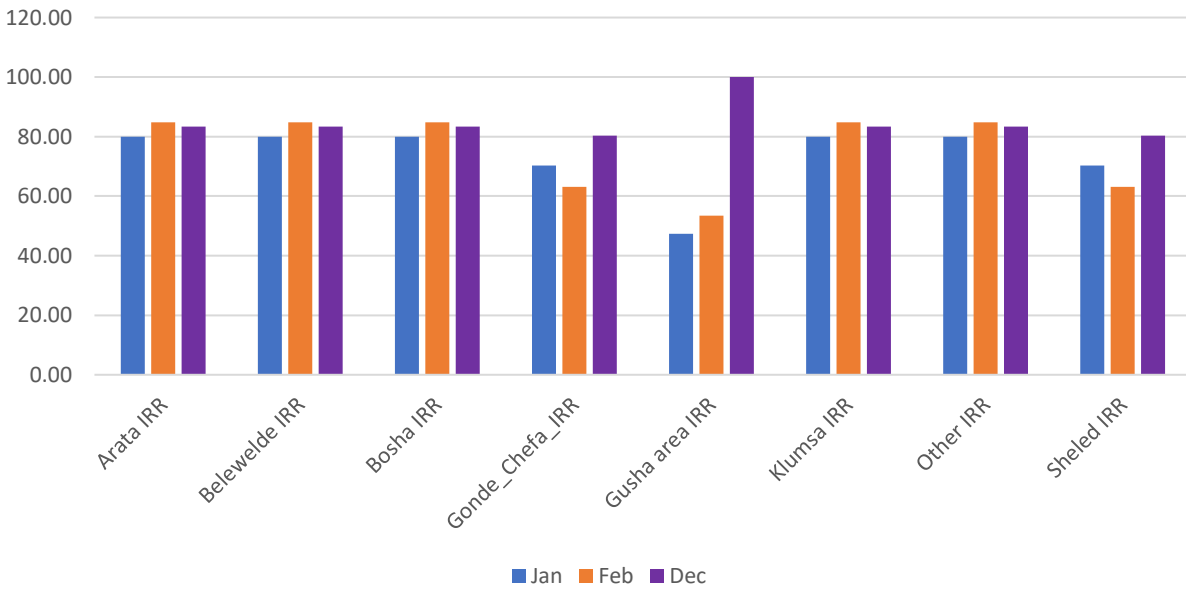


Figure 6-9 Irrigation Demand sites coverage in selected Ketar subbasin schemes (%)

6.3.7 Ketar Subbasin Water Balance

The Ketar subbasin level water balance only considering the economic uses demand is positive. The main river course Ketar has a flow throughout the year having maximum flow in August and minimum flow in January (Table 6-9) .

Table 6-9 Ketar subbasin Water balance

Description	('000,000 m ³)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ketar flow	4.8	5.4	8.7	12.9	16.5	13.0	43.8	130.0	84.0	34.7	9.5	5.2
Ketar demand	3.4	3.5	2.4	2.2	1.9	0.3	0.0	0.0	0.4	0.7	1.9	2.4
Ketar balance	1.4	1.9	6.3	10.7	14.6	12.7	43.8	130.0	83.6	34.0	7.6	2.8

The water balance characteristics of the Ketar subbasin catchments have different water balance compared to the main river course, Ketar. Most of the subbasin catchments have a negative

water balance in December, January, and February while having positive water balance in summation of the year (Table 6-10 to 6-15) except Ashebka and Kersa.

Table 6-10 Monthly water Balance of Arata Kulumsa Stream ('000 m3)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
S. water*	346	411	657	950	1205	1034	3251	9659	6228	2579	714	399	27433
Kulumsa	54	72	54	43	18	0	0	0	18	18	25	54	358
Belwelde	145	149	101	142	92	44	0	0	48	48	94	101	964
Arata	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

Table 6-11 Monthly water Balance of Gonde Chefa Stream ('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
Chefa Irr	181	186	126	178	115	55	0	0	60	60	117	126	1,205
Sheled Irr	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	13907

Table 6-12 Monthly water Balance of Bosha Stream ('000 m³)

	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	26248
Bosha	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	23134

Table 6-13 Monthly water Balance of Gusha Stream ('000 m³)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	429	484	804	1166	1500	1270	3991	11839	7646	3161	855	482
Gusha Irr	911	895	536	363	375	0	0	0	0	0	181	375
Balance	-482	-411	268	804	1125	1270	3991	11839	7646	3161	674	107

Table 6-14 Monthly water Balance of Ashebeka Stream ('000 m³)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S. Water	375	440	696	1011	1286	1089	3455	10205	6584	2732	752	402
Irr*	43	43	26	17	17	0	0	0	0	0	9	17
W.S**	195	178	195	188	195	188	195	195	188	195	188	195
sum	238	221	221	206	212	188	195	195	188	195	197	212
Balance	137	219	476	805	1074	900	3260	10010	6395	2537	555	190

*Ashebeka Irrigation ; ** Asella Water Supply

Table 6-15 Monthly water Balance of Kersa Stream ('000 m³)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
Kersa_Chemeri	536	611	964	1452	1848	1555	4901	14517	9383	3884	1063	589	41302
Chemeri IRR	503	503	302	201	201	0	0	0	0	0	101	201	2012
Balance	33	108	662	1250	1647	1555	4901	14517	9383	3884	962	388	39290

6.3.8 Environmental flow of the Ketar Subbasin

The environmental flow of the Ketar subbasin for the critical month, that is January was estimated for the main river course Ketar, Arata, Kulumsa, Gonde Chefa, Bosha, Gusha, Ashebeka, and Kersa Chemeri streams (Table 5- 16 to 5-23). The environmental flow was

estimated using the Tennant Method, the flow duration curve Q95, and the local or the Ethiopian, specifically the Oromia region irrigation development experience. The January environmental flow is assumed the minimum threshold that should be available in the river course in the current scenario.

Accordingly the Ketar river average flow (1972-2016) at Abura is 13.3 m³/sec while at Fite gauge it was found as 8m³/sec. According to the Tennant 10% AAF, the environmental flow for downstream of Abura and Fite in critical month January are 1.4 and 0.8 m³/sec respectively (Figure 6-10 & 6-11).

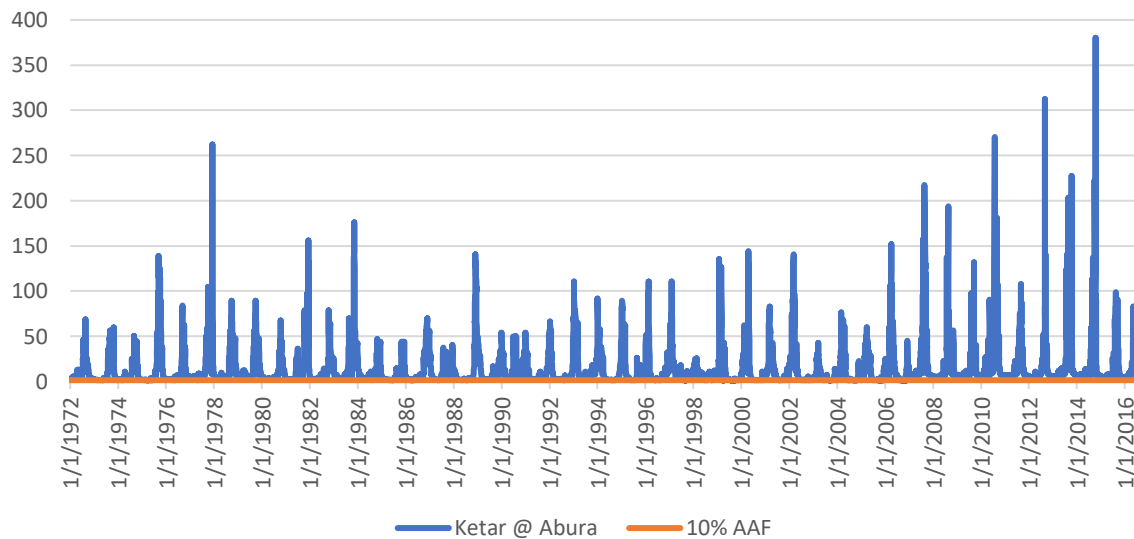


Figure 6-10 Ketar at Abura 10% AAF (m³/sec)

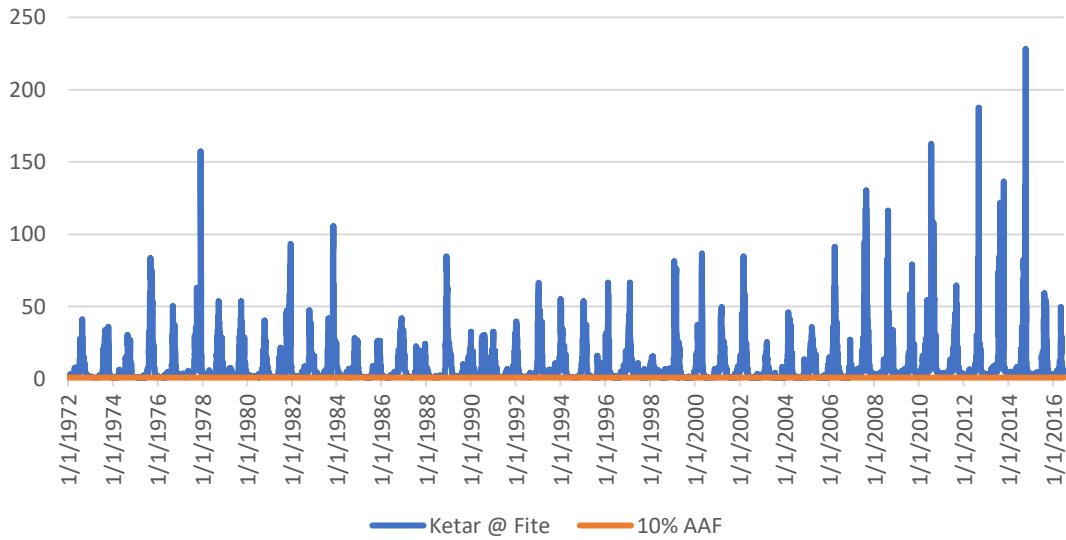


Figure 6-11 Figure Ketar at Fite 10% AAF (m3/sec)

The FDC- Q95 of Ketar at Abura and Fite, in the critical month January, flow results were found as 1.5 and 0.9 m³/sec respectively (Figure 6-12 & 6-13). The local thump rule which is 15% of the driest months were estimated as 0.27 and 0.18 for Ketar at Abura and Fite respectively taking January as the driest month of the year.

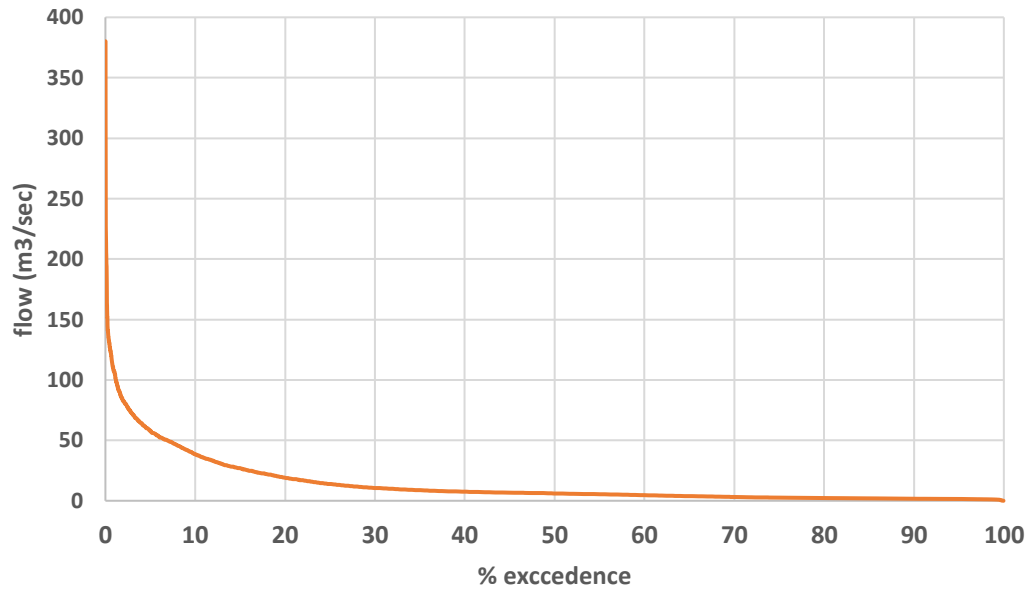


Figure 6-12 Figure 31 Ketar River at Abura flow duration curve

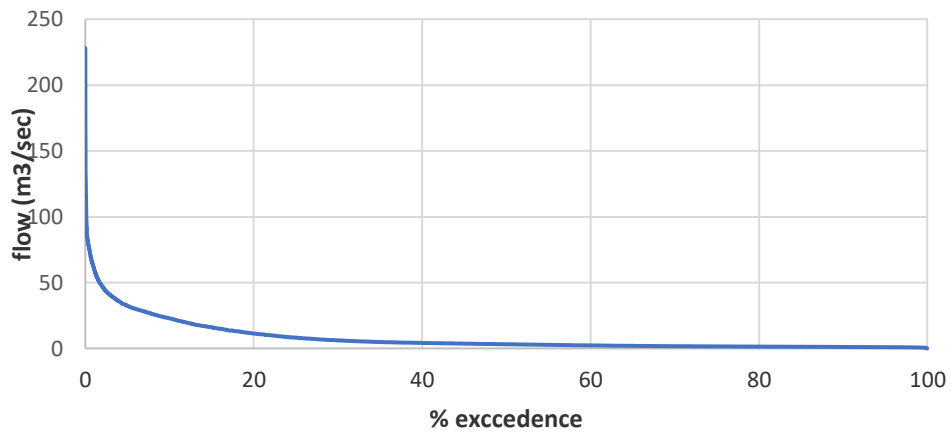


Figure 6-13 Ketar River at Fite flow duration curve

The environmental flow recommended results by the Tennant, FDC, and the thumb rule method were checked against the existing situation in the Ketar subbasin and the catchments within the subbasin. The result showed that

Table 6-16 Environmental flow²⁰ of Ketar at Abura River (m3/sec)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
W. Resource	1.79	2.23	3.26	4.98	6.16	5.38	16.37	48.53	32.40	12.96	3.66	1.94
W. Demand	1.3	1.5	0.9	0.9	0.7	0.1	0.0	0.0	0.2	0.3	0.7	0.9
W. Balance	0.53	0.78	2.35	4.12	5.46	5.27	16.37	48.53	32.24	12.69	2.94	1.04
10% Tennant	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
FDC (Q95)	2.6	3.8	2.8	2.4	2.0	1.6	1.5	1.2	1.1	1.06	1.4	2.1
15% LTR	0.27	0.33	0.49	0.75	0.92	0.81	2.46	7.28	4.86	1.94	0.55	0.29

Table 6-17 Environmental flow of Arata downstream (Kulumsa, Gonde-Chafa, and Bosha) (m3/sec)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	0.37	0.47	0.68	1.03	1.27	1.12	3.41	10.12	6.75	2.70	0.77	0.41
Demand	0.39	0.50	0.32	0.36	0.20	0.07	0.00	0.00	0.13	0.13	0.23	0.32
Balance	-0.02	-0.03	0.36	0.67	1.07	1.05	3.41	10.12	6.61	2.57	0.54	0.09
Tennant 10%	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Q95	0.55	0.8	0.57	0.50	0.42	0.32	0.31	0.24	0.23	0.22	0.31	0.44
LTR **	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table 6-18 Environmental flow Gonde_Chefa (m3/sec)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	0.07	0.09	0.14	0.21	0.26	0.22	0.68	2.01	1.34	0.54	0.15	0.08
Demand	0.08	0.09	0.06	0.08	0.05	0.02	0.00	0.00	0.03	0.03	0.05	0.06
Balance	-0.01	0.00	0.08	0.13	0.21	0.20	0.68	2.01	1.32	0.51	0.10	0.02
Tennant 10%	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

²⁰ All environmental flows were estimated for the critical month, January.

Q95	0.01	0.02	0.11	0.1	0.08	0.06	0.06	0.06	0.05	0.04	0.06	0.09
LTR	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Table 6-19 Environmental flow Bosha (m3/sec)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	0.13	0.16	0.23	0.35	0.44	0.38	1.16	3.45	2.30	0.92	0.26	0.14
Demand	0.09	0.11	0.07	0.10	0.06	0.03	0.00	0.00	0.33	0.06	0.09	0.16
Balance	0.04	0.05	0.16	0.25	0.38	0.35	1.16	3.45	1.97	0.86	0.17	-0.02
Tennant 10%	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Q95	0.06	0.04	0.06	0.07	0.08	0.11	0.11	0.14	0.15	0.15	0.11	0.08
LTR	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table 6-20 Environmental flow of Gusha (m3/sec)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gusha Flow	0.16	0.20	0.30	0.45	0.56	0.49	1.49	4.42	2.95	1.18	0.33	0.18
Gusha Demand	0.34	0.37	0.20	0.14	0.14	0.00	0.00	0.00	0.00	0.00	0.07	0.14
Gusha Balance	-0.18	-0.17	0.10	0.31	0.42	0.49	1.49	4.42	2.95	1.18	0.26	0.04
Tennant (10% AAF)	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
FDC (Q95)	0.07	0.05	0.07	0.09	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1
LTR	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table 6-21 Environmental flow of Ashebeka (m3/sec)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	0.14	0.18	0.26	0.39	0.48	0.42	1.29	3.81	2.54	1.02	0.29	0.15
Demand	0.09	0.09	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.08	0.08
Balance	0.05	0.09	0.18	0.31	0.40	0.35	1.22	3.74	2.47	0.95	0.21	0.07
Tennant 10%	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Q95	0.13	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2
LTR **	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table 6-22 Environmental flow Kersa (m3/sec)

Description	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow	0.20	0.25	0.36	0.56	0.69	0.60	1.83	5.42	3.62	1.45	0.41	0.22
Demand	0.19	0.21	0.11	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.04	0.08
Balance	0.01	0.04	0.25	0.48	0.61	0.60	1.83	5.42	3.62	1.45	0.37	0.14
Tennant 10%	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24
Q95	0.13	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.2
LTR	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Table 6-23 Summary Result of the environmental flow for critical months

Rivers/ Streams	January			February			March			December		
	Tennant	FDC	LTR	Tennant	FDC	LTR	Tennant	FDC	LTR	Tennant	FDC	LTR
Ketar												
Arata												
Gonde Chefa												
Bosha												
Gusha												
Ashebeka												
Kersa												

Note: Yellow deficit months, Light green satisfied months

6.4 Conclusion and Recommendation

The Ketar subbasin environmental flow is examined based on the inflow and demand in the subbasin as aggregate and catchment levels. The total water demand of the subbasin for irrigation, Asella water supply and livestock is found as 27.7 million m³ per year which is only 7% from the mean annual water resource. According to the WEAP result, there is no unmet demand for Asella water supply and the livestock in the subbasin. However, Arata, Chemeri, Gusha, and Yadalo area irrigations have unmet demand for December, January, and February. This unmet demand is 2.7million m³ which is 9.7% from the total demand. Irrigation areas in upstream and on the main river course, Ketar, has no un met demand. However, all irrigations in the downstream and Gusha from upstream have a deficit.

The environmental flow of the Ketar subbasin was estimated for the main river course Ketar and small streams like Arata, Kulumsa, Gonde Chefa, Bosha, Gusha, Ashebeka, and Kersa Chemeri on the annual and monthly base. Accordingly the environmental flow Ketar at Abura and Fite were estimated taking the Ketar at Abura and Fite mean flow from 1972-2016. Accordingly, the mean flow of Ketar at Abura was found as 13.3 m³/sec while at Fite gauge it was found as 8m³/sec. This resulted in turn 1.3 and 0.8 m³/sec environmental flow for downstream of Abura and Fite respectively based on Tennant 10% AAF while the annual FDC Q-95 resulted 1.5 & 0.9 for Ketar at Abura and Fite respectively. The LTR result showed 0,27 & 0.18 m³/sec in the above order. Looking into the small catchments, taking Arta as example, the environmental flow result showed 0.29, 0.31, and 0.06 m³/sec in Tenant, annual FDC-Q95, and LTR respectively. The IWMI environmental flow calculator of the FDC Q-95 for Ketar result showed 1.071 m³/sec for natural and minor modified stream which is nearly equivalent to this study.

The minimum water reliability in the Ketar subbasin is 75% which is for the Arata, Belwelde, Bosha, Gonde Chefa, Kulumsa, and other irrigation demand sites located at the downstream of the catchments. Gusha has 83.3% reliability while the other irrigation demand sites have including the livestock demand sites have 100% reliability. Arata, Belwelde, Bosha, Kulumsa, and other Ketar

downstream irrigations have a 79.9 % water coverage in January, while Bosha, Gusha, and Shelede have 79.9%, 47.4%, and 70.2% coverage in January. Sheled has 63.2% water coverage in February

The general trend of the environmental flow in the Ketar subbasin, specifically in the small catchments, is under challenge in the driest months of the year. However, in the current condition, this challenge can be managed when compared to the water resources available with in the subbasin. Employing water harvesting mechanisms to supplement the critical months is one of the solution to fulfill water demands and environmental flow.

Given the result, to alleviate the impact of irrigation water use on environmental flow in the subbasin, a proper water planning policy that considers basin level planning and implementation policy that makes environmental flow the heart should be in place..

SECTION FIVE – SYNTHESIS AND CONCLUSION

7 SYNTHESIS ON POLICY PERSPECTIVE AND PRACTICE, IMPLICATION OF THE STUDY, AND THE WAY FORWARD

7.1 Introduction

Ethiopian water policy and development is oriented to an integrated water resource management approach, which promotes efficient, equitable, and optimum utilization of available water resources to achieve significant socioeconomic development on a sustainable basis. However, in a practical scenario, the country is facing water governance and systematic environmental flow limitations. The current environmental flow practices in the country indicate the traditional human-nature paradigm which is ‘mankind versus nature’ that focuses on the exploitation of natural resources for the needs of people with minimum regard to the needs of natural ecosystems (PETTS, 1996). As a showcase, Lake Haramaya, which was covering 4.72 km² with an average depth of 3.13m, and 0.15 km³ in 1987 deteriorated to be an ephemeral lake (Lemma, 2011; Spliethoff et al., 2009). Similarly, Lake Abijata experienced a significant reduction in volume and chemistry from 1160MCM (1996) to 599MCM (2009) (Ayenew, 2007). Among many water bodies in the country, the Rift Valley Lakes, Awash, and Tekeze, basins faced water scarcity (MOWR, 2002; Negash, 2011), the surface areas of few lakes have shrunk (Ayenew and Legesse, 2007), and riverine flow in some areas dried (Desalegn et al., 2006) in the name of development. Therefore, it is necessary to examine the irrigation water governance and performance impact on environmental flow.

The objective of this study was to examine the impact of irrigation water governance and performance impact on environmental flow in the Ketar subbasin, CRV of Ethiopia. The study attempted to look in depth at the main components of irrigation such as the policy, legal framework, organization, water use, and performance at the subbasin level in general and four selected schemes, namely K. Fowafowate, K. Genet, K.T. Unshoo, and Arata in particular. Besides, the study attempted to look at the water value in CRV to learn the dominance of irrigation water demand on environmental flow in terms of water availability, quantity, and time in the

reference year 2019/20 to 2020/21. At last, it tried to link irrigation water use and the environmental flow.

Having in mind the above objectives, the study was designed with qualitative and quantitative approaches. Appropriate tools and instruments were prepared for data generation. Data were collected from the national level mainly from MoWE, MoIL, and MoA and Oromia regional institutions such as BoA, BoWR, BoIPD, and IWUAs. A structured questionnaire was used to survey irrigation users from the selected four schemes and CRV. Furthermore, FGD and interviews with experienced irrigation professionals, environmentalists, communities, and government organizations were used to generate qualitative data. Secondary data were collected from sources such as literature reviews, design documents, archives, and reports. Quantitative data were generated using different measuring tools and questioners, including water flow measuring tools, handheld GPS devices to measure elevations/datums, stopwatches to observe irrigation hours, handheld tapes to measure length and depth, and parshall flumes for flow measuring gauges. In addition, satellite images for irrigation area coverage, growing stages, and greenness were collected from MODIS. Proper analysis tools such as Arc GIS, Global Mapper, WEAP, and Google Earth for image analysis, Atlast-ti, and Stata were used for qualitative and descriptive statistics analysis respectively.

7.2 Major Findings

The major findings of this study related to irrigation water governance, performance, and environmental flow are synthesized below by specific objectives. The results are organized commencing on the scheme level and then summed to the subbasin level. At last, the link between irrigation water governance, performance, and environmental flow is discussed and recommendations are depicted.

7.2.1 Irrigation Water Governance in the Ketar Subbasin

The irrigation governance model in Ethiopia aligns with the polycentric water governance model. It entertains several institutions, including MoWE, MoIL, EEPA, MOA, regional water,

irrigation, and environmental bodies, and IWUAs. This has resulted in multiple overlaps in irrigation water governance among these institutions. The MoWE (specifically BDA), MoIL, and regional water and irrigation sectors took the lion's share in policy framing, the legal framework set up, and development, while the woreda offices with IWUA are key in operation and management. This is depicted in this study exhibiting the confusion in understanding the Ethiopian constitution and implementing the IWUA establishment Federal government proclamation 841/2014. The Ethiopian constitution article 51.11 and 52.1 which is directly related to the water governance is interpreted differently by the National and regional water institutions; this is illustrated on water bodies like Lake Ziway, Ketar and Meki rivers. Similarly, the Federal government proclamation 841/2014 that demands irrigation projects funded by the Federal government to be established by this proclamation is not working on ground due to the absence of delegated institution at bottom level. This results in uncontrolled water scramble at all level leaving the environmental flow at no persons land.

IWUA is the lower structure in the irrigation water governance but the critical institution. It plays a significant role in water abstraction, allocation, distribution, and management at the scheme level. According to this study, the IWUAs are key role players in irrigation water governance with limited strength and significant room for improvement to make them more productive. The result of the IWUAs performance at the microenvironment level, taking four irrigation schemes in the Ketar river system as a showcase and other IWUA in the system in general portrayed the determinants variables that need attention for better irrigation water governance.

Accordingly, most of the IWUAs in the system, specially those on traditional irrigation systems are not legally registered while the modern irrigation IWUAs are relatively more registered. This has a clear negative impact in the water governance. While the registered IWUAs have legal water use right the unregistered IWUAs are not aware of their water use right. Both the registered and the unregistered IWUAs have no any statement about in their bylaws about environmental flow even in the sense of downstream release.

The study taking the four irrigation schemes (Ketar Fowafowate, Ketar Genet, K. T. Unshoo and Arata) as a sample examined different determinants that have a key role in water governance which in turn contribute to the environmental flow of the subbasin status. The determinants inquired the status of the by-law implementation, water allocation, distribution, planning transparency, financial capacity, gender inclusiveness, and irrigation infrastructure management.

The result showed that the by-law implementation, planning transparency, water allocation and decision-making transparency as weak and dissatisfaction. Whenever, the IWUAs face water shortage or water allocation problem they tend to abstract more water that affect again the water remaining in the river course specially in Arata river. According to this study, the IWUAs are more inclined to punitive approach in their water governance rather than efficient water use approach like capacity building and infrastructure improvement. Moreover, though the IWUAs establishment documents encourage women to be in the IWUA leadership position to play a significant role and benefit from irrigation water governance, the result showed that each of the four IWUAs has only one woman member on its committee and the absence of any gender-related incentive instruments in their IWUAs. These weak irrigation water governance gives a chance for upstream irrigation users to exploit more water from the source and the conveyance system ignoring the environmental flow.

7.2.2 Irrigation Performance in the Ketar Subbasin

Irrigation performance is an indicator of the health and status of an irrigation scheme. Optimal irrigation performance is characterized by efficient water transportation, use, and water productivity, which entails a well-managed water abstraction that takes into account downstream flow that can address the environmental flow. The conventional irrigation performance assessment focuses on irrigation efficiencies and water productivity in which water is the key variable. In this study, in addition to the conventional performance assessment NDVI in relation to the crop coefficient was introduced for the sake of better and more reliable decision-making.

Accordingly, the four selected irrigation schemes irrigation efficiency, water productivity, and the NDVI verses Crop coefficient within the scheme at head, middle, and tail and then compared to each other at the scheme level. The results found were analyzed to represent the subbasin.

The conveyance efficiencies of the four schemes are below the FAO and other Ethiopian based study as stated in the irrigation performance section. Regarding the distribution efficiency with in the FAO range , the result found is between the value for rotational irrigation water supply with sufficient and insufficient water management and communication, however it is below the value for adequate communication and water management irrigation system efficiency, 0.65. This shows that extra water abstraction from the rivers due to inefficient irrigation system that again affect the environmental flow.

The field water productivity the four schemes is small when compared to the SSA as explained in the analysis part. This result tells us that there should be productivity improvement at least to meet with some of the SSA result as depicted in the result section. The more efficient water is used and water productivity is increased the environmental flow will be reserved rather than extracted.

The NDVI value within each scheme tail irrigation is the lowest while the upstream areas enjoy the highest value. The NDVI values for all schemes except Arata increased as the number of irrigation days increased and decreased close to the end of the irrigation season. However, the NDVI value for Arata continued to increase throughout the irrigation season, albeit slightly. The average NDVI values among the four schemes ranged between 0.32 and 0.54 having These NDVI values indicated a very low greenness level. The anomaly in the NDVI within the scheme and among the scheme expresses the inadequate water distribution to certain plots taking all other factors that affect the yiel as a constant. This is further confirmed by the assessment of the specific objective regarding the irrigation water governance assessment.

As clearly indicated the irregularity of the water abstraction and distribution irrigation users are compelled to abstract more water from the rivers or their near by canal system to ensure sufficient water for their crop. Similarly, the IWUAs comitee tend to divert more water from the source. This again clearly affects the water in the main water resource and in consequences decreases the environmental flow.

7.2.3 Environmental flow

The environmental flow assessment in this study was conducted in terms of quantity and timing only. Besides, it is researched in selected ecosystem services based on multiple water value approaches and sociocultural use on a yearly base. The study addressed the multiple water value at the CRV level in general and the Ketar subbasin level in particular. The results were presented in the main body of the document in chapters four, five, and six.

The environmental flow which usually is explained in quantity, quality, and time is the main element for ecosystem services such as provisioning, regulating, cultural, and supporting. Hence, a study on environmental flow should also show the level of the ecosystem services in different functions, and water values. This study tried to understand the multiple water value status of the Ketar subbasin that can impact the water allocation of the subbasin within the CRV umbrella.

As a result, about 24 perceived values, priority water uses, and associated values were identified in household surveys as perceived by diverse water users in the CRV of Ethiopia. Accordingly, domestic water use was given the highest number of mentions (97) followed by agricultural use (92). The smallest number of mentions of the water use types by the household survey respondents were on the water as a commodity (27) and water as a source of energy (8). Based on the identified use types multiple water value is apparent. The result further illustrates the pluralistic nature of water value and the dichotomy of preference by people of different backgrounds. The instrumental value type is the dominant water value while the relational water values are rated as medium and intrinsic water values earned the lower level. The overall result reflects the basic needs for food and water security. It is in line with the Ethiopian government

water policy (MoWR 1999) which prioritizes domestic water uses, and water for livestock in that order of magnitude and without detailing other water use and values including environmental flow. The food security value of water is high but rarely quantified– and it is often a political imperative irrespective of other values (UNESCO 2021). The current finding is substantiated by the findings of Houston et al., (2002) who suggested that the best way to determine how people value water is to determine how people use water. Additionally, Mekuria et al., (2021) reported that in many parts of CRV, increasing demand for water for food production is a major driver of dwindling ecosystem service values.

Comparing the water balance tables along with the water use event calendar developed in consultation with the community gives a complete insight into spatial and temporal details of water value trade-offs. Some relational values are throughout the year (e.g., aesthetic, holy water) while others concentrate in October and January (e.g., spiritual, and cultural values) and in these months the water availability is already deficit for environmental flow under some of the scenarios considered and validations from focus group discussion.

As these cultural and spiritual events are non-consumptive water use some arguments maintain environmental flow is sufficient to meet the socio-cultural needs. But as elaborated earlier, under different scenarios and different scales, the environmental flow has already suffered a shortage. Nevertheless, the different values of water need to be reconciled, and the trade-offs between them resolved and incorporated into systematic and inclusive planning and decision-making processes (HLPW 2017). The way forward, therefore, will be to further develop common approaches to valuation where feasible but also to prioritize improved approaches to compare, contrast and merge different values, and to incorporate fair and equitable conclusions into improved policy and planning.

We can learn from these findings that though there exist multiple values of water in the subbasin, the instrumental value of water in this subbasin is the governing water value. This can increase the risk to the environmental flow of the subbasin which in turn can risk the sustainability of the irrigation and other water values.

The environmental flow of the Ketar subbasin was estimated for the main river course Ketar, Arata, Kulumsa, Gonde Chefa, Bosha, Gusha, Ashebeka, and Kersa Chemeri streams. 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 result of this study showed that 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.

The total water demand of the Ketar subbasin for irrigation, Asella water supply, and livestock are found as 27.7 million m³ per year which is only 7% of the mean annual water resource. According to the WEAP result, there is no unmet demand for the Asella water supply and the livestock in the subbasin. However, Arata, Chemeri, Gusha, and Yadalo area irrigations have unmet demand for December, January, and February. This unmet demand is 2.7 million m³ which is 9.7% of the total demand. Irrigation areas in upstream and on the main river course, Ketar, have no unmet demand. However, all irrigations in downstream and Gusha upstream have a deficit.

The environmental flow Ketar at Abura and Fite is found as river average flow from 1972-2016 for Abura is 13.3 m³/sec while at Fite gauge it was found as 8m³/sec which in turn resulted

in 1.3 and 0.8 m³/sec environmental flow for downstream of Abura and Fite respectively based on AAF. The minimum water reliability in the Ketar subbasin is 75% which is for the Arata, Belwelde, Bosha, Gonde Chefa, Kulumsa, and other irrigation demand sites located downstream of the catchments. Gusha has 83.3% reliability while the other irrigation demand sites including the livestock demand sites have 100% reliability. Arata, Belwelde, Bosha, Kulumsa, and other Ketar downstream irrigations have a 79.9 % water coverage in January, while Bosha, Gusha, and Shelede have 79.9%, 47.4%, and 70.2% coverage in January. The Sheled irrigation scheme has 63.2% water coverage in February.

7.3 Translations of Findings into Practices and Policies

Ensuring environmental flow is critical in water management as it directly affects the health and the sustainability of the ecosystem services. Thriving for healthy water ecosystem service should be the mission of a country like Ethiopia where the survival a lot of people is dependent on the wellbeing of water body. Hence, allocation of sufficient water in the river course to address environmental flow for ecological needs of rivers should be the center of the water policy in parallel to development objectives.

Therefore, to align irrigation developments with healthy water ecosystem service needs to consider good irrigation water governance, better irrigation performance that optimized water use in terms of water productivity and environmental flow. This requires to solve the findings of this study in the area of institutional overlap over water governance between National and regional level; institutions at national and regional level should reconcile overlapped mandates and design implementation modality including policy directions. Besides, the irrigation performance which is the significant determinant of the water use should be improved in capacity building in terms of water measuring, allocation equipment, and water saving technologies. Furthermore, irrigation water use right should entitle the amount water permitted for one irrigation schemes and an incentive policy for water saving. Environmental flow inspection system should come on rivers currently affected.

7.4 Future Research area

The study on environmental flow in Ethiopia is infant and most of water centered small scale developments like irrigation overlook it. Hence, I recommend further detailed study on the link between irrigation and environmental flow in Ethiopian subbasins with different. This helps to establish tailored local area and catchment context environmental flow estimation methodology. Besides, I recommend irrigation performance researches to incorporate remote sensing data correlating it with yield and irrigation water supply in addition to the conventional performance analysis for better assessment of irrigation impact on water use.

7.5 Conclusion

In Ethiopia, Irrigation - environmental flow studies are at an infant stage, especially in the development and operation of small-scale irrigation which can be labeled as nonexistent. Hence, this study aimed to contribute to sustainable development that optimizes the irrigation development result while keeping the ecosystem service which is dependent on the environmental flow variable. Besides, it aspires to make irrigation–environmental flow link a policy agenda to give due consideration to multiple water values and sustainable development.

According to this study, the general trend of the environmental flow in the Ketar subbasin, specifically in the small catchments, is under challenge in the driest months (December, January, and February) of the year. However, in the current condition, this challenge can be managed when compared to the water resources available within the subbasin. Employing water harvesting mechanisms to supplement the critical months is one of the solutions to fulfill water demands and environmental flow.

Methodology-wise, this study recommends the academic arena and the water and irrigation sector of the sub-Saharan countries to develop tailored environmental flow determination methods and recommendations. Besides, it recommends the inclusion of remote sensing data such as NDVI correlating it with yield and irrigation water supply as a standard approach for assessing irrigation scheme performance, encompassing multidimensional but achievable objective-based scheme

evaluation criteria for better irrigation performance and detailed study on the link between irrigation and environmental flow in large, medium and full ecosystem service oriented small scale related irrigation.

At last, as discussed in detail in the document, to have an understandable decision-making process on environmental flow estimation, Ethiopia should adopt one environmental flow estimation method. 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 here I recommend the FDC Q95 for medium rivers like Keta and the 15% of the driest month flow for small rivers that have feeder streams within one km distance after abstraction points. This recommendation for the small rivers is based on the consideration of the existence of other nearby small streams without going further with water scarcity.

To make irrigation water governance more environmentally flow-oriented, all irrigation development and water governance stakeholders in Ethiopia should give environmental flow due consideration. IWUAs should be empowered in water abstraction, distribution and measuring infrastructures and equipment, O&M fee collection, water allocation basics, and gender inclusiveness and be more environmentally flow conscious. The IWUAs should be supported by the government and other stakeholders in installing water measuring structures and water allocation recording for equitable water distribution services which should be based on land size, crops, and plot locations rather than blanket allocation and distribution. In addition Women, irrigators should get due attention in the irrigation governance leadership. The government should assign irrigation experts in proximity based on irrigation size, water scarcity, and the density of irrigation on water resources.

Taking the result of the study into consideration, to alleviate the impact of irrigation water governance and performance on environmental flow in the subbasin, a proper water planning policy that considers basin-level planning and implementation that makes environmental flow the heart of the planning system should be in place.

8 REFERENCES

- Abernethy, C. L. (1984). *Indicators of the Performance of irrigation Water distribution system* (p. 22). p. 22. Colombo: International Irrigation Management Institute.
- Acreman, M. (2016). Environmental flows-basics for novices. *Wiley Interdisciplinary Reviews: Water*, 3(5), 622–628. <https://doi.org/10.1002/wat2.1160>
- Acreman, M. C., & Dunbar, M. J. (2004). Defining environmental river flow requirements – a review. *Hydrology and Earth System Sciences*, 8(5), 861–876. <https://doi.org/10.5194/hess-8-861-2004>
- Acreman, M., Dunbar, M., Hannaford, J., Mountford, O., Wood, P., Holmes, N., ... Crookall, D. (2008). *Developing environmental standards for abstractions from UK rivers to implement the EU Water Framework Directive / Développement de standards environnementaux sur les prélèvements d '... Developing environmental standards for abstractions from UK rivers t.* (January).
- Adamala, S., Rajwade, Y. A., & Reddy, Y. V. K. (2016). *Estimation of wheat crop evapotranspiration using NDVI vegetation index Estimation of wheat crop evapotranspiration using NDVI vegetation index.* (March). <https://doi.org/10.31018/jans.v8i1.767>
- Adane, H. D. (2014). *Reflecting on the Right to Water in Ethiopia with a Special Reference to Water Resources Development and Abstraction in the Central Rift Valley of Ethiopia.*

Agathe Euzen and Barbara Morehouse. (2011). *Water : What values ?* 30, 237–247.

<https://doi.org/10.1016/j.polsoc.2011.10.005>

Agide, Z., Hailelassie, A., Sally, H., Erkossa, T., Schmitter, P., Langan, S., & Hoekstra, D. (2016). Analysis of water delivery performance of smallholder irrigation schemes in Ethiopia : Diversity and lessons across schemes, typologies and reaches. *LIVES Working Paper 15*, (15), 38.

Agyenim, J. B. (2011). *Investigating institutional arrangements for integrated water resource management in developing countries: the case of White Volta Basin, Ghana*. 287.

Akuriba, A. M., Haagsma, R., Heerink, N., & Dittoh, S. (2018). *Irrigation governance and performance : the case of smallholder irrigated agriculture in northern Ghana*. 1–29.

Allen, R. G. (1998). *FAO Irrigation and Drainage Paper No . 56 Crop Evapotranspiration*, FAO. Rome.

Amenu, K., Markemann, A., & Zárata, A. V. (2013). *Water for human and livestock consumption in rural settings of Ethiopia : Assessments of quality and health aspects* *Water for human and livestock consumption in rural settings of Ethiopia : assessments of quality and health aspects*. (June 2015). <https://doi.org/10.1007/s10661-013-3275-3>

Aranguren, M., Castell, A., & Aizpurua, A. (2020). *Wheat Yield Estimation with NDVI Values Using a Proximal Sensing Tool*.

Araral, E., & Wang, Y. (2013). *Water Governance 2.0: A Review and Second Generation*

Research Agenda. *Water Resources Management*, 27(11), 3945–3957.

<https://doi.org/10.1007/s11269-013-0389-x>

Arthington, A. H. (2020). Environmental Flows: History of Assessment Methods, Ecosystem Frameworks and Global Uptake. In *Reference Module in Earth Systems and Environmental Sciences* (2nd ed.). <https://doi.org/10.1016/b978-0-12-409548-9.12450-9>

Atosina, M., Haagsma, R., Heerink, N., & Dittoh, S. (2020). Assessing governance of irrigation systems : A view from below. *World Development Perspectives*, (April 2019), 100197. <https://doi.org/10.1016/j.wdp.2020.100197>

Awulachew, S. B., & Ayana, M. (2011). Performance OF irrigation: An assessment at different scales in ethiopia. *Experimental Agriculture*, 47(S1), 57–69. <https://doi.org/10.1017/S0014479710000955>

Ayenew, T. (2007). Water management problems in the Ethiopian rift: Challenges for development. *Journal of African Earth Sciences*, 48(2–3), 222–236. <https://doi.org/10.1016/j.jafrearsci.2006.05.010>

AZILDO. (2017). *Arsi Zone Irrigation and Livestock Developemnt*. Assella.

Baldwin, E., McCord, P., Dell’Angelo, J., & Evans, T. (2018). Collective action in a polycentric water governance system. *Environmental Policy and Governance*, 28(4), 212–222. <https://doi.org/10.1002/eet.1810>

Balvanera, P., Pascual, U., Christie, M., Baptiste, B., Lliso, B., Monroy, A. S., ... Gonzalez-

- Jimenez, D. (2022). Chapter 1: The role of the values of nature and valuation for addressing the biodiversity crisis and navigating towards more just and sustainable futures. In *Methodological assessment report on the diverse values and valuation of nature of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*.
<https://doi.org/doi.org/10.5281/zenodo.6418971>
- Barker, R., & Molle, F. (2004). Evolution of irrigation in South and Southeast Asia. In *Research Report 5*.
- Batchelor, C., Reddy, V. R., Linstead, C., Dhar, M., Roy, S., & May, R. (2014). Do water-saving technologies improve environmental flows? *Journal of Hydrology*, 518(PA), 140–149.
<https://doi.org/10.1016/j.jhydrol.2013.11.063>
- Bekele, R. D., & Mekonnen, D. (2021). Local empowerment and irrigation devolution in Ethiopia. *International Journal of Water Resources Development*, 00(00), 1–27.
<https://doi.org/10.1080/07900627.2021.1936465>
- Biemans, H., Haddeland, I., Kabat, P., Ludwig, F., Hutjes, R. W. A., Heinke, J., ... Gerten, D. (2011). Impact of reservoirs on river discharge and irrigation water supply during the 20th century. *Water Resources Research*, 47(3). <https://doi.org/10.1029/2009WR008929>
- Billib, M., Bardowicks, K., & Arumí, J. L. (2009). Integrated water resources management for sustainable irrigation at the basin scale. *Chilean Journal of Agricultural Research*, 69(SUPPL. 1), 69–80. <https://doi.org/10.4067/s0718-58392009000500007>

- Bjornlund, H. (2014). Water governance for sustainable irrigation: The role of civil society. *WIT Transactions on Ecology and the Environment*, 185, 211–222.
<https://doi.org/10.2495/SI140191>
- Bjornlund, Henning. (2016). *Water governance for sustainable irrigation : The role of civil society* *Water governance for sustainable irrigation : the role of civil society*. (June 2014).
<https://doi.org/10.2495/SI140191>
- Bos, M. G., & Wolters, W. (1990). Water charges and irrigation efficiencies. *Irrigation and Drainage Systems*, 4(3), 267–278. <https://doi.org/10.1007/BF01117746>
- Brinegar, H. R., & Ward, F. A. (2009). Basin impacts of irrigation water conservation policy. *Ecological Economics*, 69(2), 414–426. <https://doi.org/10.1016/j.ecolecon.2009.07.020>
- Bruin, A. de, Cinderby, S., Mbilinyi, B., Mahoo, H., & Barron, J. (2012). *Agricultural Water Management Scenarios in the Mkindo Watershed Wami Basin, Tanzania*.
- Bruinsma, N. A. and J. (2012). World Agriculture Towards 203/2050. In *FAO Working Paper* (Vol. 12–03).
- Bruns, B. (2021). Polycentric solutions for groundwater governance in Sub-Saharan Africa: Encouraging institutional artisanship in an extended ladder of participation. *Water (Switzerland)*, 13(5). <https://doi.org/10.3390/w13050630>
- Bryan, B. A., Raymond, C. M., Crossman, N. D., & Macdonald, D. H. (2010). Targeting the management of ecosystem services based on social values: Where, what, and how?

Landscape and Urban Planning, 97(2), 111–122.

<https://doi.org/10.1016/j.landurbplan.2010.05.002>

Buchanan, C., Moltz, H. L. N., Haywood, H. C., Palmer, J. B., & Griggs, A. N. (2013). A test of The Ecological Limits of Hydrologic Alteration (ELOHA) method for determining environmental flows in the Potomac River basin, U.S.A. *Freshwater Biology*, 58(12), 2632–2647. <https://doi.org/10.1111/fwb.12240>

Bunn, S. E., & Arthington, A. H. (2002). Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. *Environmental Management*, 30(4), 492–507. <https://doi.org/10.1007/s00267-002-2737-0>

BWILDO. (2019). *Batu Woreda 2019 Irrigation and Pastoralist Developemnt Office, BWIDO, Report*. Batu.

Cai, X. M., & Rosegrant, M. W. (2009). World water productivity: current situation and future options. *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, 163–178. <https://doi.org/10.1079/9780851996691.0163>

Cambaza, C., Hoogesteger, J., & Veldwisch, G. J. (2020). Irrigation management transfer in sub-Saharan Africa : an analysis of policy implementation across scales. *Water International*, 45(1), 3–19. <https://doi.org/10.1080/02508060.2019.1702310>

Carpenter, S., Baldwin, E., & Cole, D. H. (2017). *THE POLYCENTRIC TURN : A CASE STUDY OF KENYA ' S EVOLVING LEGAL REGIME FOR IRRIGATION WATERS* Published by :

Regents of the University of New Mexico on behalf of its School of Law Stable URL :
<https://www.jstor.org/stable/10.2307/26202189> THE POLYCENTRIC T. 57(1), 101–138.

Causapé, J., Quílez, D., & Aragüés, R. (2004). Assessment of irrigation and environmental quality at the hydrological basin level: I. Irrigation quality. *Agricultural Water Management*, 70(3), 195–209. <https://doi.org/10.1016/j.agwat.2004.06.005>

Challenge, T. H. E., Providing, O. F., Flow, E., Sustain, T. O., & Ecosystems, R. (2006). *the Challenge of Providing Environmental Flow Rules. 16(4), 1311–1318.*

Chen, A., Wu, M., Wu, S. nan, Sui, X., Wen, J. ya, Wang, P. yuan, ... Jia, W. lin. (2019). Bridging gaps between environmental flows theory and practices in China. *Water Science and Engineering*, 12(4), 284–292. <https://doi.org/10.1016/j.wse.2019.12.002>

Claudia Pahl-Wostl, Joyeeta Gupta, and D. P. (2008). Governance and the Global Water System : A Theoretical Exploration. *Global Governance*, 14(4), 419–435.

Clemmens, A. J., & Molden, D. J. (2007). Water uses and productivity of irrigation systems. *Irrigation Science*, 25(3), 247–261. <https://doi.org/10.1007/s00271-007-0067-y>

Cooley, H., Ajami, N., Ha, M., Srinivasan, V., Morrison, J., Donnelly, K., & Christian-Smith, J. (2013). *Global Water Governance in the st 21 Century.*

Costanza, R., D'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., ... Van Den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253–260. <https://doi.org/10.1038/387253a0>

CSA. (2007). *The Federal Democratic Republic of Ethiopia Central Statistical Agency Report*.
(December 2008).

CSA. (2022). *The Federal Democratic Republic of Ethiopia Central Statistical Agency 2022 Report*. Addis Ababa Ethiopia.

Damtew Fufa Tufa, Yerramsetty Abbulu, and G. V. R. S. R. (2015). *HYDROLOGICAL IMPACTS DUE TO LAND-USE AND LAND-COVER CHANGES OF KETAR WATERSHED , LAKE ZIWAY CATCHMENT , ETHIOPIA*. 6(10), 36–45.

Das Gupta, A. (2008). Implication of environmental flows in river basin management. *Physics and Chemistry of the Earth*, 33(5), 298–303. <https://doi.org/10.1016/j.pce.2008.02.004>

Davis, R., & Hirji, R. (2003). Water Resources and Environment Technical Note C.3
Environmental Flows: Floods Flow. *The World Bank Washington*, 28.

Demelash Wondimagegnehu Goshime, Alemseged Tamiru Haile, Rafik Absi, B. L. (2021).
Impact of water resource development plan on water abstraction and water balance of Lake
Ziway , Ethiopia. *Sustainable Water Resources Management*, (April).
<https://doi.org/10.1007/s40899-021-00516-w>

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of
farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia.
Global Environmental Change, 19(2), 248–255.
<https://doi.org/10.1016/j.gloenvcha.2009.01.002>

Derib, S. D., Descheemaeker, K., Hailelassie, A., & Amede, T. (2011a). Irrigation water productivity as affected by water management in A small-scale irrigation scheme in the blue Nile basin, Ethiopia. *Experimental Agriculture*, 47(S1), 39–55.

<https://doi.org/10.1017/S0014479710000839>

Derib, S. D., Descheemaeker, K., Hailelassie, A., & Amede, T. (2011b). Irrigation water productivity as affected by water management in A small-scale irrigation scheme in the blue Nile basin, Ethiopia. *Experimental Agriculture*, 47(S1), 39–55.

<https://doi.org/10.1017/S0014479710000839>

Derseh, M. G., Nigatu, T. A., Mhiret, D. A., & Steenhuis, T. S. (2020). *Hydrological Foundation as a Basis for a Holistic*.

Descheemaeker, K., Amede, T., & Hailelassie, A. (2010). Improving water productivity in mixed crop – livestock farming systems of sub-Saharan Africa. *Agricultural Water Management*, 97(5), 579–586. <https://doi.org/10.1016/j.agwat.2009.11.012>

Descheemaeker, K., & Hailelassie, A. (2011). *IRRIGATION WATER PRODUCTIVITY AS AFFECTED BY WATER MANAGEMENT IN A SMALL-SCALE IRRIGATION SCHEME IN THE BLUE NILE BASIN, ETHIOPIA*. (January).

<https://doi.org/10.1017/S0014479710000839>

Descheemaeker, K., & Tolera, A. (2011). *Livestock water productivity in a water stressed environment in northern*. (October 2014). <https://doi.org/10.1017/S0014479710000852>

- Dessalegn, R. (1999). Water Resource Development in Ethiopia: Issues of Sustainability and Participation. *Forum for Social Studies*, (1), 1–37.
- Desta, H., Lemma, B., Stellmacher, T., & Gebremariam, E. (2019). Water use and management of Lake Ziway and its watershed , Ethiopia : the perception of experts vis - à - vis the latest state of research. *Environment, Development and Sustainability*, (0123456789).
<https://doi.org/10.1007/s10668-019-00359-8>
- Didan, K., Munoz, A. B., & Huete, A. (2015). *MODIS Vegetation Index User ' s Guide (MOD13 Series)* (Vol. 2015). Arizona.
- Dinar, J. M. S. F. A. (2016). *Water Governance Decentralization in Sub-Saharan Africa: Between Myth and Reality*.
- Dirwai, T. L., Senzanje, A., & Mudhara, M. (2019). Water governance impacts on water adequacy in smallholder irrigation schemes in KwaZulu-Natal province, South Africa. *Water Policy*, 21(1), 127–146. <https://doi.org/10.2166/wp.2018.149>
- Dissanayake, P., & Smakhtin, V. (2007). Environmental and Social Values of River Water : Examples from the Menik Ganga , Sri Lanka. In *Iwmi*.
- Doorenbos, J., & Pruitt, W. O. (1977). Guidelines for predicting crop water requirements. *FAO Irrigation and Drainage Paper*, Vol. 24, p. 144.
- Douglas G. Emerson, Aldo V. Vecchia, and A. L. D. (2005). Evaluation of Drainage-Area Ratio Method Used to Estimate Streamflow for the Red River of the North Basin, North Dakota

and Minnesota. *Scientific Investigations Report*, 5017.

Dynesius, M., & Nilsson, C. (1994). Fragmentation and flow regulation of river systems in the northern third of the world. *Science*, 266(5186), 753–762.

<https://doi.org/10.1126/science.266.5186.753>

Dyson, M., Bergkamp, G., & Scanlon, J. (2008). *The essentials of environmental flow*.

ECoM. (2021). *Ethiopian Council of Ministers Definition of Powers and Duties of the Executive Organs Proclamation 1263/2021* (p. 125). p. 125. Addis Ababa Ethiopia.

Eefje Aarnoudse, A. C. and N. L. (2018). *Water User Associations: A Review of Approaches and Alternative Management Options for Sub-Saharan Africa*.

EEPA. (1997). *Ethiopian ENVIRONMENTAL PROTECTION AUTHORITY ENVIRONMENTAL POLICY* (p. 31). p. 31. Addis Ababa Ethiopia.

Elias, E., Gessesew, W. S., & Haile, B. T. (2019). *Impact of land use / cover changes on lake ecosystem of Ethiopia central rift valley*. (March).

<https://doi.org/10.1080/23311932.2019.1595876>

Enrique Playán, J. A. S. and R. C. (2018). *Irrigation Governance in Developing Countries* : 1–24. <https://doi.org/10.3390/w10091118>

Ethiopian Ministry of Agriculture, M. (2018). *Small Scal Irrigation Scheme Operation*. Addis Ababa Ethiopia: Ethiopian Ministry of Agriculture.

- Etissa, E., Dechassa, N., Alamirew, T., Alemayehu, Y., & Desalegne, L. (2014). Irrigation Water Management Practices in Smallholder Vegetable Crops Production: The Case of the Central Rift Valley of Ethiopia. *Science, Technology and Arts Research Journal*, 3(1), 74.
<https://doi.org/10.4314/star.v3i1.13>
- FAO. (2006). World agriculture: towards 2030/2050 Prospects for food, nutrition, agriculture and major commodity groups. *Fao*, p. 78.
- FAO. (2017a). *The future of food and agriculture Trends and challenges*.
- FAO. (2017b). Water for Sustainable Food and Agriculture Water for Sustainable Food and Agriculture. In *A report produced for the G20 Presidency of Germany*.
- FAO. (2018). *Food and Agriculture Organization of the United Nations. Water Accounting for Water Governance and Sustainable Development*.
- FAO. (2022). *The State of the World's Land and Water Resources for Food and Agriculture – Systems at breaking point*. <https://doi.org/10.4060/cb9910en>
- FAO and UN Water. (2021). Progress on change in water-use efficiency. In *Progress on change in water-use efficiency*. <https://doi.org/10.4060/cb6413en>
- FDRE. (1995). Constitution of the Federal Democratic Republic of Ethiopia. *Federal Negarit Gazeta*, 1(1), 21 August 1995.
- FDRE. (2014). *Ethiopian Democratic Republic of Ethiopia Irrigation Water Users' Associations Proclamation No. 841/2014*. 2. (p. 27). p. 27.

- FDRE. (2021). Federal Demoractic Republic of Ethiopia Ten Years Development Plan: A Pathway to Prosperity. In *ten Years Development Plan: A Pathway to Prosperity* (Vol. 2).
- Fetahi, T. (2016). Greening a Tropical Abijata-Shala Lakes National Park, Ethiopia - A Review. *Journal of Ecosystem & Ecography*, 06(01), 1–8. <https://doi.org/10.4172/2157-7625.1000179>
- Fufa, D. (2017). *Technical Performance Evaluation of Ketar Medium Scale Irrigation Scheme , Southeast of Oromia Regional State , Ethiopia*. 9(9), 13–21.
- Gadissa, T., Nyadawa, M., Mutua, B., & Behulu, F. (2019). *Comparative Assessment of the Effect of Climate Change and Human Activities on Streamflow Regimes in Central Rift Valley Basin , Ethiopia*. 7(1), 23–29. <https://doi.org/10.12691/ajwr-7-1-4>
- Ge, J., Peng, W., Huang, W., Qu, X., & Singh, S. K. (2018). Quantitative assessment of flow regime alteration using a revised range of variability methods. *Water (Switzerland)*, 10(5). <https://doi.org/10.3390/w10050597>
- Gebremicael, T. G., Mohamed, Y. A., Zaag, P. V., & Hagos, E. Y. (2017). Temporal and spatial changes of rainfall and streamflow in the Upper Tekezē-Atbara river basin, Ethiopia. *Hydrology and Earth System Sciences*, 21(4), 2127–2142. <https://doi.org/10.5194/hess-21-2127-2017>
- Geleta, Y., B, S., & A.Engdawork, A. H. (2022). Polycentric irrigation water governance : Irrigation water users associations service delivery in Ketar. *African Journal of Agricultural*

Research, 18(10), 783–791. <https://doi.org/10.5897/AJAR2022.16153>

Genesis T. Yengoh, David Dent, Olsson, Lennart Olsson, Anna E. Tengberg, & C. J. T. (2014).

The use of the Normalized Difference Vegetation Index (NDVI) to assess land degradation at multiple scales : a review of the current status , future trends , and practical considerations The use of the Normalized Difference Vegetation Index (NDVI) to .
Sweden.

Gianfagna, C. C., Johnson, C. E., Chandler, D. G., & Hofmann, C. (2015). Watershed area ratio accurately predicts daily streamflow in nested catchments in the Catskills, New York.

Journal of Hydrology: Regional Studies, 4(January), 583–594.

<https://doi.org/10.1016/j.ejrh.2015.09.002>

Gilvear, D. J., Spray, C. J., & Casas-mulet, R. (2013). River rehabilitation for the delivery of multiple ecosystem services at the river network scale. *Journal of Environmental*

Management, 126, 30–43. <https://doi.org/10.1016/j.jenvman.2013.03.026>

Giordano, M., & Shah, T. (2014). From IWRM back to integrated water resources management.

International Journal of Water Resources Development, 30(3), 364–376.

<https://doi.org/10.1080/07900627.2013.851521>

GIRDC, G. I. R. D. C. (2018). *Assessment of National Water Used and Demand Forcast.*

Gleick, P. H. (2003). Water Use. *Annual Review of Environment and Resources*, 28(1), 275–314.

<https://doi.org/10.1146/annurev.energy.28.040202.122849>

- Grafton, R. Q., Williams, J., Perry, C. J., Molle, F., Ringler, C., Steduto, P., ... Allen, R. G. (2018). The paradox of irrigation efficiency. *Science*, *361*(6404), 748–750.
<https://doi.org/10.1126/science.aat9314>
- Gretchen C Daily. (1997). Light stable isotope evidence for a metamorphogenic origin for bedding-parallel, gold-bearing veins in Cambrian flysch, Meguma Group, Nova Scotia. In *Exploration and Mining Geology* (Vol. 1, pp. 1–10).
- Grigg, N. S. (2011). Water governance: From ideals to effective strategies. *Water International*, *36*(7), 799–811. <https://doi.org/10.1080/02508060.2011.617671>
- Group, N. R. (2008). *Socio-economic assessment of two small-scale irrigation schemes in Adami Tullu Jido Kombolcha Woreda , Central Rift Valley of Ethiopia Socio-economic assessment of two small-scale irrigation schemes in Adami Tullu Jido Kombolcha Woreda , Central Rift Vall.*
- Guan, S., Fukami, K., Matsunaka, H., Okami, M., & Tanaka, R. (2019). *Assessing Correlation of High-Resolution NDVI with Fertilizer Application Level and Yield of Rice and Wheat Crops using Small UAVs.* <https://doi.org/10.3390/rs11020112>
- Guoyong Leng, Maoyi Huang, Qihong Tang, and L. R. L. (2015). *Journal of Advances in Modeling Earth Systems.* 1285–1304. <https://doi.org/10.1002/2015MS000437>.Received
- Gurmu, Z. A., Ritzema, H., Fraiture, C. De, Riksen, M., & Ayana, M. (2021). *Sediment Influx and Its Drivers in Farmers ' Managed Irrigation Schemes in Ethiopia.*

Haddad, L. (2021). *Water is Life - Perspectives on Water in Mesopotamia* (F. S. (Beirut), Ed.).

IV: elbarlament- cultures of democracy GmbH.

Hailesilassie, W. T., & Tegaye, T. A. (2019). *Comparative Assessment of the Water Quality*

Deterioration of Ethiopian Rift Lakes : The Case of Lakes Ziway and Hawassa Comparative

Assessment of the Water Quality Deterioration of Ethiopian Rift Lakes : The Case of Lakes

Ziway and Hawassa. (December). <https://doi.org/10.18280/eesrj.060403>

Haileslassie, A., Agide, Z., Erkossa, T., Hoekstra, D., Schmitter, P., & Langan, S. (2016). *On-*

farm smallholder irrigation performance in Ethiopia : From water use efficiency to equity

and sustainability. (May). <https://doi.org/10.13140/RG.2.2.12801.66408>

Haileslassie, Amare, Ludi, E., Roe, M., & Button, C. (2020). *Water Values: Discourses and*

Perspective. (October), 946–955. https://doi.org/10.1007/978-3-319-95846-0_140

Hailu, R., Tolossa, D., & Alemu, G. (2017). Water institutions in the Awash basin of Ethiopia :

the discrepancies between rhetoric and realities Water institutions in the Awash basin of

Ethiopia : the discrepancies between rhetoric and realities. *Intl. J. River Basin Management,*

0(0), 1–15. <https://doi.org/10.1080/15715124.2017.1387126>

Hamidov, A., Thiel, A., & Zikos, D. (2015). Institutional design in transformation: A

comparative study of local irrigation governance in Uzbekistan. *Environmental Science and*

Policy, *53*, 175–191. <https://doi.org/10.1016/j.envsci.2015.06.012>

Hart, B., & Chan, T. (2011). *Bayesian network models for environmental flow decision-making :*

1 . *Latrobe River Australia BAYESIAN NETWORK MODELS FOR ENVIRONMENTAL FLOW DECISION-MAKING* : (March). <https://doi.org/10.1002/rra.1348>

Hassing, J., Ipsen, N., & Clausen, T. J. (2009). Integrated Water Resources Management (IWRM) in Action. In *The United Nations World Water Assessment Programme*.

Heinrichs, D. H., & Rojas, R. (2022). *Cultural Values in Water Management and Governance : Where Do We Stand ?*

Herco Jansen, Huib Hengsdijk, Dagnachew Legesse, Tenalem Ayenew, Petra Hellegers, P. S. (2007). *Land and water resources assessment in the Ethiopian Central Rift Valley*. Alterra, Wageningen.

Herrfahrtd-Pähle, E. (2010). South african water governance between administrative and hydrological boundaries. *Climate and Development*, 2(2), 111–127.
<https://doi.org/10.3763/cdev.2010.0038>

Herrmann, H., & Bucksch, H. (2014). Irrigation (Water) Requirement. *Dictionary Geotechnical Engineering/Wörterbuch GeoTechnik*, (September 1993), 750–750.
https://doi.org/10.1007/978-3-642-41714-6_91866

Hirji, R., & Davis, R. (2009). Environmental Flows in Water Resources Policies, Plans, and Projects. *Environmental Flows in Water Resources Policies, Plans, and Projects*, (117).
<https://doi.org/10.1596/978-0-8213-7940-0>

Hirpo, L. A. (2016). Current Ecological Scenario of some Rift Valley Lakes of Ethiopia: A

review. *ECronicon- EC Agriculture*, 570–580.

HLPW. (2017). *Bellagio principles on valuing water*. (May), 5–7.

Hoanh, C. T., Suhardiman, D., & Anh, L. T. (2014). Irrigation development in the Vietnamese Mekong Delta: Towards polycentric water governance? *International Journal of Water Governance*, 2(2), 61–82. <https://doi.org/10.7564/14-ijwg59>

Hoekstra, A. Y. (2011). The global dimension of water governance: Why the river basin approach is no longer sufficient and why cooperative action at global level is needed. *Water (Switzerland)*, 3(1), 21–46. <https://doi.org/10.3390/w3010021>

Hordofa, A. T., Leta, O. T., & Alamirew, T. (2022). *Response of Winter Wheat Production to Climate Change in Ziway Lake Basin*. 1–17.

Howell, T. A. (2003). Irrigation efficiency. *Encyclopedia of Water Science*, (January). <https://doi.org/10.1081/E-EWS>

Hughes, F. M. R., & Rood, S. B. (2003). Allocation of River Flows for Restoration of Floodplain Forest Ecosystems: A Review of Approaches and Their Applicability in Europe. *Environmental Management*, 32(1), 12–33. <https://doi.org/10.1007/s00267-003-2834-8>

Huitema, D., Mostert, E., Egas, W., Moellenkamp, S., Pahl-Wostl, C., & Yalcin, R. (2009). Adaptive water governance: Assessing the institutional prescriptions of adaptive (co-)management from a governance perspective and defining a research agenda. *Ecology and Society*, 14(1). <https://doi.org/10.5751/ES-02827-140126>

- Hurni, H. (1998). *Agroecological Belts of Ethiopia*. BERNE.
- Hussain, I., Hussain, Z., Sial, M. H., Akram, W., & Farhan, M. F. (2011). Water Balance , Supply and Demand and Irrigation Efficiency of Indus Basin. *Water*, 49(1), 13–38.
- Irmak, S., Odhiambo, L.O., Kranz, W.L., A., & Eisenhauer, D. E. (2011). Irrigation efficiency and uniformity and crop water use efficiency. University of Nebraska-Lincoln Extension. *Biological Systems Engineering: Papers and Publications*, 451(January).
- Israel, G. D. (2013). *Determining Sample Size 1*. (April 2009), 1–5.
- Jacobson, P. C., Cross, T. K., Dustin, D. L., & Duval, M. (2016). Stream Hydrology An Introduction for Ecologists. In *Fisheries* (Vol. 41).
<https://doi.org/10.1080/03632415.2016.1172482>
- Jager, H. (2014). *Designing Instream Flows to Satisfy Fish and Human Water Needs*. 9496(February). [https://doi.org/10.1061/\(asce\)0733-9496\(1996\)122](https://doi.org/10.1061/(asce)0733-9496(1996)122)
- Jensen, M. E. (2007). Beyond irrigation efficiency. *Irrigation Science*, 25(3), 233–245.
<https://doi.org/10.1007/s00271-007-0060-5>
- JICA. (2002). *The study on Meki Irrigation and Rural Development Project Oromia Region , Ethiopia*. I(March), 270.
- Jiménez, A., Saikia, P., Giné, R., Avello, P., Leten, J., Lymer, B. L., ... Ward, R. (2020). Unpacking water governance: A framework for practitioners. *Water (Switzerland)*, 12(3), 1–21. <https://doi.org/10.3390/w12030827>

- Kaini, S., Harrison, M. T., & Gardner, T. (2022). *The Impacts of Climate Change on the Irrigation Water Demand , Grain Yield , and Biomass Yield of Wheat Crop in Nepal*. 1–17.
- Kammerer, J. C. (1987). Rivers, Streams, and Creeks. <https://doi.org/10.3133/ofr87242>
- Karakoyun, Y., Yumurtaci, Z., & Dönmez, A. H. (2018). Environmental Flow Assessment Methods: A Case Study. *Exergetic, Energetic and Environmental Dimensions*, 1061–1074. <https://doi.org/10.1016/B978-0-12-813734-5.00060-3>
- Karimi, S. S., Yasi, M., & Eslamian, S. (2012). *Use of Hydrological Methods for Assessment of Environmental Flow in a River Author ' s personal copy Use of hydrological methods for assessment of environmental flow in a river reach*. (July). <https://doi.org/10.1007/s13762-012-0062-6>
- Kebede, E., Zinabu, G., & Ahlgreni, I. (1994). *The Ethiopian Rift Valley lakes : chemical characteristics of a salinity- alkalinity series The Ethiopian Rift Valley lakes : chemical characteristics of a salinity-alkalinity series*. (February 2014). <https://doi.org/10.1007/BF00006801>
- Kedir, Y. (2015). *Estimation of Conveyance Losses of Wonji-Shoa Sugarcane Irrigation Scheme , Ethiopia*. 5(17), 38–45.
- Kemp, A., & Hafi, A. (2001). Benefits of increased irrigation efficiency in the Murrumbidgee Irrigation Area. *45th Conference of the Australian Bureau of Agricultural and Resource Economics*, 1–21.

- Kendy, E., Apse, C., & Blann, K. (2012). A practical guide to environmental flows for policy and planning with nine case studies in the United States. *Nat Conservancy*, 74.
- Kim, S. K. (2019). *Comparison of environmental flows from a habitat suitability perspective : A case study in the Naeseong - cheon Stream in Korea*. (May).
<https://doi.org/10.1002/eco.2119>
- King, Jackie, Brown, C., & Sabet, H. (2003). A scenario-based holistic approach to environmental flow assessment for rivers. *River Research and Applications*, 19(5–6), 619–639. <https://doi.org/10.1002/rra.709>
- King, JM, Tharme, R., & de Villiers, M. (2008). Environmental Flow Assessments for Rivers: Manual for the Building Block Methodology (Updated Edition), WRC Report No TT 354/08. In *Water Research Commission* (Vol. 17). <https://doi.org/10.1049/el:19810113>
- Knieper, C., & Pahl-Wostl, C. (2016). A Comparative Analysis of Water Governance, Water Management, and Environmental Performance in River Basins. *Water Resources Management*, 30(7), 2161–2177. <https://doi.org/10.1007/s11269-016-1276-z>
- Lankford, B. (2006). *LOCALISING IRRIGATION EFFICIENCY* y. 362, 345–362.
<https://doi.org/10.1002/ird>
- Legesse, D., & Ayenew, T. (2006). Effect of improper water and land resource utilization on the central Main Ethiopian Rift lakes. *Quaternary International*, 148(1), 8–18.
<https://doi.org/10.1016/j.quaint.2005.11.003>

Leimgruber, W. (2019). Setting the Frame. *Between Global and Local*, 15–35.

<https://doi.org/10.4324/9781351162722-3>

Lemi, T. (2019). *Threats and Opportunities of Central Ethiopia Rift Valley Lakes*. 22(2).

<https://doi.org/10.19080/IJESNR.2019.22.556082>

Lenny Wall, Denis Larocque, P.-M. L. (2006). *The early explanatory power of a satellite-based measure in crop yield modeling*. (April 2008), 27.

<https://doi.org/10.1080/01431160701395252>

Li, Q., Peng, Y., Wang, G., Wang, H., Xue, B., & Hu, X. (2019). A combined method for estimating continuous runoff by parameter transfer and drainage area ratio method in ungauged catchments. *Water (Switzerland)*, 11(5). <https://doi.org/10.3390/w11051104>

Likert, R. (1932). *A Techniques for the Measurment of Atitudes*.

Linstead, C. (2018). The Contribution of Improvements in Irrigation Efficiency to Environmental Flows. *Frontiers in Environmental Science*, 6(June), 1–6.

<https://doi.org/10.3389/fenvs.2018.00048>

Livelihoods, R. P. (2016). *Policies and Proclamations Relevant to Pastoral Areas Land Management for Ethiopia , Kenya and Uganda*. (December).

Loë, R. C. De, & Bjornlund, H. (2008). *Irrigation and water security : the role of economic instruments and governance*. 112, 35–42. <https://doi.org/10.2495/SI080041>

Lozano Sandoval, G., Monsalve Durango, E. A., García Reinoso, P. L., Rodríguez Mejía, C. A.,

- Gómez Ospina, J. P., & Triviño Loaiza, H. J. (2015). Environmental Flow Estimation Using Hydrological and Hydraulic Methods for the Quindío River Basin: WEAP as a Support Tool. *Inge CUC, 11*(2), 34–48. <https://doi.org/10.17981/ingecuc.11.2.2015.04>
- Maas, A. (2011). Water , Governance and Sustainability : A Case Study of Water Allocation in
by.
- Maliehe, M., & Mulungu, D. M. M. (2017). Assessment of water availability for competing uses using SWAT and WEAP in South Phuthiatsana catchment, Lesotho. *Physics and Chemistry of the Earth, 100*, 305–316. <https://doi.org/10.1016/j.pce.2017.02.014>
- Malzbender, D., Goldin, J., Turton, A., & Earle, A. (2005). Traditional Water Governance and South Africa ’ s “ National Water Act ” – Tension or Cooperation ? Case examples : Tshikombani village and rural villages in Tzaneen Municipality. *Water*, (January), 26–28.
- Marinus, G., B. (2011). *Performance assessment for irrigation and drainage*. 14.
- Marshall, G. R. (2015). *Polycentricity and adaptive governance*. (JANUARY).
- Martin, D. M., Labadie, J. W., & Poff, N. L. (2015). Incorporating social preferences into the ecological limits of hydrologic alteration (ELOHA): A case study in the Yampa-White River basin, Colorado. *Freshwater Biology, 60*(9), 1890–1900.
<https://doi.org/10.1111/fwb.12619>
- Mathews, R., & Richter, B. D. (2007). Application of the indicators of hydrologic alteration software in environmental flow setting. *Journal of the American Water Resources*

Association, 43(6), 1400–1413. <https://doi.org/10.1111/j.1752-1688.2007.00099.x>

Mazvimavi, D., Madamombe, E., & Makurira, H. (2007). Assessment of environmental flow requirements for river basin planning in Zimbabwe. *Physics and Chemistry of the Earth*, 32(15–18), 995–1006. <https://doi.org/10.1016/j.pce.2007.07.001>

McClain, M. E., Kashaigili, J. J., & Ndomba, P. (2013). Environmental flow assessment as a tool for achieving environmental objectives of African water policy, with examples from East Africa. *International Journal of Water Resources Development*, 29(4), 650–665. <https://doi.org/10.1080/07900627.2013.781913>

McGinnis, M. D. (2013). Costs and Challenges of Polycentric Governance: An Equilibrium Concept and Examples from U.S. Health Care. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.2206980>

McGinnis, M. D., & Walker, J. M. (2010). Foundations of the Ostrom workshop: Institutional analysis, polycentricity, and self-governance of the commons. *Public Choice*, 143(3), 293–301. <https://doi.org/10.1007/s11127-010-9626-5>

McMahon, T. A., & Finlayson, B. L. (2003). Droughts and anti-droughts: The low flow hydrology of Australian rivers. *Freshwater Biology*, 48(7), 1147–1160. <https://doi.org/10.1046/j.1365-2427.2003.01098.x>

Megan Dyson, G. B. and J. S. (2008). *Flow The essentials of environmental flows* (2nd Editio; G. B. and J. S. Megan Dyson, Ed.). <https://doi.org/10.1016/B978-0-444-62644-8.00008-X>

- Mirbahar, A. A., Markhand, G. S., Mahar, A. R., & Abro, S. A. (2009). *Effect of water stress on yield and yield components of wheat (Triticum aestivum L .) varieties*. (June).
- Mkhabela, M. S., Mkhabela, M. S., & Mashinini, N. N. (2005). *Early maize yield forecasting in the four agro-ecological regions of Swaziland using NDVI data derived from NOAA ' s- AVHRR*. 129, 1–9. <https://doi.org/10.1016/j.agrformet.2004.12.006>
- MOA. (2022). , *Ethiopian Minsitry of Agriculture Ten year strategic Plan*.
- Molden, D.J.Bos, M. G., & Burton, M. A. (2005). *Irrigation And Drainage Performance Assesemnt Practical Guidelines*.
- Molden, D. (2013). Water for food water for life: A Comprehensive assessment of water management in agriculture. In *Water for Food Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. <https://doi.org/10.4324/9781849773799>
- Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., & Kijne, J. (2010). *Improving agricultural water productivity : Between optimism and caution*. 97, 528–535. <https://doi.org/10.1016/j.agwat.2009.03.023>
- Molle, F., Wester, P., & Hirsch, P. (2010). River basin closure: Processes, implications and responses. *Agricultural Water Management*, 97(4), 569–577. <https://doi.org/10.1016/j.agwat.2009.01.004>
- Moore, M. (2004). Perceptions and Interpretations of Environmental Flows and Implications for Future Water *Unpublished Master Thesis, Dept of Water and ...*, (Tharmer), 1–10.

- Moss, T., & Newig, J. (2010). *Multilevel Water Governance and Problems of Scale : Setting the Stage for a Broader Debate*. 1–6. <https://doi.org/10.1007/s00267-010-9531-1>
- MoWIE. (2021). , *Ethiopian Ministry of Water Irrigation and Energy Ten year strategic Plan (2013-20)*.
- MOWIE. (2018). *ASSESSMENT OF NATIONAL WATER USED AND DEMAND FORECAST PART I: WATER RESOURCES POTENTIAL ASSESSMENT I-A: Surface Water Resource Potential Generation Integrated Rural Development Consultant (GIRDC) G Asse*. Addis Ababa Ethiopia.
- MoWR. (1999). *Ethiopian Minstry of Water Resource, Water Resources Management Policy* (p. 37). p. 37.
- MoWR. (2009). *Ethiopian Minstry of Water Resource, Rift Valley Lakes Basin Integrated Resources Development Master Plan*. Addis Ababa.
- MOWR. (1999). , *Ethiopian Ministry of Water Resource Ethiopian Water Resources Management Policy*.
- Muchara, B., Ortmann, G., Wale, E., & Mudhara, M. (2014). *Collective action and participation in irrigation water management : A case study of Mooi River Irrigation Scheme in KwaZulu-Natal Province , South Africa*. 40(4), 699–708.
- Musie, M., Momblanch, A., & Sen, S. (2021). Exploring future global change-induced water imbalances in the Central Rift Valley Basin, Ethiopia. *Climatic Change*, 164(3–4).

<https://doi.org/10.1007/s10584-021-03035-x>

Mutambara, S., Darkoh, M. B. K., & Atlhopheng, J. R. (2016). A comparative review of water management sustainability challenges in smallholder irrigation schemes in Africa and Asia. *Agricultural Water Management*, *171*, 63–72. <https://doi.org/10.1016/j.agwat.2016.03.010>

Naiman, R. J., Bunn, S. E., Nilsson, C., Petts, G. E., Pinay, G., & Thompson, L. C. (2002). Legitimizing fluvial ecosystems as users of water: An overview. *Environmental Management*, *30*(4), 455–467. <https://doi.org/10.1007/s00267-002-2734-3>

Naser, M. A., Khosla, R., & Longchamps, L. (2020). *Using NDVI to Differentiate Wheat Genotypes Productivity Under Dryland and Irrigated Conditions*.

Negash, F. (2011). Managing water for inclusive and sustainable growth in Ethiopia: key challenges and priorities. *European Report on Development*, *38*.
<https://doi.org/10.1093/intimm/dxp065>

NewForesight, University Nyenrode Business, Wageningen University and Research, & Government of the Netherlands. (2020). *Valuing water: A conceptual framework for making better decisions impacting water*.

Nilsson, C., Reidy, C. A., Dynesius, M., & Revenga, C. (2005). Fragmentation and flow regulation of the world's large river systems. *Science*, *308*(5720), 405–408.
<https://doi.org/10.1126/science.1107887>

Olagunju, A., Thondhlana, G., Chilima, J. S., Sène-Harper, A., Compaoré, W. R. N., &

Ohiozebau, E. (2019). Water governance research in Africa: progress, challenges and an agenda for research and action. *Water International*, 44(4), 382–407.

<https://doi.org/10.1080/02508060.2019.1594576>

ONRS, O. N. R. S. (2007). *Oromia Rural Land Use and Administration Proclamation No. 130/2007*. (130).

ORNG, O. R. N. G. (2017). *A Proclamation to Determine Irrigation Water Users Associations of Oromia Regional State No: 204/2017* (p. 31). p. 31.

ORSON W. ISRAELSEN. (1932). *Irrigation Principles and Practices* (3rd ed.).

<https://doi.org/10.1038/132047a0>

Ostrom, E. (1990). *Governing the Commons: The Evolution of Institutions for Collective Action*.

In *Cambridge University Press*. Cambridge University.

Ostrom, E. (2014). Beyond markets and states: Polycentric governance of complex economic systems. *Nobel Lectures: Economic Sciences: 2006 - 2010*, 100(June), 171–176.

https://doi.org/10.1142/9789814635585_0004

OWWDSE, O. W. W. D. and S. V. (2019). *Oromia Irrigation Potential Assesment*.

Özerol, G., Vinke-De Kruijf, J., Brisbois, M. C., Flores, C. C., Deekshit, P., Girard, C., ...

Schröter, B. (2018). Comparative studies of water governance: A systematic review.

Ecology and Society, 23(4). <https://doi.org/10.5751/ES-10548-230443>

Pahl-Wostl, C. (2015). *Water Governance-Concepts, Methods, and Practice Series editors* (J. G.

Claudia Pahl_Wostl, Ed.). <https://doi.org/10.1007/978-3-319-21855-7>

Pahl-Wostl, C., Arthington, A., Bogardi, J., Bunn, S. E., Hoff, H., Lebel, L., ... Tsegai, D.

(2013). Environmental flows and water governance: Managing sustainable water uses.

Current Opinion in Environmental Sustainability, 5(3–4), 341–351.

<https://doi.org/10.1016/j.cosust.2013.06.009>

Pahl-Wostl, C., Holtz, G., Kastens, B., & Knieper, C. (2010). Analyzing complex water governance regimes: The Management and Transition Framework. *Environmental Science and Policy*, 13(7), 571–581. <https://doi.org/10.1016/j.envsci.2010.08.006>

Pahl-Wostl, C., Lebel, L., Knieper, C., & Nikitina, E. (2012). From applying panaceas to mastering complexity: Toward adaptive water governance in river basins. *Environmental Science and Policy*, 23, 24–34. <https://doi.org/10.1016/j.envsci.2012.07.014>

Palmer, M. A., Lettenmaier, D. P., Poff, N. L., Postel, S. L., Richter, B., & Warner, R. (2009). Climate change and river ecosystems: Protection and adaptation options. *Environmental Management*, 44(6), 1053–1068. <https://doi.org/10.1007/s00267-009-9329-1>

Pang, A., Sun, T., & Yang, Z. (2013). Economic compensation standard for irrigation processes to safeguard environmental flows in the Yellow River Estuary, China. *Journal of Hydrology*, 482, 129–138. <https://doi.org/10.1016/j.jhydrol.2012.12.050>

Park, A. L. N., & Estifanos, T. K. (2008). Integrated Assessment of ecosystem services and stakeholder analysis of Integrated Assessment of ecosystem services and stakeholders

- analysis of Abijata-Shalla Lakes National Park , Ethiopia. *Environmental Sciences*, (April).
- Pascual-ferrer, J., & Candela, L. (2015). *Water Balance on the Central Rift Valley Water Balance on the Central Rift Valley Global Dimension in Engineering Education*.
- Pastor, A. V., Ludwig, F., Biemans, H., Hoff, H., & Kabat, P. (2014). Accounting for environmental flow requirements in global water assessments. *Hydrology and Earth System Sciences*, 18(12), 5041–5059. <https://doi.org/10.5194/hess-18-5041-2014>
- Paudyal, K., Baral, H., & Keenan, R. J. (2018). Assessing social values of ecosystem services in the Phewa Lake Watershed, Nepal. *Forest Policy and Economics*, 90(January), 67–81. <https://doi.org/10.1016/j.forpol.2018.01.011>
- Peck, M., & Khirfan, L. (2021). Improving the validity and credibility of the sociocultural valuation of ecosystem services in Amman , Jordan. *Ecological Economics*, 189, 107111. <https://doi.org/10.1016/j.ecolecon.2021.107111>
- PETTS, G. E. (1996). Water Allocation To Protect River Ecosystems. *Regulated Rivers: Research & Management*, 12(45), 353–365. [https://doi.org/10.1002/\(sici\)1099-1646\(199607\)12:4/5<353::aid-rrr425>3.3.co;2-y](https://doi.org/10.1002/(sici)1099-1646(199607)12:4/5<353::aid-rrr425>3.3.co;2-y)
- Piniewski, M., Laizé, C. L. R., Acreman, M. C., Okruszko, T., & Schneider, C. (2014). Effect of Climate Change on Environmental Flow Indicators in the Narew Basin, Poland. *Journal of Environmental Quality*, 43(1), 155–167. <https://doi.org/10.2134/jeq2011.0386>
- Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegard, K. L., Richter, B. D., ...

- Stromberg, J. C. (2013). *The Natural Flow Regime A paradigm for river conservation and restoration*. 47(11), 769–784.
- Poff, N. L. R., & Matthews, J. H. (2013). Environmental flows in the Anthropocene: Past progress and future prospects. *Current Opinion in Environmental Sustainability*, 5(6), 667–675. <https://doi.org/10.1016/j.cosust.2013.11.006>
- Poff, N. L. R., Tharme, R. E., & Arthington, A. H. (2017a). Evolution of Environmental Flows Assessment Science, Principles, and Methodologies. In *Water for the Environment: From Policy and Science to Implementation and Management*. <https://doi.org/10.1016/B978-0-12-803907-6.00011-5>
- Poff, N. L. R., Tharme, R. E., & Arthington, A. H. (2017b). Evolution of Environmental Flows Assessment Science, Principles, and Methodologies. In *Water for the Environment: From Policy and Science to Implementation and Management*. <https://doi.org/10.1016/B978-0-12-803907-6.00011-5>
- Poff, N. L., Richter, B. D., Arthington, A. H., Bunn, S. E., Naiman, R. J., Kendy, E., ... Warner, A. (2010). The ecological limits of hydrologic alteration (ELOHA): A new framework for developing regional environmental flow standards. *Freshwater Biology*, 55(1), 147–170. <https://doi.org/10.1111/j.1365-2427.2009.02204.x>
- Poudel, U., Stephen, H., & Ahmad, S. (2021). *Evaluating Irrigation Performance and Water Productivity Using EEFlux ET and NDVI*.

- Rapport, D. J., Costanza, R., & McMichael, A. J. (1998). *Assessing ecosystem health*. 10(Box 3), 397–402.
- Reaugh-Flower, K. (2011). Abijata-Shalla Lakes National Park: Assessment of Factors Driving Environmental Change for Management Decision-Making. *Sustainable Development of the Protected Area System of Ethiopia Program*, (January).
- Reitberger, B., & McCartney, M. (2011). Nile River Basin. *Nile River Basin*.
<https://doi.org/10.1007/978-94-007-0689-7>
- Ricart, S., Rico, A., Kirk, N., Bülow, F., Ribas-palom, A., Ricart, S., ... Ribas-palom, A. (2018). How to improve water governance in multifunctional irrigation systems ? Balancing stakeholder engagement in hydrosocial territories. *International Journal of Water Resources Development*, 0627, 1–34. <https://doi.org/10.1080/07900627.2018.1447911>
- Richards, N. (2019). *Water Users Associations in Tanzania : Local Governance for Whom ?*
- Roberto Arranz, A., & McCartney, M. (2007). Application of the Water Evaluation And Planning (WEAP) Model to Assess Future Water Demands and Resources in the Olifants Catchment, South Africa. In *International Water Management Institute*.
- Rogers, B. P., & Hall, A. W. (2003). *Effective Water Governance*. Stockholm: Global Water Partnership.
- Rost, S. (2017). *Water management in Mesopotamia from the sixth till the first millennium B . C*. 4(October), 1–23. <https://doi.org/10.1002/wat2.1230>

- Scholten, W. (2007). *Agricultural development and water use in the Central Rift Valley of Ethiopia : A rapid appraisal Agricultural development and water use in the Central Rift Valley of Ethiopia : A rapid appraisal.*
- Scott, C. A., Vicuña, S., Blanco-Gutiérrez, I., Meza, F., & Varela-Ortega, C. (2014). Irrigation efficiency and water-policy implications for river basin resilience. *Hydrology and Earth System Sciences, 18*(4), 1339–1348. <https://doi.org/10.5194/hess-18-1339-2014>
- SDG-UNDP, U. N. development P. (2016). Agenda for Sustainable developemnt 2030. In *UNDP*. <https://doi.org/10.1201/b20466-7>
- Sehring, J. (2009). Path dependencies and institutional bricolage in post-Soviet water governance. *Water Alternatives, 2*(1), 61–81.
- Setegn, S. G., Chowdary, V. M., Mal, B. C., Yohannes, F., & Kono, Y. (2011). Water Balance Study and Irrigation Strategies for Sustainable Management of a Tropical Ethiopian Lake: A Case Study of Lake Alemaya. *Water Resources Management, 25*(9), 2081–2107. <https://doi.org/10.1007/s11269-011-9797-y>
- Seyoum, W. M., Milewski, A. M., & Durham, M. C. (2015). Understanding the relative impacts of natural processes and human activities on the hydrology of the Central Rift Valley lakes, East Africa. *Hydrological Processes, 29*(19), 4312–4324. <https://doi.org/10.1002/hyp.10490>
- Shiferraw, A., & McCartney, M. (2008). *Investigating Environmental Flow Requirements At the Source of the Blue Nile River. Paper presented at the International Nile Basin Development*

Forum, Khartoum, Sudan, 3-5 November 2008. (February), 14.

Shumet, A. G., & Mengistu, K. T. (2016). Assessing the Impact of Existing and Future Water Demand on Economic and Environmental Aspects (Case Study from Rift Valley Lake Basin: Meki-Ziway Sub Basin), Ethiopia. *International Journal of Waste Resources*, 6(2).
<https://doi.org/10.4172/2252-5211.1000223>

Sieber, J., & Purkey, D. (2015). WEAP User Guide. *Environment*, p. 400.

Siebert, S., Kummu, M., Porkka, M., Döll, P., Ramankutty, N., & Scanlon, B. R. (2015). Historical Irrigation Dataset (HID). *Hydrology and Earth System Sciences*, 19, 1521–1545.
<https://doi.org/10.13019/M20599>

Sileshi, Z., Tegegne, A., & Tsadik, G. T. (2003). Water resources for livestock in Ethiopia: Implications for research and development. *Integrated Water and Land Management Research and Capacity Building Priorities for Ethiopia*, 66–79.

Sime, C. H., & Abebe, W. T. (2022). *Sediment Yield Modeling and Mapping of the Spatial Distribution of Soil Erosion-Prone Areas. 2022.*

Smakhtin, V. (2008). Basin closure and environmental flow requirements. *International Journal of Water Resources Development*, 24(2), 227–233.
<https://doi.org/10.1080/07900620701723729>

Smakhtin, V. U., Shilpakar, R. L., & Hughes, D. A. (2006). Hydrology-based assessment of environmental flows: An example from Nepal. *Hydrological Sciences Journal*, 51(2), 207–

222. <https://doi.org/10.1623/hysj.51.2.207>

Smith, H. F., & Sullivan, C. A. (2014). Ecosystem services within agricultural landscapes- Farmers' perceptions. *Ecological Economics*, 98, 72–80.

<https://doi.org/10.1016/j.ecolecon.2013.12.008>

Sood, A., Smakhtin, V., Eriyagama, N., Villholth, K., Liyanage, N., Wada, Y., ... Dickens, C. (2017). *Global Environmental Flow Information for the Sustainable Development Goals*.

<https://doi.org/10.5337/2017.201>

Spliethoff, P., Wudneh, T., Tariku, E., & Senbeta, G. (2009). *Past, Current and Potential Production of Fish in lake Ziway Central Rift Valley in Ethiopia*. (Document refelet on lake Ziway), 1–31.

Stein, C., Pahl-Wostl, C., & Barron, J. (2018). Towards a relational understanding of the water-energy-food nexus: an analysis of embeddedness and governance in the Upper Blue Nile region of Ethiopia. *Environmental Science and Policy*, 90(January), 173–182.

<https://doi.org/10.1016/j.envsci.2018.01.018>

Suen, J., & Eheart, J. W. (2006). *Reservoir management to balance ecosystem and human needs : Incorporating the paradigm of the ecological flow regime*. 42(March), 1–9.

<https://doi.org/10.1029/2005WR004314>

Sultana, S. R., Ali, A., Ahmad, A., Mubeen, M., Ahmad, S., Ercisli, S., & Jaafar, H. Z. E. (2014). *Normalized Difference Vegetation Index as a Tool for Wheat Yield Estimation : A Case*

Study from Faisalabad , Pakistan. 2014.

Svendsen, L. E. S. and M. (1992). *A Framework for Assessing Irrigation Performance* (No. Working Paper on Irrigation Performance 1). Washington DC: International Food Policy Research Institute.

Svendsen, M. (2009). Irrigation and river basin management: options for governance and institutions. In M. Svendsen (Ed.), *Irrigation and river basin management: options for governance and institutions*. <https://doi.org/10.1079/9780851996721.0000>

Teferra, F., & Beyene, F. (2014). Indigenous claims and conflicts in managing the Abijata-Shalla Lakes National Park, Ethiopia. *International Journal of Biodiversity Science, Ecosystem Services and Management*, 10(3), 216–227. <https://doi.org/10.1080/21513732.2014.942372>

Tegos, M., Nalbantis, I., & Tegos, A. (2017). Environmental flow assessment through integrated approaches. *European Water*, 60, 167–173.

Tennant, D. L. (1976). Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources. *Fisheries*, 1(4), 6–10. [https://doi.org/10.1577/1548-8446\(1976\)001<0006:ifrffw>2.0.co;2](https://doi.org/10.1577/1548-8446(1976)001<0006:ifrffw>2.0.co;2)

Tesfaye, T. W., & Gosain, C. T. D. A. K. (2020). Modeling the impact of climate change on the environmental flow indicators over Omo - Gibe basin , Ethiopia. *Modeling Earth Systems and Environment*, (0123456789). <https://doi.org/10.1007/s40808-020-00813-x>

Teshome, Y., Biazin, B., Wolka, K., & Burka, A. (2018). Evaluating performance of traditional

surface irrigation techniques in Cheleleka watershed in Central Rift Valley , Ethiopia.

Applied Water Science, 8(8), 1–14. <https://doi.org/10.1007/s13201-018-0862-z>

Tharme, R. E. (2003). A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications*, 19(5–6), 397–441. <https://doi.org/10.1002/rra.736>

The Brisbane Declaration. (2007). *The Brisbane Declaration - Environmental flow*.

The Brisbane Declaration. (2018). Flows, Brisbane Declaration and Global Adjenda on Environmental flows. *Brisbane*, Vol. 66, pp. 37–39.

UN, U. N. (1977). *Report of the United Nations Water Conference*. (March), 14–25.

UNDESA, U. N. D. of E. and S. A. (2003). *Governing Water wisely for sustainable Developemnt*. Geneva.

UNDP. (2013). What is water Governance. Retrieved from <http://www.watergovernance.org/governance/what-is-water-governance/>

UNDP, U. N. D. P. (2004). *Water Governance for Poverty Reduction*.

UNESCO, UN-WATER, U. N. W. W. D. R. (2020). *WATER AND CLIMATE CHANGE*. Paris.

UNESCO. (2021). *The United Nations World Water Development Report: Valuing Water*. Perugia.

Vala, K. V, Saiyed, F., & Joshi, D. C. (2014). *Evaporative Cooled Storage Structures : An Indian*

Scenario. *Trends in Post Harvest Technology*, 2(3), 22–32.

Van Halsema, G. E., Keddi Lencha, B., Assefa, M., Hengsdijk, H., & Wesseler, J. (2011).

Performance assessment of smallholder irrigation in the central rift valley of Ethiopia.

Irrigation and Drainage, 60(5), 622–634. <https://doi.org/10.1002/ird.613>

Veettil, P. C., Speelman, S., Frija, A., Buysse, J., & Van Huylenbroeck, G. (2011).

Complementarity between water pricing, water rights and local water governance: A

Bayesian analysis of choice behaviour of farmers in the Krishna river basin, India.

Ecological Economics, 70(10), 1756–1766. <https://doi.org/10.1016/j.ecolecon.2011.04.018>

Wang, L., Fang, L., & Hipel, K. W. (2008). Basin-wide cooperative water resources allocation.

European Journal of Operational Research, 190(3), 798–817.

<https://doi.org/10.1016/j.ejor.2007.06.045>

Wang, X., Otto, I. M., & Yu, L. (2013). How physical and social factors affect village-level

irrigation: An institutional analysis of water governance in northern China. *Agricultural*

Water Management, 119, 10–18. <https://doi.org/10.1016/j.agwat.2012.12.007>

Wang, Z., Zerihun, D., & Feyen, J. (1996). *General irrigation efficiency for field water*

management. 3774(32).

WB, T. W. B. G. (2016). Climate Change, Water, and the Economy. In *Water Global Practice*.

WB, W. B. (2019). World Bank Support for Irrigation Service Delivery :Responding to

Emergent Challenges and Opportunities. Independent Evaluation Group. In *World Bank*

Support for Irrigation Service Delivery. <https://doi.org/10.1596/33201>

World Bank. (2006). *Reengaging in Agricultural Water*. Washington DC: The World Bank.

Worqlul, A. W., Collick, A. S., Rossiter, D. G., Langan, S., & Steenhuis, T. S. (2015). Catena Assessment of surface water irrigation potential in the Ethiopian highlands : The Lake Tana Basin. *Catena*, 129, 76–85. <https://doi.org/10.1016/j.catena.2015.02.020>

Yameen, Q., Arshad, M. F., & Saqlain, M. (2019). *Normalized Difference Vegetation Index as a Tool for Wheat Crop Coefficient and Evapotranspiration Estimation : A case study of Nankana Sahib District Pakistan*. 3(10), 32–39.
<https://doi.org/10.31080/ASAG.2019.03.0642>

Yohannes H, Mohammed A, & Elias E. (2017). *Land Use/Land Cover Dynamics and Its Impact on Biodiversity Resources in the Abijata Shalla National Park, Central Rift Valley Lakes Region, Ethiopia*. 13(5), 1–14.

Yu, H. H., Edmunds, M., Lora-wainwright, A., & Thomas, D. (2016). Environmental Science & Policy Governance of the irrigation commons under integrated water resources management – A comparative study in contemporary rural China. *Environmental Science and Policy*, 55, 65–74. <https://doi.org/10.1016/j.envsci.2015.08.001>

Yu, W., Uhlenbrook, S., von Gnechten, R., & van der Bliet, J. (2021). Can water productivity improvements save us from Global Water Scarcity? White paper 1. *FAO (Food and Agriculture Organization)*.

- Zarghaami, M. (2006). Integrated water resources management in Polrud irrigation system. *Water Resources Management*, 20(2), 215–225. <https://doi.org/10.1007/s11269-006-8048-0>
- Zeiringer, B., Seliger, C., Greimel, F., & Schmutz, S. (2018). River Hydrology, Flow Alteration, and Environmental Flow. *Riverine Ecosystem Management*, 67–89. https://doi.org/10.1007/978-3-319-73250-3_4
- Zwart, S. J., Bastiaanssen, W. G. M., Fraiture, C. De, & Molden, D. J. (2010). A global benchmark map of water productivity for rainfed and irrigated wheat. *Agricultural Water Management*, 97(10), 1617–1627. <https://doi.org/10.1016/j.agwat.2010.05.018>

9 ANNEXES-

9.1 Annexes 1 Crop water Requirement of the study area for selected Crops

Cropwat Results – Onion

Mo	Dec	St	K	ETc	ETc	Eff	Irr.
			co	mm/	mm/d	mm/	mm/
No	3	Ini	0.	1.91	3.8	0	3.8
De	1	Ini	0.	1.84	18.4	0	18.4
De	2	D	0.	1.87	18.7	0	18.7
De	3	D	0.	2.31	25.4	0.1	25.3
Jan	1	D	0.	2.78	27.8	0	27.8
Jan	2	M	0.	3.12	31.2	0	31.2
Jan	3	M	0.	3.19	35.1	1.1	34
Fe	1	M	0.	3.26	32.6	4.8	27.8
Fe	2	M	0.	3.32	33.2	7	26.2
Fe	3	La	0.	3.35	26.8	6.6	20.2
Ma	1	La	0.	3.28	32.8	3.8	29
Ma	2	La	0.	3.17	31.7	2.7	29.1
Ma	3	La	0.	3.03	24.2	7.7	13.6
					341.9	33.9	305.
					effici	0.5	152.
					T.W.		457.

Cropwat Results – Tomato

Mo	Dec	Sta	K	ETc	ETc	Eff	Irr.
			co	mm/d	mm/	mm/	mm/
No	3	Ini	0.	1.53	3.1	0	3.1
Dec	1	Ini	0.	1.47	14.7	0	14.7
Dec	2	Ini	0.	1.42	14.2	0	14.2
Dec	3	De	0.	1.51	16.6	0.1	16.5
Jan	1	De	0.	2.15	21.5	0	21.4
Jan	2	De	0.	2.98	29.8	0	29.8
Jan	3	De	0.	3.86	42.5	1.1	41.4
Feb	1	Mi	1.	4.42	44.2	4.8	39.4
Feb	2	Mi	1.	4.51	45.1	7	38.1
Feb	3	Mi	1.	4.55	36.4	6.6	29.9
Ma	1	Mi	1.	4.6	46	3.8	42.2
Ma	2	Mi	1.	4.65	46.5	2.7	43.8
Ma	3	La	1.	4.34	47.8	10.6	37.2
Apr	1	La	0.	3.46	34.6	23.6	11
Apr	2	La	0.	2.72	19	22.8	0
				461.9	83.1	382.	
				efficie	0.5	191.	
				T.W.		573.	

Cropwat Results – Potato

Mo	Dec	St	K	ETc	ETc	Eff	Irr.
			co	mm/	mm/d	mm/	mm/
No	3	Ini	0.	1.91	3.8	0	3.8
De	1	Ini	0.	1.84	18.4	0	18.4
De	2	D	0.	1.79	17.9	0	17.9
De	3	D	0.	2.37	26.1	0.1	26
Jan	1	D	0.	3.17	31.7	0	31.7
Jan	2	D	1.	3.98	39.8	0	39.8
Jan	3	M	1.	4.53	49.9	1.1	48.7
Fe	1	M	1.	4.63	46.3	4.8	41.5
Fe	2	M	1.	4.73	47.3	7	40.2
Fe	3	M	1.	4.77	38.2	6.6	31.6
Ma	1	M	1.	4.82	48.2	3.8	44.4
Ma	2	La	1.	4.86	48.6	2.7	45.9
Ma	3	La	1.	4.5	49.5	10.6	38.9
Ap	1	La	0.	4.09	28.6	16.5	5.1
					494.4	53.2	434.
					effici	0.5	217.
					T.W.		651.

Cropwat Results – Wheat

Mo	Dec	Sta	K	ETc	ETc	Eff	Irr.
			co	mm/	mm/d	mm/	mm/
No	3	Ini	0.	1.91	3.8	0	3.8
Dec	1	Ini	0.	1.84	18.4	0	18.4
Dec	2	De	0.	2	20	0	20
Dec	3	De	0.	2.93	32.2	0.1	32.2
Jan	1	De	1.	3.94	39.4	0	39.4
Jan	2	Mi	1.	4.64	46.4	0	46.4
Jan	3	Mi	1.	4.75	52.2	1.1	51.1
Feb	1	Mi	1.	4.84	48.4	4.8	43.6
Feb	2	Mi	1.	4.94	49.4	7	42.4
Feb	3	Mi	1.	4.99	39.9	6.6	33.4
Ma	1	La	1.	4.75	47.5	3.8	43.7
Ma	2	La	0.	3.8	38	2.7	35.3
Ma	3	La	0.	2.85	22.8	7.7	12.2
					458.6	33.9	421.
					efficie	0.5	210.
					T.W.		632.

9.2 Annexes 2 Ketar and Arata Schemes Layout

