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Water Demand Investigation and Irrigation Requirement Analysis for Major Crops: A Case Study of Somodo Sub-watershed

Etefa Tilahun Ashine

Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center, Jimma, Ethiopia

Email address:
etefatilahun@gmail.com

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Abstract: The social and economic transformations associated with growing urbanization, as well as the widespread implementation of irrigation to address climate change limits, have radically altered the pattern of water usage. The determination of water demands is the beginning point for water resource planning and management. As a result, this study was initiated with the objective of determining the various water demands in the Somodo watershed. The data employed in this investigation was secondary data. The data was population and livestock statistics gathered by the central statistical agency. Domestic water demand was calculated by multiplying the projected population number by the appropriate per capita demand, and from this, 10% of domestic water demand was adopted for industrial water demand. Water demand for livestock was estimated by multiplying the livestock population by the tropical livestock unit and the unit water requirement for each livestock. From the available water resources, 10% of the total available flow was left for the satisfaction of the environmental flow requirements. The total water demand for irrigation was estimated by multiplying the total area under irrigation with the irrigation water requirement for each cropping pattern. The total water demand for domestic and industrial water was 0.242 million cubic meters per year, according to the results. The demand for livestock water was 0.015 million cubic meters of water. The yearly environmental flow requirement was 5.6 million cubic meters (MCM), or 10% of total annual water flow. Irrigation requires a total of 0.107 million cubic meters of water.

Keywords: Irrigation, Million Cubic Meter, Somodo, Water Demand

1. Introduction

The social and economic transformation associated with rapid urbanization and the wide-spread adoption of irrigation to overcome climate change constraints have profoundly altered the pattern of water use [1]. Management of water resources entails approaches that require more and better-quality information about the current and potential future status of the water resource systems to be able to devise smart decisions [1].

Nowadays, water resources are a critical component for any type of socio-economic development all over the world. Thus, its availability and use are the key determinants of economic growth and social prosperity. However, water is a finite resource and its use for one purpose reduces its availability for other purposes. Competing water needs trigger conflicts between disparate water users [2, 3]. Increased demand for water stemming from population and economic growth and ecosystem services on the one hand, and the problem of water management in flood control situations on the other, have posed significant challenges for the planning and allocation of its uses among competing demands [4]. Many regions are facing formidable freshwater management challenges, as well as allocation of limited water resources, environmental quality and policies for sustainable water use are issues of increasing concern [5].

The growing pressure on the world's fresh water resources which is enforced by population growth can lead to conflicts between demands for different uses [6]. The conflict is mainly between the environment and other purposes like irrigation for agriculture, hydropower, domestic and industrial water supply. As the demand for water increases across the world, the availability of freshwater in many regions is likely to decrease due to population growth, industrialization, land use and climate change [7, 8]. Hence, utilization of integrated water resources management is an optimum way to handle the question of water resource management and planning.

Water management is the most critical issue that impacts the livelihoods of people, the productivity of the land, and society in general. For thousands of years, inhabitants of dry areas have constructed water harvesting systems that help them cope with water scarcity [9, 10]. However, water harvesting technologies are still limited due to inaccurate estimates of the volume of surface runoff water. Inappropriate allocation of water for users due to demand management problems, imprecise water harvesting structure location, inappropriate water harvesting techniques, and design problems of structure and delivery system are the problem.

The overall goal of the Water Resources Policy is to enhance and promote all national efforts towards the efficient, equitable, and optimum utilization of the available water resources of Ethiopia for significant socioeconomic development on a sustainable basis. Effective water allocation among water users in a basin will enable a better management of water resources. Water allocation among water users is very crucial and important in order to avoid conflicts among water users, adopt sustainable mechanisms of water resources management and improve the life standard of the people through effective and efficient water use based on different water demands.

The determination of water demands is the starting point for water resource planning and management. Water demand for water use sectors can be analysed based on empirical and conceptual equations. It can be done based on disaggregated or aggregated consumption of water evolving overtime in all sectors. Therefore, the objective of this study was to determine the different water demands in the Somodo watershed as a basis for effective water allocation in the watershed.

2. Material and Methods

2.1. Description of the Study Area

The study area is 368 kilometers South-West of Addis Abeba and 15 kilometers west of Jimma town. Its latitude ranges from $7^0$46′00" to $7^0$54′30"N, while its longitude ranges from $36^0$46′30" to $36^0$56′30"E. It has a good agro-ecological zone that is appropriate for the production of numerous crops. According to long-term climatic data, the watershed's minimum and highest temperatures are 13°C and 25°C, respectively. The annual rainfall average is 1500mm, which is distributed irregularly throughout the year. The average relative humidity, solar radiation, and wind speed are 72 percent, 2.5m/s, and 6.7 hours, respectively.

The kebele is administratively subdivided into three zones and it has 11 villages, called Jiga, that were established during the Derg. The house settlement is dense along the main road which cuts across the kebele, and fairly scattered in the other parts. The market and public offices are concentrated on one side of the road not very far from it.

In Somodo, there is no, as such, an urban area. But the settlement is denser along the main road crossing the kebele, and there are a number of medium-sized shops and tea rooms and hairdressers around the kebele offices. Although there is not such an urban centre, roadside land is much valued because people living there easily get electricity and access to water, and it is also conducive to small business activities.

2.2. Sources of Data

The data used for conducting this study was secondary data generally. The data consisted of population and livestock data gathered by the central statistical agency (CSA).

2.3. Method of Determining the Water Demands in the Watershed

2.3.1. Domestic Water Demand

Quantity of domestic water demands is determined basically based on collecting information how many people are living and how much amount does an individual need in the watershed. But, obtaining tangible figure on amount of water used for each individual use is difficult task because People′s needs are not always predictable. To establish how much an individual needs, standard quantities have been established as guidelines in different literature measured in litres per second per person (capita) per day (Lpcd).

The World Health Organization (WHO) recommends about 100 liters of water per person per day to ensure that most basic needs are met [11]. According to GTP-1 of Ethiopia, urban and rural water supply targets were 20 and 15 liters per capita per day, respectively. By keeping these data, the country could not achieve full coverage with this level. The country again developed a new standard of quantity supplied 25 liters per capita per day for rural and 40-100 liters per capita per day for urban [12]. In this study 25 Lpcd was taken since it is a rural area and according to the standard developed by GTP-2 to meet the water demand which is 25 liters per capita per day for rural area.

Domestic water demand was determined by multiplying the predicted population by the appropriate per capita demand. The method of future population prediction was chosen by taking into account the community's growth between consecutive censuses. Geometric approaches are most commonly used in growing towns and rural areas with the potential for growth. The population data for the Bilida area, the Somodo community, and the Urigayi area acquired from the CSA for the year 2014 [13] were used to forecast the future population using the geometric increase approach and equation 1. The water demand was determined by multiplying the total population by the per capita water consumption.

$$P_n=P_o\ (1+K)^n \quad (1)$$

Where; P_o=initial population, P_n= Population at n decade or years, n =decade K = percentage (geometric) increase.

2.3.2. Industrial Water Demand

Industrial water demand is water required for factories and industries. In the watershed and nearby, there are coffee washing factories and coffee processing factories. But, none of them have been recorded water use/consumption information. [14] recommends 5% to 10% of domestic water for industrial demand. But, the number of industries will be expected to increase in the future. By assuming this, 10% of domestic water demand was adopted for industrial water demand.

2.3.3. Livestock and Wildlife Water Demand

Livestock water consumption includes water used for livestock watering, feedlots, dairy operations, and other on-farm purposes. Ethiopia's cattle population is one of the biggest in Africa, putting further strain on water and land resources. Ethiopia is home to over 35 million tropical livestock units (TLU), and each TLU requires approximately 25 liters of water per day [15]. Using a conversion factor, livestock population type is expressed in tropical livestock units (TLUs). Water demand for cattle was calculated by multiplying the livestock population by TLU and computing the unit water need for each livestock.

$$\text{Livestock Water Demand} = \text{Per capita water consumption (l/d)} \times \text{livestock population} \times \text{TLU} \quad (2)$$

2.3.4. Environmental Flow Requirement

Environmental flows are flows that are left in or released into a river system with the specific purpose of managing some aspect of its condition. Their purpose is to ensure the maintenance of a healthy riverine ecosystem. Environmental flow requirement (EFR) can be calculated by using Indicators of Hydrologic Alteration (IHA) software. In the case of this study, 10% of the total available flow was left for the satisfaction of the environmental flow requirements.

2.3.5. Irrigation Water Demands

The total water demand for irrigation was estimated by multiplying the total area under irrigation with the irrigation water requirement for each cropping pattern. The cropping pattern of the watershed was determined from unpublished documents (Mana woreda Agriculture and Rural Development Office) and consultation with beneficiaries in the kebeles. CWR for different crops was calculated using ETo, kc, and Peff by the following equation.

$$ETc = Kc \times ETo \quad (3)$$

$$IWR = ETc - Peff \quad (4)$$

Where: ETC- Crop evapotranspiration (mm/period),
P_{eff} - is effective rainfall (mm),
IWR- is irrigation water requirement in (mm/period),
Kc- is crop coefficient,
ETo- reference evapotranspiration (mm/ day).

ETo was calculated by the FAO Penman-Monteith Method using meteorological data [16]. Crop coefficient (Kc), crop growth stages, rooting depths, critical depletion fraction, yield response factor, maximum crop height, and length of growth stage were fixed for crops that were planted in the watershed according to local conditions of the study area and using literature [16-18].

3. Result and Discussion

3.1. Domestic Water Demand

In the watershed, there is no reliable information on water supply and sanitation coverage, but the coverage is very low and it is a rural area. But there is a water pump and a non-functional water supply reservoir was constructed in the watershed. Whatever rural areas lack in terms of availability, satisfactory and reliable water supply schemes, low water supply and sanitation coverage, demand determination is crucial to the analysis of the water balance of the watershed.

Therefore, during the study period, domestic water demands for a projected total population of 24050 in the watershed from Babo, Bilida area, Tumuga Dela, Tumuga Nole, Urguai and Bebela Basao was 0.22 million cubic meters (MCM) of water annually. Furthermore, ten percent (10%) of domestic water demand was required for industrial purposes, resulting in 0.022 million cubic meters (MCM) of water for industrial use. Therefore, the total water demand for domestic water and industrial water demand was 0.242 million cubic meters (MCM) annually.

3.2. Livestock Water Demand

Livestock developments are key sources for rural livelihoods and income, as well as a source of animal energy and proteins in diets. Livestock population puts additional pressure on water and land resources. There is high production of livestock in Jimma zone [13]. The livestock water demands from Somodo watershed for the current was 0.015 million cubic meter (MCM) of water annually based on the total number of the livestock population and tropical livestock unit water consumption (table 1). Even though the livestock can use the water resource from rivers, the demand was determined by considering that the sources of water is from the water that will be drained from the watershed which can be generated by the precipitation through the hydrological cycle.

Table 1. *Livestock population and water demand.*

No	Livestock	TLU	Per capita water demand (l/d) of TLU	Total population	Water demand (l/d)	Total water demand (m^3/d)	Total water demand (m^3/year)
1.	Cattle	0.7	25	2097	36698	36.698	13394.6
2.	Sheep	0.1	25	815	2038	2.038	743.688
3.	Goats	0.1	25	400	1000	1.0	365
4.	Donkeys	0.4	25	48	480	0.48	175.2
5.	Horses	0.4	25	71	710	0.71	259.15
6.	Mules	0.4	25	68	680	0.68	248.2
7.	Poultry	0.004	25	2281	228.1	0.2281	83.2565
Total livestock water demand				15270			

3.3. Environmental Flow Requirement

The environmental flow requirement relies on the use of hydrological data, usually in the form of historical flow records, for making environmental flow recommendations. They are usually referred to as fixed-percentage, where a fixed proportion of flow, known as the minimum flow which represents the environmental flow recommendation intends to maintain the fishery or other ecological feature at some acceptable level [19]. Ten Percent (10%) of the average monthly flow (AMF) correspond to defined categories of environmental flow conditions, were remained to formulate river base flow regimes on a seasonal basis, to satisfy environmental flow needs. Accordingly, a total of 5.6 million cubic meter (MCM) which is ten percent (10%) of the total annual flow of water was the environmental flow requirement annually.

3.4. Irrigation Water Demand

Ethiopia appears to have adequate annual rainfall for food crop production and cattle pasture. However, the spatial and temporal distribution of rainfall is too irregular, resulting in a lack of available water at the required time. Taking this variability in rainfall distribution into account, [20] developed the Ethiopian Water Resources Management Policy (irrigation policy) to develop the vast irrigated agriculture potential for the production of food crops and raw materials required by agro industries in an efficient and sustainable manner, without degrading the fertility of the production fields and water resources base. Planning and implementation of irrigation should be provided considering the availability of water in sufficient quantity and quality.

Evaporation and transpiration are the basic parameters for irrigation water demand and irrigation water management in the field. The irrigation water demand observed in the watershed was calculated by using CROPWAT 8.0, and the reference evapotranspiration, effective precipitation, and soil samples collected from the fields were used as input data for CROPWAT 8.0.

The major crops in the watershed were coffee, vegetables, root and tuber crops, cereals, and tropical fruit and tree crops which are cultivated by rain-fed agriculture, irrigation only, and supplementary irrigation. At present, there are a total of twenty-nine hectares (29ha) of land covered by vegetables that are cultivated by irrigation (unpublished Mana woreda irrigation and NRM report).

After adjusting for effective rain fall, the total amount of water needed for irrigation was 0.107 million cubic meters (MCM). Throughout the growing season, the CWR for the major crops grown in the watershed were 464.8 millimetres, 848.1 millimetres, 580.7 millimetres, 485.6 millimetres, 624.8 millimetres, 362.1 millimetres, and 503.7 millimetres for tomato, maize, carrot, potato, cabbage, beet root, and pepper, respectively (table 2). The IWR of the crops cultivated in the watershed were 375.7 millimetre, 336.8 millimetre, 447.1 millimetre, 402.3 millimetre, 469.9 millimetre, 248.3 millimetre, 336.9 millimetre, 336.9 millimetre for Tomato, Maize, Carrot, Potato, Cabbage, and Pepper, respectively. There was a little bit of variation from the results obtained by other authors for CWR of cabbage and tomato [21], this may be because of the variations in the total growth period and the agro ecology.

Table 2. *Irrigation water requirement demand for crops cultivated in the watershed.*

No	Crop type	Area (ha)	IWR (mm)	IWR in volume (m^3)
1	Tomato	8	375.7	30056
2	Maize	12	336.8	40416
3	Carrot	2.5	447.1	11177.5
4	Potato	0.5	402.3	2011.5
5	Cabbage	2.5	469.9	11747.5
6	Beet root	0.5	248.3	1241.5
7	Pepper	3	336.9	10107
	Total			106757

4. Conclusion

The identified water demands in the watershed were domestic and industrial water demand, irrigation, and livestock. Estimated water demands were 0.242 million cubic meters, 0.015 million cubic meters, and 0.107 million cubic meters of water for domestic and industrial water supply, livestock, and irrigation, respectively. In the watershed, irrigation was the highest water user. This data can be used as a base line for water resources planning and policy makers.

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