American Journal of Water Science and Engineering
2023; 9(3): 69-76
http://www.sciencepublishinggroup.com/j/ajwse
doi: 10.11648/j.ajwse.20230903.13
ISSN: 2575-1867 (Print); ISSN: 2575-1875 (Online)

Assessment of Surface Irrigation Potential Using Geospatial Technology in the Megecha River Catchment

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To cite this article:
Girma Bekele Goba, Teshale Fita. Assessment of Surface Irrigation Potential Using Geospatial Technology in the Megecha River Catchment. *American Journal of Water Science and Engineering*. Vol. 9, No. 3, 2023, pp. 69-76. doi: 10.11648/j.ajwse.20230903.13

Received: April 20, 2023; **Accepted**: July 13, 2023; **Published**: July 31, 2023

Abstract: The world is suffering from different crises, like the energy crisis, food insecurity, and a basic shortage of natural resources. This study has been conducted to assess the surface irrigation suitability of the Megecha River using geospatial models. The slope gradient, soil depth, soil drainage, soil type, land use (land cover), distance from a water source, and distance of the access road were considered to assess the land's suitability for surface irrigation. After preparing each criteria map, the weight for each parameter was calculated using the analytic hierarchy process and weight overlay map analysis conducted in the GIS environment. After conducting a pair-wise comparison matrix and normalizing the pair-wise comparison matrix, slope gradient, soil type, and soil depth were weighted at 33%, 23%, and 17%, respectively. The land use and land cover change detection revealed that agriculture and built-up areas had shown significant expansion while range land was promptly decreased. The reasons for these are mainly population growth, soil fertility loss, small industries, and business company expansion. About 581.74 km^2 of area is moderately suitable, but the Megecha River has the potential to irrigate only 200ha for those selected crops based on CROPWAT 8.0 analysis. Finally, I recommend that the concerned offices enhance the soil and water conservation practices in the Megecha river watershed since it is the main water source for the private sector and the local community and its land use is changing in a hydrologically negative way.

Keywords: Irrigation, Potential, Assessment, Geospatial, Megecha River, Gurage Zone

1. Introduction

Presently, in the worldwide, food insecurity especially in Africa and pollution has emerged as a serious issue. And the entire world reveals itself in low food production caused by insufficient rainfed based agricultural productivity and the increasing curve of the elements. The food insecurity has happened all over the world because of prompt increase of the population, socio economic development, living standards with the fast mounting of industry, poverty, conflict, climate and weather, lack of investment in agriculture and unstable markets. In addition urbanization, incessant land cover change, soil, water and environmental degradation problems intensified due to increased demand of population for food and energy, development of land and climatic change. Arable land is required and this mainly initiate land use changes within their own boundaries and also influences availability of water resources and the sustainability of ecosystem. Furthermore has laid massive pressure on natural resource in the world at global scale [1, 2].

Nowadays to address these problems a variety of computer-based assessment tools have been developed to provide a prospect for developer to make initial assessment whether economically their project is viable before outlay of substantial amount of resources. Both geospatial GIS and RS techniques and CROPWAT 8.0 were used in this study for the assessment of irrigation potential. Therefore, this study examined irrigation potential in Megecha River found in Southern Regional state, Gurage zone to give insight to the government, private investor and interested NGO who are eager to contribute development of the country. Also the assessment method depicted the suitable land and water resources availability and accessibility for surface irrigation from locally available streams for end users.

In the past decades, water resources shortages have become increasingly severe in many parts of the world, associated with the impacts of natural and anthropogenic activity. And this may be seriously affecting the economic growth of the world. Ethiopia is one of the well-endowed countries in Sub-Saharan Africa in terms of natural resources and appreciated diversity production in the environment. But now; Ethiopia's natural resources is under considerable pressure because of a rapidly increasing population, development of infrastructures, intensifying agricultural activities and increasing deforestation [3]. However, one of the most important infrastructure for sustainable development is the availability of irrigating suitable land by artificial methods. The country's agriculture sector depends highly on rainfed systems. Irrigation development has high importance in the country to achieve desired food security and economic level of national and household levels [4]. It helps in supplying crops with required amount of water for the whole growing season or supplements the rainfall during inadequacy. However, irrigated agriculture is not practiced in organized and sustainable manner in the areas. Temporal and spatial variability of rain fall and its inadequacy enforced farmers to farm once per year. Farmers of the catchment are not familiar with double cropping system and growing cash crops those may have high crop water requirement in integrated and sustainable manner. Because of an inadequate rainfall crop failure occurs frequently in the area and the farmers are leading a subsistence life. To bring food security in the national as well as in the household level, improvement, expansion of irrigated agriculture and developing the surface irrigation potential assessment based on the prevailing socioeconomic enforced to identify the available irrigation potential and site in the Megecha River. The land use land cover change within 2017 and 2021 was detected, to develop surface irrigation potential map by matching water resources potential and land suitability and to estimate potentially usable available physical resources; land and water for irrigation and suggest techniques to be used to compromise between the two.

2. Materials and Methods

2.1. Description of the Study Area

Megecha River catchment is found in the south western part of Ethiopia and upper Omo Gibe River basin. It covers a drainage area of about 1091 km^2. Megecha River is a tributary of upper Omo Gibe River basin (see Figure 1), about 185km southwest of Addis Ababa, found in Cheha woreda/district, which is one of the districts of Gurage zone in Southern Nation, Nationalities and Peoples Region (SNNPR). The altitude of the study sites ranges from 1670 to 1860 m.a.s.l. The land use of the areas includes seasonal (annual) field crops, permanent (perennial) crops, forest and bushland, area occupied by construction (village), grazing land, and uncultivable land. The mean annual temperature of the area is between 15°C and 37°C. The mean annual rainfall is 1294.2 mm.

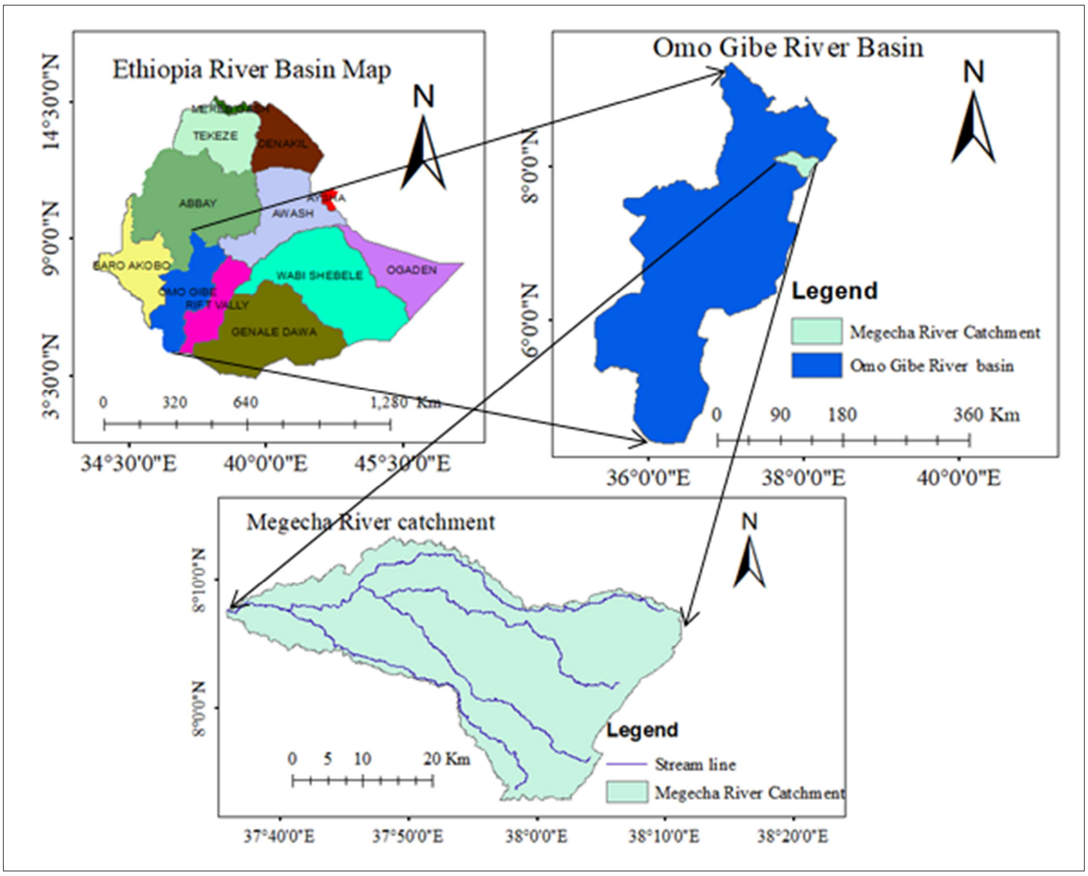

Figure 1. *Location map of the study area.*

2.2. Types of Data Used and their Sources

In order to ensure reliability and to meet the objectives of this research, different kinds of data were collected from different organizations, fields and satellite imagery. The two important types of data a were spatial and time series data from both primary and secondary sources (see table 1). The data from primary sources include spatial data and field data. Secondary data contains time series data such as precipitation, temperature, wind speed, relative humidity, solar radiation and stream flow data. Also different previous research works and different tools such as ArcGIS 10.3, and CROPWAT 8.0 are supportive secondary data sources and tools respectively.

2.3. Development of Surface Irrigation Potential Map

To develop map of irrigable areas, identification of suitable sites for irrigation were carried out by seeing the slope, soil, land use/ cover and distance between water supply and the potential command area as factors. The individual suitability of each factor was first evaluated and finally weighted to get potential irrigable sites using GIS and remote sensing tool which more familiar for the same study [5-7].

Table 1. *Sources of datasets.*

Data Type	Resolution/Frequency	Source
Digital Elevation Model (DEM)	30 m	The Shuttle Radar Topography Mission (SRTM) DEM https://earthexplorer.usgs.gov
Land Cover data	30 m	Ethiopian Ministry of Water, Irrigation and Energy (MoWIE), GIS and Remote sensing department and satellite image
Soil data	1:50,000	Ethiopian Ministry of Water, Irrigation and Energy (MoWIE), GIS and Remote sensing department
Weather data	Daily	Ethiopian National Meteorological Services Agency
Discharge	Daily	Ethiopian Ministry of Water, Irrigation & Energy (MoWIE) hydrology department

2.3.1. Slope Gradient

Slope is the incline or gradient of a surface and is commonly expressed in percent. Slope is important for soil formation and management because of its influence on runoff, drainage, erosion and choice of crops. The slope gradient of the land has great influence on the length of the irrigation run, crop adaptability, erosion control practices and irrigation method. With surface irrigation, the following adverse effects occur as the gradient increases: erosion hazard increases, water control becomes more difficult, the practical length of irrigation runs decreases, and crop selection becomes more limited. Slope also order the irrigation method used. These factors intensify as the gradient increases. Steep gradients usually result in lower productivity and higher costs of production.

According to FAO standard guidelines for the evaluation of slope gradient, slopes, which are less than 2%, are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended [8]. Slope map was generated from the digital elevation model (DEM) data of 30m resolution. Based on FAO manual [9], agricultural suitability of different slope classes for the study area is defined as in Table 2.

Table 2. *Slope class for surface irrigation suitability.*

Slope class (%)	Suitability score	Area (%)
0-2	4	5.61
2-5	3	20.90
5-8	2	21.20
>8	1	52.29

The result obtained after reclassifying Megecha watershed slope map was that 47.7% of the total watershed area has slope 0 to 8% and which is suitable for surface irrigation according FOA standard.

2.3.2. Soil Depth

The soil data of the study area was accessed from FAO of the United Nations portal Harmonized World Soil Database v 1.2. The soil depth of the study area was divided in to five suitability classes to select surface irrigation potential.

Table 3. *Factor rating for suitability of soil depth.*

Factor	Factor rating				
	S1 (Highly Suitable)	S2 (Moderately Suitable)	S3 (Marginally Suitable)	N1 (Currently Not Suitable)	N2 (Permanently Not Suitable)
Depth (cm)	>100	80-100	50-80	20-50	<20

Rating factor was given for the value of soil depth and weighting them to evaluate the suitability of surface (gravity) irrigation potential of the study area. Rating factor was adopted from FAO guidelines [10]. Based on the given suitability score for each soil depth of the study area, soil depth suitability map of the study area for surface irrigation potential is generated in to raster using GIS reclassify environment. The study area soil depth ranges 80 to 100cm which is S2 factor rating.

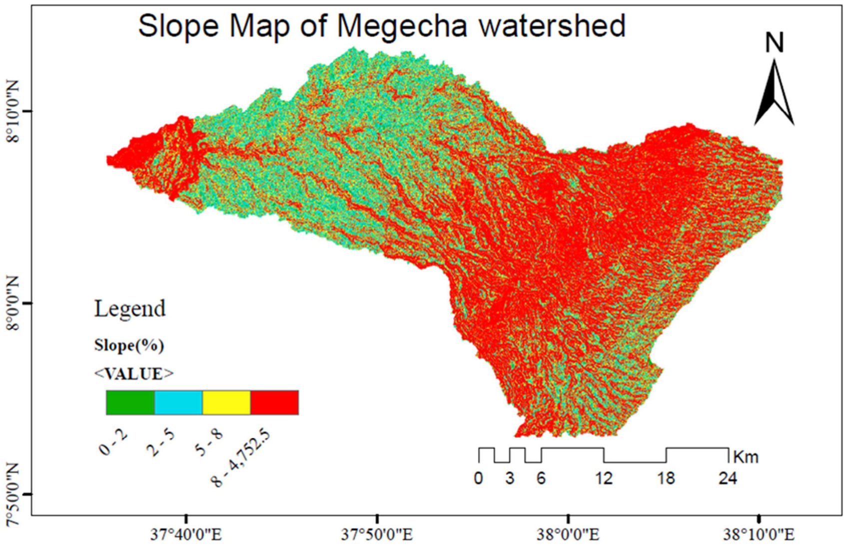

Figure 2. *The slope suitability map for surface irrigation.*

2.3.3. Soil Drainage

Soil drainage permits normal plant growth. Evaluation of the soil drainage requirement is a critical element in selecting land for irrigation, particularly with diversified upland crop production [11]. Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. The soil texture can determine the permeability of the soil for water in the study area. The soil drainage properties of the study area were classified in to highly suitable 58.5km^2 (5.25%) mainly in lower end and upper edge of the study area and 1055.3 km^2 (94.75%) of watershed is moderately suitable.

2.3.4. Soil Type

There are four types of soil groups observed in Megecha watershed those are leptosols, vertisols, nitisols and luvisols. Most part of Koga watershed is covered by vertisols and nitisols. These soil types were characterized and categorized based on the soil classification and characterization guide for agricultural suitability by FAO standard in to moderately suitable class.

2.3.5. Land Use Land Cover

Land use / land cover is also another factor, which is used to evaluate the land for irrigation suitability. The 2021, 10m resolution land use/land cover map of the watershed was accessed from ArcGIS Living Atlas of the World. Land use / land cover influences on the cost of irrigation practice to prepare the land for agriculture. It was taken as one input for the evaluation of land qualities for irrigation for the study area. Vegetation and rock are the most common cover types that require removal for successful irrigation. Rocks may also be a factor in construction of farm distribution and drainage systems and in land grading operations. The type of land use/land cover in the study area included agricultural area, rangeland, trees, built area, water body, bare ground and clouds.

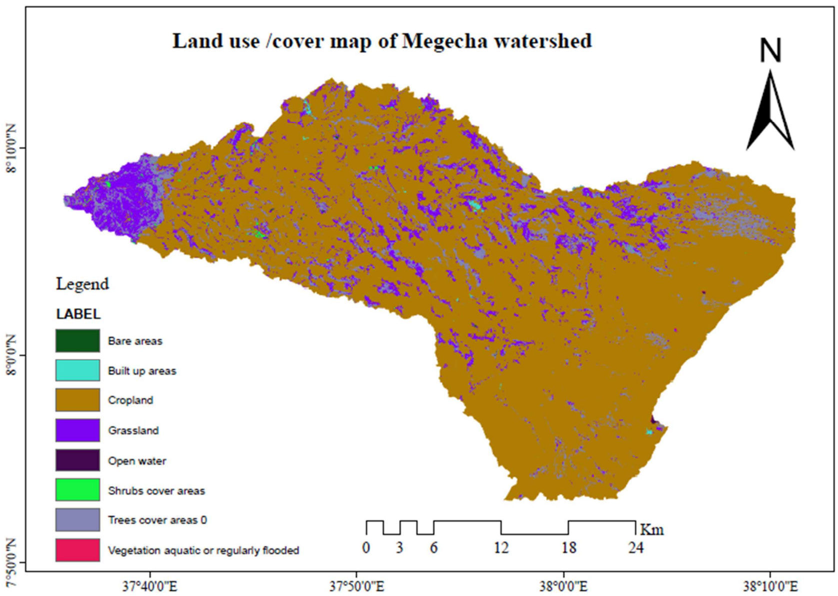

Figure 3. *The LULC map of Megecha watershed in 2021.*

2.3.6. Distance from Water Supply (Source)

The availability of water near to our study area to minimize cost for canal construction as well as loss of water is the factor that considered to map suitable land for surface irrigation potential. To identify irrigable land close to the water supply (rivers), straight-line (Euclidean) distance from the main streamline in raster format was used to generate river Euclidian distance map. The suitability map (figure 4. a) due to river distance shows that 4 (highly suitable) which is within distance ranges 0 to 1.5km, 1.5km to 3km scores moderately suitable (3), 3 km to 5km scores marginally suitable (2) and the area with distance of greater than 5km scores unsuitable (1).

2.3.7. Road Accessibility

The existing road to the irrigable area has its impact on the land suitability for irrigation due transportation accessibility for raw material supply and transporting irrigation products to market. Due to this reason the road Euclidean distance is considered as one the factor for identifying land suitability for surface irrigation. The proximity to road is classified into 0-3km highly suitable (4), 3-6km moderately suitable (3), 6-10km marginally suitable (2) and greater than 10km unsuitable (1) (see figure 4. b).

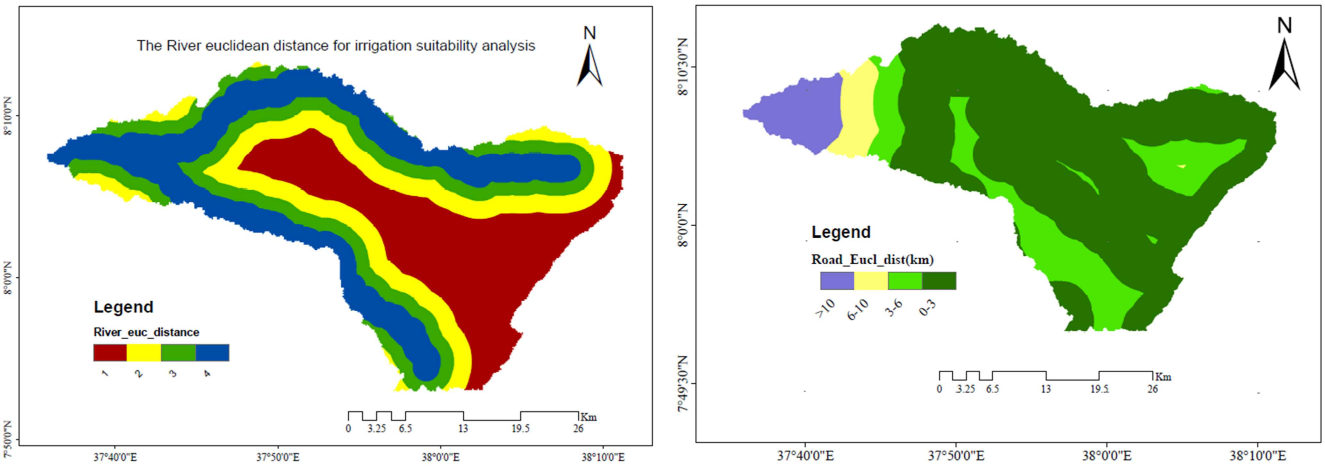

Figure 4. *a) the River accessibility map b) the road accessibility map for surface irrigation.*

2.4. Calculation of Weight for Criteria Maps

The analytic hierarchy process (AHP) is used to calculate weights for the criteria maps. It is a structured method for analyzing complex decisions by breaking them into pairwise alternatives of two at a time [12, 13].

Using the pair-wise comparison matrix, the analytic hierarchy process calculates comparative importance weights for individual criterion layers. It also produces consistency ratio (CR) that serves as a measure of logical inconsistency of expert/user judgments during pairwise criteria comparisons. Consistency ratio is the ratio of consistency index and random index. Consistency ratio helps to understand the judgments during pairwise comparison are trustworthy or not. When CR is exceeds 0.1 the judgments during pairwise comparison are untrustworthy, because they are too close for randomness.

Computing pair-wise comparison matrix of the criteria layers while performing an AHP each criterion is compared with the other criteria, relative to its importance, on a scale from 1 to 9. Scale 1 indicates equal preference between a pair of criteria layers whereas 9 indicates a particular criteria layer is extremely favored over the other during expert judgment [13].

Table 4. *Weights of each considered factors.*

Factor	Weight	Weight (%)
Slope	0.33	33
soil type	0.23	23
Soil depth	0.17	17
Soil drainage	0.11	11
LULC	0.07	7
Euclidian river distance	0.05	5
Euclidian road distance	0.03	4

Weights of each considered factors determined after conducting Pair-wise comparison matrix and normalizing pairwise comparison matrix in spreadsheet MMULT( ). The original preference ratings were consistent i.e. CR=0.088. After computation of weights for each raster layer using AHP, weighted overlay analysis (WOA) is performed on an ArcGIS environment. The weights quantify the relative importance of the suitability criteria considered. Assigning a weight to each raster in the overlay process allows controlling the influence of different criteria in the suitability model. Multiplying each layer's weight by each cell's suitability value produces a weighted suitability value. Weighted suitability values are totaled for each overlaying cell and then written to an output layer.

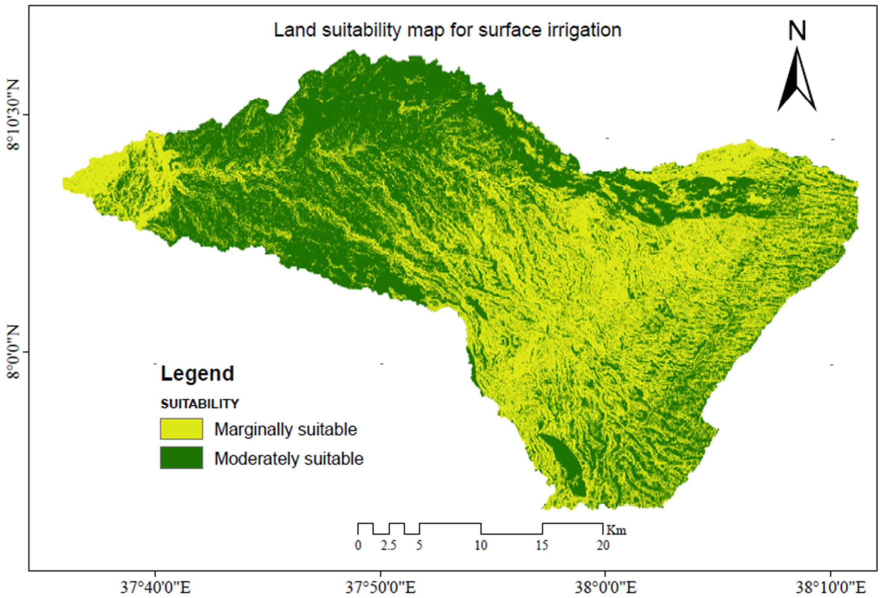

Figure 5. *Surface irrigation suitability map of Megecha watershed.*

2.5. CROPWAT Model

CROPWAT is a computer program that uses the FAO Penman-Monteith model to calculate reference evapotranspiration (ETO), crop water requirements (ETc) and crop irrigation requirements [14]. It is a decision support system developed by the Land and Water Development Division of FAO. Its main functions are to calculate reference evapotranspiration, crop water requirements and crop irrigation requirements in order to develop irrigation schedules under various management conditions.

For the calculations of the crop water requirements and irrigation requirements CROPWAT model needs climatic, crop and soil data. The climatic data includes rainfall (mm), mean maximum and minimum temperature (^{0}C), relative humidity (% per month), wind speed (km/day) and sunshine hours (hrs).

The crop agronomic data was accessed from FAO CLIMWAT 2.0 data base. The monthly rainfall of Emdibir metrology station which is within the study area and other climate data of Hossana station which is nearby station were used for this study. Crop types were selected by informal questioners for the Central Gurage zone crop and agricultural office, and from the study area farmers. Based on the above source, the selected crop types are tomato, potato and maize.

2.6. Surface Water Availability

Before beginning any hydrological analysis, it is important to make sure that the data are complete, sufficient and homogenous with no missing data. Based on visual examination, stream flow records of each selected gauging stations (Megecha, Gogeb and Wabe) have a good quality of flow data that shows strong serial correlation. The time interval of 1990 to 2007 daily stream flow data was accessed from Ethiopia ministry of water and energy. The missing data was filled by developing correlations between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods.

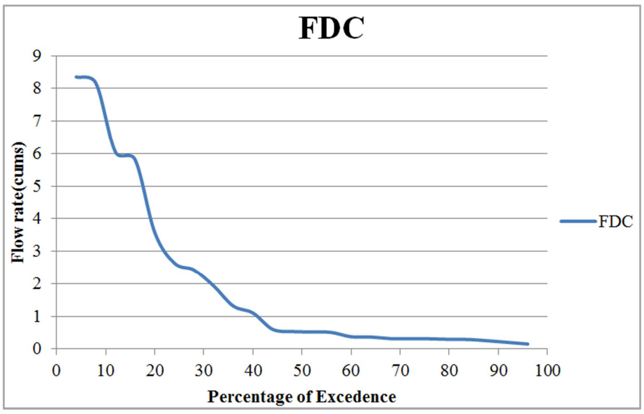

Figure 6. *Flow duration curve of Megecha river.*

After filling the missed daily stream flow the average monthly data was used to develop flow duration curve (FDC) to determine the availability surface water. The driest year, 1997 and 1991 with average annual flow of 1.827 and 2.072cums was selected ~~for~~ to determine the driest year stream potential. Based on the FDC analysis the Megecha river flow rate with 88 percentage of exceeded is 0.251cums. Different scholars use more than one percentage of exceedance to check stream flow potential [7].

3. Results and Discussions

3.1. Land use and Land Cover Changes Detection

Land use and land cover classes categorized from ArcGIS Living Atlas of the World 2017, 2021 contains Trees, Crops, water, Built Area, Bare ground, Rangelands and clouds. The

2017 lulc sourced from Living Atlas have the same lulc type with that classified by ERDAS Imagine model in the same river basin of the same year [15]. The analysis result depicted agriculture, range land and forest cover were the dominant LU/LC types in the watershed and jointly accounted 40.18% (48188 ha), 41.31% (49549.29 ha), 28.33% (33980 ha), 22.40% (26870.09 ha) and 20.40% (24464ha) from total watershed area in years 2017 and 2021 respectively. During the entire study period agriculture, built-up area and forest land had shown expansion, in nearby Wabe watershed the same lulc change observed [16] and overall Omo Gibe river basin [17]. On the other hand, LU/LC analysis showed that the area coverage of range land accounted 28.33% (33980 ha) and 22.4% (26870.09 ha) in 2017 and 2021 respectively and it was promptly decreased as figure indicates. Generally, throughout the study period LU/LC change was linked with several proximate and underlying causes. For example, improper agricultural practices, climate variability and change and demand for firewood and construction materials, demographic change, economic activities, poverty, policy and institutional changes.

Table 5. *LU/LC types and coverage area in Megecha watershed between 2017 and 2021.*

LU/LC Category	2017		2021	
	Area (ha)	%	Area (ha)	%
water	228	0.19	229.63	0.19
Trees	24464	20.40	24513.6	20.44
Crops	48188	40.18	49549.29	41.31
Built Area	12832	10.70	18762.76	15.64
Bare ground	0.5	0.00	0.62	0.00
clouds	240	0.20	16.58	0.01
Rangelands	33980	28.33	26870.09	22.40

Continuous expansion of built area in Megecha watershed was primarily related via rapid population growth, gradual change in the economic activities of communities in the area, small industries and Business Company's expansion. Likewise, increases in agriculture area closely allied to population growth, loss of soil fertility and the local community's socio-economic activities dependency on agriculture are the main deriving agents. Due to the soil fertility loss farmers look for new land resources to sustain their life. From the table 5 one can identify that the rangeland land highly reduced within the study five years.

3.2. Suitability Analysis of Irrigable Land

Identification of suitability areas for irrigation were obtained by creating irrigation suitability model analysis using a model builder tool in ArcGIS 10.7.1, this model performs Weighted overlay analysis and accept only integer raster as inputs, for all data sets such as suitable soil that obtained from soil physical properties for surface irrigation, slope, land cover/use, road accessibility and distance from water source/supply and the final results of suitability areas for surface irrigation potential were obtained as shown on the Figure 5. The model output shows that 581.74 km^2 area is moderately suitable and 524.73 km^2 area is marginally suitable. This result is comparably overstated the same study conducted on Abay-Chamo catchment [7, 6] and almost comparable with the result of the same study considering the same criterias in Megech catchment [18].

3.3. Gross Irrigation Water Requirements of the Identified Command Areas

Using CROPWAT the gross irrigation water requirements of maize, tomato and potato in the identified potential irrigable areas with 50% of maize, 25% of onion and 25% of potato in areal coverage was determined. GIWR for surface irrigation methods were estimated using CROPWA which needs climate data, crop type and characteristics, planting and harvesting date, cropping pattern as input. The GIWR was calculated by dividing the NIWR by the product of field application efficiency and field conveyance efficiency. From the literature review the field application efficiency and field conveyance efficiency were adopted as 60% and 70% respectively. Calculated monthly gross irrigation water requirements must be fitted with the river capacity.

Table 6. *The CROPWAT output for GIRW analysis.*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. MAIZE (Grain)	58.3	47.8	14.9	0	0	0	0	0	0	0	66	74.2
2. Potato	120.2	104.2	41.9	0	0	0	0	0	0	0	34	85.1
3. Tomato	111.1	107.1	86.5	0	0	0	0	0	0	0	42.3	78.2
Net scheme irr.req.												
in mm/day	2.8	2.7	1.3	0	0	0	0	0	0	0	1.7	2.5
in mm/month	87	76.7	39.6	0	0	0	0	0	0	0	52.1	77.9
in l/s/h	0.32	0.32	0.15	0	0	0	0	0	0	0	0.2	0.29
Irrigated area (% of total area)	100	100	100	0	0	0	0	0	0	0	100	100
Irr.req. for actual area (l/s/h)	0.32	0.32	0.15	0	0	0	0	0	0	0	0.2	0.29
Irr.req. for actual area * 10^{-4} (m^3/s/h)	3.2	3.2	1.5	0	0	0	0	0	0	0	2.0	2.9
GIWR for actual area *10^{-4} (m^3/s/h)	7.6	7.6	3.6	0	0	0	0	0	0	0	4.8	6.9
GIWR. for actual area (m^3/s)	0.31	0.31	0.143	0	0	0	0	0	0	0	0.191	0.276
Available flow (cums)	0.321	0.351	0.66	1.47	1.51	2.67	8.10	13.0	6.6	2.73	0.704	0.393

According to table 6 the general overview of monthly water demands of the crops that should be abstracted from the rivers by assuming a single cultivation in a year during the local cropping period (mono-cropping). The reveal that the available water resource is patented to irrigate about 200ha land without the need of source storage of water resource. The minimum flow rate with probability of exceedance about 90% is 0.23cums which exceeds the maximum GIWR based on 1990 to 2007 observed flow data. Another water source like rain water harvesting, ground water can be used as supplementary source to optimize the irrigation potential of the watershed.

4. Conclusion

The land use land covers significantly changing from rangelands to built area and croplands. The irrigation suitability analysis basically to develop a GIS-based map of the soil depth, soil drainage, soil type, land use, slope, road accessibility and stream network of the basin. All these attributes are superimposed and implemented within the GIS environment for identifying potentially suitable areas for crop development and suggesting appropriate methods of irrigation. A large portion of Megecha is characterized by suitable soil units. They have good inherent fertility and a high moisture holding capacity. Besides, these areas have a very flat land slope, as observed from the DEMs, which falls below 8% and is suitable for surface irrigation.

In all the basins, the potentially irrigable land exceeds the available surface water capacity during the low flow periods. This does not mean that the total annual flow capacity is less than the irrigation water demand. There is a large amount of river flow as well as runoff during the peak flow periods, which is able to satisfy the demand of irrigated areas. Due to seasonal variation in stream flow, provision of rainwater harvesting and groundwater withdrawal (use) has to be implemented in all basins. This is because the distribution of available water is not even in both the space and time domains. I recommend the concerned offices to enhance the best management practices for water resources conservation and to think about this limited resource while licensing investors having high water consumption needs.

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