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GIS AND SWAT BASED HYDROPOWER POTENTIALASSESSMENTOFTIGDAR RIVER IN GONCHA SISO ENESIE,ETHIOPIA,

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BAHIR DAR UNIVERSITY

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BAHIR DAR ENERGY CENTER

Sustainable Energy Engineering

MSc THESIS ON

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By:

Seman Aschale

November, 2021

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GIS AND SWAT BASED HYDROPOWERPOTENTIALASSESSMENT OF TIGDARRIVERIN GONCHASISO ENESIE, ETHIOPIA.

By

Seman Aschale Kassie

A Thesis submitted in Partial Fulfillment of the Requirements for the Degree of Masters Of Science in **Sustainable Energy Engineering**

Advisor: Mr. MulukenTemesgen (Ph candidet)

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Approval of Thesis for defense

I hereby certify that I have supervised, read and evaluated this thesis titled "GIS and SWAT based Hydropower Potential Assessment of Tigdar River in Gonche Siso Enese, Ethiopia" prepared by Seman Asahale under my guidance. I recommend the thesis to be submitted for oral defense.

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I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of Student Seman Aschale Signature ________ Date: 02/03/2014

As members of the board of examiners, we examined this thesis entitled "GIS and SWAT based Hydropower Potential Assessment of Tiqdar River in Gondar Sorr Zone, Ethiopia." by Seman Aschale. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Masters of Science in "Sustainable Energy Engineering"

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Declaration

I, Seman Aschale, declare that this is my own original work that has not been and will not be submitted to any other university for a similar or any degree award.

01/03/2014

Signature

Date

Abbreviations

ARSR	Amhara regional states report
CSA	Central statistical agency
CUP	Calibration uncertainty program
DEM	Digital elevation model
EEPCo	Ethiopian electric power generation
FDC	Flow duration curve
FDRE	Federal democratic republic of Ethiopia
FDREABA	Federal Democratic Republic of Ethiopia Abay Basin Author
GERD	Grand Ethiopian Renaissance Dam
GHG	Greenhouse gas
GPS	Global Positioning System
HRU	Hydrological Response Unit
HSR	Hydropower Status Report
IEA	International Energy Agency
IJHD	International Journal on Hydropower & Dams
MNRE	Ministry of New and Renewable Energy
MWR	Ministry of Water Resources
NSE	Nash Sutcliffe Efficiency
PPU	Percentage of prediction uncertainty
SSH	Small scale Hydropower
SWAT	Soil and Water Assessment Tool
DESAUNS	Department of Economic and Social Affairs of the United Nations Secretariat
WER	World Energy resources
WGI	Weather generator input

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Abstract

Energy plays an important role inthe economic and social development of one’s country. The world is currently experiencing an energy crisis due to environmental pollution caused by urbanization, economic development,and rapid population growth. Ethiopia facing a significant challenge in meeting rapidly increasing energy demands. Identifying and utilizing new renewable energy sources, such as hydropower, is critical to reduce the country's energy shortage and reliance on fossil fuels.

This research aimed to identify hydropower potential sites and estimate the Tigdar River's capacity for power generation using an integrated Geographical Information System and Soil and Water Assessment Tools.SWAT model, satellite data, and GIS tools were utilized to identify the outlet of the river. In Tigdar watershed, eight sub-basinswere identified within 38.3469km length and 199.11km^{2}area.Daily flow data was used for the identification of potential sites in the watershed. The calibration and validation models were found to be the most correlated between simulated and observed data sets. The values of R^2 and E_{NS} were found in a very good performance of the model (>=0.75).

Three potential site have been identified. This study estimates water availability for hydropower based on 90% dependable flow. Observed and simulated daily flow data were used to calculate the River's discharge at each potential site. In most cases, maximum discharge was found in Potential site 3 of the Tigdar watershed, with 90% dependability.

Hydropower site 3 and 1 have maximum and minimum power production capacities of 4462.04KW and 2294.83KW, respectively. The total power production capacity of the Tigdar watershed is 9194.093KW (9.2 MW). The result shows that the selected River hydropower sites are feasible (in small scale hydropower) based on their installed capacity. As a result, if a hydropower plant is built in the watershed, the surrounding communities will have access to electricity.

Keywords: GIS, SWAT, DEM,Tigdar Watershed, Small hydropower .

1. Introduction

1.1. Background of the Study

Energy plays an important role inthe economicand social development of one's country. The world is under energy crisis `due to environmental pollution associated with urbanization, economic development, industrialization and rapid population growt[1]. United Nations report revealed that 1.6 billion people live in extreme poverty; 2.4 billion people rely on traditional biomass, and a quarter of the world's population, or1.6 billion people, do not have access to electricity. Access to modern, safe, and affordable energy is considered as one of the attributes having a great potential to reduce pover[2]

Energy consumption and demand are growing in the world for the past 50 years ([3]. The demand for energy was expected to rise from 164 PWh/year in 2011 to 200 PWh/year 2020 [4]. With the ongoing depletion of fossil fuels, inevitably, alternative energy resources such as hydropower, biofuels, wind, solar, and geothermal energy play an increasingly significant role[5] The energy contributions from these sources are growing rapidly, and hydropower plants currently make the greatest contribution. Currently, only 15% of the world's total energy production is from renewable energy sources. It is expected and agreed that renewable energy resources furnish more than 50% of the world's energy consumption within 40 years[6].

Hydropower is one of the most reliable renewable energy sources. It has been used in the world for many years [7]. It is known that water is the most fundamental resource covering 75 percent of the earth's surface and is essential for a variety of purposes like the generation of electricity. Wise use of this resource was vital for hydropower, irrigation,and other purposes [3].Currently, hydropower is contributing about16% of global electricity production [8]. It has low operating and maintenance costs, development of sustainable energy, is environmentally friendly, high efficiency (about 60～80%), and offers a significant role in the reduction of greenhouse gas (GHG) emission[9]. However, hydropower is affected by the variation of water flow rates throughout the year, requirement of higher initial investment and long construction period, and lack of ability to construct them near load centers in most cases [10].

Particularly, Ethiopia is a former water-rich African country with several lakes and rivers originating from the country's highland areas[11]. According to the Ministry of Water Resources (MoWR) report ([12], Ethiopia has 12 river basins, 22 lakes, and the renewable ground water resource is approximately 2.6 billion cubic meters. Even though Ethiopia has a huge water resource, very little has been developed for agriculture,hydropower, industry, water supply, and other purposes[13].

Most rural households in Ethiopia are highly dependent on traditional biomass for their energyneeds,and 70 % of the population is not covered by electricity (IEA 2014). A Central Statistics Agency survey (CSA, 2004) showed that about 71.1% of the total households use kerosene for lighting followed by firewood (15.7%) and electricity (12.9%), and this has led to deforestation and environmental degradation.

Ethiopia is currently facing a significant challenge in meeting rapidly increasing energy demands due to rapid population growth and economic development (Arthur, 2014). To address these issues, Ethiopia has launched a green growth policy by implementing the Climate Resilient Green Economy strategy, which aims to achieve a middle-income economy with zero net emissions by 2025[14].This can be accomplished by converting hydro-potential resources into renewable energy by building small and large dams, such as the Grand Ethiopian Renaissance Dam (GERD) on the Blue Nile River. The Ethiopian government's Ministry of Water and Energy has also been working to make renewable energy a major energy source for the rural community. However, the existing hydropower sources have not met the energy demand of the country. As a result, large rivers with hydropower potential must be assessed for potential hydropower plant development. As a result, the study's goal was to assess the small-scale hydropower potential of the Tigdar watershed in Amhara Regional State.

The Tigdar watershed is one of the largest rivers in the Goncha Siso Enesie District, and the hydropower potential of the river has not yet been studied.

Realistic topography (particularly elevation) and flow data and careful analysis of these data using GIS-based tools in conjunction with hydrological models are required to correctly assesspotential hydropower sites.

This study aimed to assess and characterize the hydropower potential of the Tigdar River in the East Gojjam zone's Goncha Siso Enesie district using the powerful and recently accepted Geographical Information System (GIS) and Soil and Water Assessment Tools (SWAT) models. Since no previous research has been conducted, this study provides the best answer to how a water resource can be used to generate electricity.

1.2. Statements of the problem

Goncha SisoEnesie is one of the district of Eastern Gojjam which has no access to modern energy supply. There are several huge rivers, but neither of these water resources isused for energy production. The livelihoods of this area cook on three-stone fires and light their houses with smoky kerosene lamps. They do not use electrical and electronic devices.The main energy source of the community is fuel wood and cow dugs. Women and children spend hours walking to gather fuel, wood, and animal dung for cooking and lighting purposes, leaving no time to pursue other economic opportunities. These causes deforestation, land degradation, and environmental pollution in general.

Several studies have been conducted to assess hydropower;most of them do not evaluate model performance, do not study dependability, and do not estimate power using a high percentage of dependability.In Tigdar catchment, the surrounding rural communities suffer from energy crises using modern technology like hydropower. Therefore, to meet the demand of most of the population for electricity, it is necessary to study the rivers in the country and build small power plants. In addition, most rivers in Ethiopia are ungauged or very poorly gauged, and therefore, the observed discharge data are not sufficient for assessing hydropower potential.To identifythe hydropower potential site of a river basin, spatial thematic map data such as Digital elevation model, soil and land use, discrete data at specific locations, and free available GIS and SWAT modern application software are used.

Therefore, the study aimed to assess and characterize the small hydropower potential of Tigdar River in Goncha SisoEnesie district.Since no previous study has been conducted, this study answers the location of stream order and potential hydropower sites and how the water resource can be functional to power generation.

1.3. Objectives

1.3.1. General Objective

The main objective of this study is to identify and characterize the small hydropower potential sites in Tigdar river District Goncha siso Enesie using GIS and SWAT hydrological model, 2021.

1.3.2. Specific Objectives

The specific objective of this research is:

- ✓ To assess and identify the potential hydropower sites along the Tigdar River.
- ✓ To characterize the potential hydropower sites for the development of small-scale hydropower plants.
- ✓ To estimate the power production capacity of selected hydropower potential sites

1.4. Significance of the study

The importance of assessing hydropower potential has been highlighted by many researchers forthe planning of energy supply and hydropower plant development in many parts of the world. Identifying new renewable energy resources like hydropower is crucial to reducing fossil fuel dependency and addressing environmental problems. This study is used to determine the hydropower potential of the watershed in the river basin.

The significance of this study could be;

- ✓ There is a baseline for the future further detailed feasibility study
- ✓ Decrease environmental impact due to the use of biofuel energy sources.
- ✓ To recognize the river's hydropower potential in the district, the regional and national water and energy sectors can use the results as inputs to use the river for hydropower generation and expand electricity services.
- ✓ Furthermore, the study also serves as baseline information for studying rivers in other districts.

1.5. Scope of the study

This research focused on assessments, characterization and estimation of power production capacity of small hydropower potential sites in Tigdar Riverlocated in the Goncha Siso Enesie district of East Gojjam, Amhara regional state. The study provides inputs on how the water resource can be functional to power generation sinceno study has been made before.In addition, the findings of this study are used forfurther project detail planning, design and analysis as an additional data source.

2. Literature Review

2.1. Energy sources

It is essential to know the energy sources conducted in which the energy can be stored, converted, and upgraded for the use and required to bring into the light for some of the description, theory, economics, and problems of the various types of energy. Energy can be categorized as renewable and nonrenewable energy. Renewable energy is a more desirable source of fuel than nuclear power due to the absence of risk and disasters. The primary motivators that encourage renewable energy technologies are energy security, economic impacts, and carbon dioxide emission reduction. Some renewable energies are wind power, solar energy, hydropower, biomass, biogas, geothermal, tidal fusion energy[15].

Hydropower technology utilizes the potential energy possessed by water body between two elevation levels, which is proportional to the rate of flow of water and elevation difference, referred to as the head. Therefore, hydropower planning and design are focused towards increasing these two parameters by selecting proper sites and construction measures. Various types of hydropower plants have been developed depending upon the availability of head and control of discharge. They are listed as follows [14].

I. **Based on layout:** Based on layout hydropower plants classified as Run-of-river, Storage hydropower plants and Pumped storage plants

II. **Based on generation capacity:**

Large hydropower (>2500kw), small hydropower (2001-2500kw), mini hydropower (101-2000kw), micro hydropower (5-100kw) and pico hydropower (5-100kw)

2.2. Development of Hydropower

Water is the most important and irreplaceable natural resource for all living species, and humans have been using water to perform various activities for thousands of years. It is also the principal source of energy like hydropowery[15]. Water has been used as a source of power, and people are benefiting from it for more than two thousand years, starting with a wooden water wheel. In many parts of Asia, water wheels were used to grind wheat into flour as early as 100 B.C. During the 19th century, the water wheel was gradually replaced by modern-day turbines and soil and rock dams built to control water flow and produce electricity[13].The modern hydropower turbine was evolved in the mid-1700s. Europe and North America built large hydropower plants; equipment suppliers spread to supply this thriving business [16]. Hydropower generates electricity through the use of the gravitational force of falling or flowing water.It has been used for hundreds of years because it becomes a more important economic resource than other renewable sources and can be harnessed with relatively basic technology[12].

Hydropower is the most consistent form of renewable energy and contributes the highest share of 16% of global renewable electricity production [17]. Currently, hydropower is one of the most cost-effective and widely used renewable energy in the world. The hydropower plant is a long-lasting and economical energy source without environmental impacts [5]. It is most advantageous than other sources of energy like fossil fuels and nuclear energy. Because hydropower is the simplest, cleanest, most reliable, [10]. Hydropower has generated extensive attention because of renewable energy sources and provides electricity to far-flung areas in hilly regions [18]. Hydropower does not consume the water that drives the turbines, and after power generation, the water is available for various other essential uses [19].

Power plant is considered as the best appropriate method for renewable energy generation from low head and flow Rivers due to the supply of electricity from natural sources without causing any pollution or damage to the environment[5]. It requires low head and flow to drive the hydro-turbine [20]. Currently, the demand of energy has been increased in the world due population growth, urbanization, industrialization and enhancement of the living standard of the people and electricity demand of the service sectors. The supply of electricity does not meet the demand of the people in the world, especially in Africa. Hydropower is not generated as the estimated amounts of renewable energy sources are available in the world.revealed that the global small hydropower installed capacity was around 47,000MW against an estimated potential of 180,000MW.Due to due lack of available investment capital, the annual generation of power in Africa is less and has a large technical potential and could develop 11 times its current level of hydroelectric generation compared to other continents[21].Even though there is an insufficient power supply globally, there is an increase of small- to medium-sized hydropower plant developments covering a very large range of scales, from a few watts to several TWh as shown in Fig 2.1 .

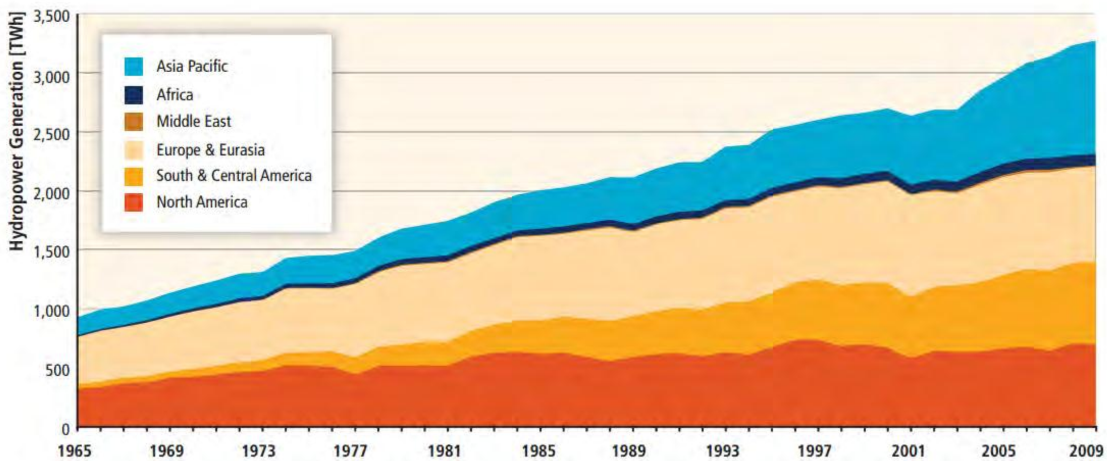

Figure 2.1: Hydropower generation (TWh).

Ethiopia has a huge hydropower potential, which is estimated to be about 15,000 - 30,000 MW. The Central and Southwestern highlands of the country have an annual water surplus which provides the basis for run-of-river hydro development on a small scale [13]. However, all hydropower plants found in Ethiopia, including the Renaissance Dam, can generate 13 320 MW .The existing hydropower plants of Ethiopia are shown in Table

Table 2.2: Hydropower plants in Ethiopia.

Name of River Basin	Installed Capacity (MW)	Name of River Basin	Installed Capacity (MW)
Aba Samuel	6.6	Melka Wakena	153
Koka (Awash I)	43	Tana Beles	460
Awash II & III	63	Tekeze	300
Fincha	134	Tis Abay I & II	84.4
Fincha Amerti Neshe	95	GERD Hidase	6450
Gilgel Gibe I	184	Genale Dawa III	254
Gilgel Gibe II	420	Genale Dawa VI	257
Gilgel Gibe III	1870	Geba I & II	387
Koysha	2160		
Total			**13,320**

As shown in Table 2.2, only 44.4% of the vast potential has been harnessed for hydropower generation. More than 80% of the remaining demand for electricity is fulfilled by these installed hydropower plants [7]. So that the potential hydropower sources available in the country have to be studied and used for electricity generation to enhance the living standard of the community and minimizing environmental pollution. This also helps in future energy planning and the selection of potential sites for hydropower development., nearly 200 identified economically feasible potential sites for hydropower plant development in the country. Particularly, the Amhara region has the largest water resources in Ethiopia, and the community is suffering from a shortage of electricity. As referred by[22], there are more than 21 rivers in Amhara regional state that can generate electricity (Table 2.2).

Table 2.1: Small Hydro Power Potential Site and Rivers Capacity in Amhara National Regional State[23].

No	Zone	Woreda	Name of River	Energy Potential (kw)	Head (m)	Discharge Flow(CMS)	Installation Capacity	Firm Output (KW)
1	E/ Gojjam	Huneltejju Enesie	Temi	14300	76	0.212	122.2	122
2	E/ Gojjam	Huneltejju Enesie	Azawari -1	12500	5	0.797	28.86	9.5
3	E/ Gojjam	Dejen	Suha shet	20300	92.1	0.212	166.6	166.6
4	E/ Gojjam	Dejen	Muga	29600	47.3	0.446	166.4	166.8
5	E/ Gojjam	Machakel	Gedaba-1	107000	30.4	0.708	146.7	127
6	E/ Gojjam	Machakel	Gedaba-2	150,000	45.1	0.62	222.2	195.7
7	E/ Gojjam	Gozamen	Chemoga I and II	13H91/Y (Gr)W			290(MW)	
8	W/Gojjam	Achefer	Kilte	960	5	0.397	14.43	5.3
9	W/Gojjam	B/Dar Zuria	Andassa - 1	21000	5.4	2.2	88.89	43.5
10	W/Gojjam	B/Dar Zuria	ABnrda acshsa	11900	11.6	1.03	87.89	69
11	W/Gojjam	Denbecha	Gula-1	34700	9.2	0.42	26	16.7
12	W/Gojjam	Denbecha	Gula-2	34800	11.4	0.522	40	22
13	W/Gojjam	Denbecha	Temcha	72900	14	0.6	59.8	59.8
14	W/Gojjam	Jabitenan	Lahi	37800	19	0.422	59.6	49
15	W/Gojjam	Jabitenan	Birr	7800	10	0.154	13.6	13.6
16	W/Gojjam	Banjashikudad	Fettam-1	6600	25	1.36	277.8	102
17	Awi	Wonberm	Fittame-	122000	58	0.966	434	235

		a	3					
18	Awi	Ankisha	Fettam-2	25800	18	1.492	224	71.8
19	Awi	Dangila	Asher	35800	11	1.912	166.6	75.5
20	Awi	Gowangoa	Ardie	35600	14.5	0.788	92	80
21	Awi	Gowangoa	Dura	151000	26	2.34	519	228

Hydropower potential watersheds like Tigdar River in Goncha Siso Enesie district have not been studied yet. Because of this, the study was aimed at the assessment of the small-scale hydropower potential of Tigdar River.

2.3 . Hydropower Potential Assessment

Assessment of hydro power resources required to justifying project risks through sound assessment and analysis. Traditionally the historical data of discharge correspondingly to fixed location is considered for estimation of water resources.Several countries using GIS technology for the assessment of hydropower sources. Different models have been used for potential hydropower assessment of rivers (Table 2.3).

Table 2.2: Hydropower potential assessment and stream flow simulation models

No	**Authors**	**Model type**	**Input**	**Application**	**Limitation**
1.	[5] Yu &Ghadimi , 2019,[21]	GIS	DEM and Delineated stream network	Cost-effective, used for calculating hydraulic head and assessing the hydropower potential at the watershed or wider scales.	Not evaluate model performance(NSE and R2
2.	[24]	SWAT	DEM, land-use and soil maps, slope map, and	used for the simulation of flow	To identify the potential site didn’t study dependability

			meteorological data (maximum, minimum temperature, rainfall, humidity, solar radiation)		
3.	[25][5]	GIS integrated with SWAT	DEM, Delineated stream network, land-use and soil maps, slope map, and meteorological data (maximum, minimum temperature, rainfall, humidity, solar radiation)	Popular, very effective, and reliable for identification of potential hydropower sites and estimation of river flow	To identify the potential sit used low percentile dependability
4.	[26]	Artificial Neural Network (ANN)	rainfall and daily stream flow	To simulate streams flow	Not evaluate the model performance

In recent studies, Geographical Information system (GIS) and Soil and Water Assessment Tool (SWAT) models are the most popular and cost-effective models for identifying and determining potential hydropower and estimation of river discharging.

2.3.1 Geographical Information System

GIS is one of the most advanced and user-friendly computer-based tools used to digitally represent and analyze the geographic features present on the earth's surface[27].According to [8] study, GIS software is used to identify suitable locations and calculate the total potential for small hydroelectric power plants and ensure sustainable water resource management at the catchment scale supports energy management strategies. This method takes less time, cost-effective and efficient method for assessing the water potential of small hydroelectric power stations, and identifies suitable locations along the river.GIS-based methodologies have been used to identify potential hydropower sites of rivers in many countries [5]. Recently, it is also been widely used to assess the hydropower potential at the watershed.

Researchers showed that GIS computations started at the main outlet of the watershed and then proceeded in the upstream direction to assess potential hydraulic heads along the river. A location is identified as a potential hydropower site when a head of 20m or more is available in a stream. A head of greater than or equal to 10meters is also considered a hydropower site, so that sufficient power is generated even for low flows. The minimum distance between two successive sites should not be less than 1000 meters in ensuring a sufficient gap between the tail race of one site and the diversion arrangement of the next site [18].A low-head hydropower application uses river current or tidal flows falling through 20m or less to produce energy. This is to ensure that the reservoir of the downstream site does not influence the tailrace of the upstream site. The assessment for the next potential site is carried out from the last selected site, and the process continues to the upstream end of the river.

2.3.2 Soil and Water Assessment Tool

Soil and Water Assessment Tool (SWAT) is a physically-based long-term hydrological simulation model which has proven tremendous applicability in various hydrological studies[21]; [24]; It is used for estimating river discharging, assessment of the head, site selection, and simulation of flow at each selected site.

Based on[3]), SWAT divides a watershed into stream network sub-basins, which are later distributed again spatially into multiple Hydrological Response Unit (HRU) which have homogenous land use, slope, and soil type characteristics. The HRU is distributed into sub-basins spatially within SWAT [3].

The SWAT model is set to produce daily, monthly discharge (yearly) to obtain dependable discharge for SHP generation. SHP potential (kW) was calculated using the following formula:

$$Shp = \rho . g . Q . H . \eta \quad (1)$$

Where ρ is the density of water (kgm^{-3}), g is the acceleration due to gravity (9.8 ms^{-2}), Q is the dependable discharge (m^3s^{-1}), H is the head (height difference) or elevation drop (m), and η is the efficiency constant [16].

2.3.2.1 Input Data for SWAT Model

The main components or inputs of SWAT are topographical data or Digital Elevation Model (DEM), soil type data, land use/land cover data, and weather data [3]. Other inputs required for the model are long-term weather data and soil properties [28].

i) Digital Elevation Model

Digital Elevation Model (DEM) represents the elevation of the earth's surface in the form of a digital image where each pixel contains an elevation value of the center point of the pixel. DEM is used to determine terrain attributes, such as elevation at any point, slope, and aspect. It is also used to determine drainage networks and watersheds. As revealed by (Sammartano, et al, 2019) **t**he DEM of the river basin is analyzed to detect suitable hydropower sites. Specifically, the 30 × 30 m DEM was used to delineate the stream network, to calculate the length of the river channels, to evaluate the river bed slope, to identify the sub-basins areas, and, finally, to assess the elevation of a great number of points along the river network (intersecting the DEM raster with the points layer).

ii) Land-Use Land-Cover Data

The land-use land cover data shows the extent of land management carried out in a watershed.

This ultimately affects the flow of water through the watershed. A land-use land-cover data of Tigdar River from the Federal Democratic Republic of Ethiopia Abay Basin Author(FDREABA) was used.

iii) Soil Data

The soil data shows the soil properties in the watershed, which is very important as the water flow in the watershed depends on the type of soil it is passing through. The SWAT requires different physical, chemical, and texture properties of soil such as available water content, soil texture, bulk density, hydraulic conductivity, and organic carbon content of different layers for each soil type [5]. The soil data from theFDREABA was used. There are different types of soil present in the Tigdar River.

iv) Meteorological and River Flow Data

The SWAT requires daily meteorological data (maximum and minimum temperature, rainfall, wind speed, solar radiation, and relative humidity) to simulate water flow in the watershed. For this study, 13 years of meteorological data were obtained from the Meteorological Department of Amhara Regional State. The SWAT also requires the stream flow data for the calibration and validation of the model. 13years of flow data (from 2008 to 2020) were obtained from the FDREABAwithin Tigdar River.

2.3.2.2 SWAT Model Calibration and Validation

Calibration is the adjustment of various parameters that affect the flow of water in the watershed. It is used to minimize the difference between the model output and the discharge data of the gauging stations. This enables the SWAT model to simulate and predict the flow in the watershed as close as possible to the observed data obtained from the gauging stations. Monthly discharge data from one available gauging station will be used to calibrate the model[5].Validation is the process of determining the degree to which a model or simulation is a correct representation of the observed behavior from the perspective of the intended uses. It is essential to test its simulation performance. The values of simulated discharge at a specified location were compared with the observed discharge for validation of the model [29]. The calibrated SWAT model was validated using a different set of weather and discharge data recorded during three consecutive years[28].

As shown in Table 4.2, the model performance was evaluated from a comparison of simulated and observed discharge data in terms of mean, standard deviation, maximum daily discharge and total discharge using commonly-used indices such as coefficient of determination (R^2) and Nash-Sutcliffe coefficient (E_{NS})[24].

Table 2.3: General Rate Performance for time ste[30].

Performance Rating	**R^2**	**NSE**
Very good	$0.75<R^2=<1$	0.75=<NSE=<1
Good	$0.65< R^2<=0.75$	065<NSE<=0.75
Satisfactory	$0.5< R^2<=0.65$	0.5<NSE<=0.65
Unsatisfactory	$R^2<=0.5$	NSE<=0.5

The p-factor range from zero (0) to one, and r- factor range between zero and infinity

In general, numerous studies have been conducted on using GIS or hydrological models to evaluatewater resources and hydropower[14]

Several studies revealed that SWAT is very effective and reliable in identifying potential hydropower sites[21].Following the proposed approach[26], in this study, GIS tools coupled with the application of the SWAT model have been used to identify potential hydropower locations in the Tigdar river basin, Amhara Regional State of Ethiopia. The SWAT model has been calibrated, validated, and applied to evaluate river flow in several sub-basins of the Tigdar watershed. The results have been provided using maps showing the potential hydropower sites for different ranges of potential power.

Though many studies have been carried to evaluate the model performance the only use R^2 andNSE but in these study to evaluate the model performance additionally use p-factor and r-factor.

3. Materials and Methods

3.1 Description of the study area

The study was conducted in Goncha Siso Enesie District, East Gojjam of Amhara National Regional State, Ethiopia. It is located at a distance of 147km from Bahir Dar and 333km from Addis Ababa. The district has two towns and 41 rural Keble. Gindeweyin is the capital of Goncha Siso EnesieDistrict. The district is bordered on the south by Enarj Enawga, on the west by HuneltejjuEnesie, on the north by the Abay River , which separates it from the South Gondar Zone, and on the east by Enebsie Sarmidir. Itlies between 380 0’ 12.2” and 380 23’ 46.2” E longitudes, and 100 46’ 11.6” and 110 9’ 31.9” N Latitudes with an elevation range from 1400m to 3400 m above sea level. The district has a total surface area of 1,038.17 km^2

The average annual rain fall is with a range of 1100 to 1360 mm. Temperature is between 22-27^{o}C in the lowlands and 10 and 22^{o}C in the highlands [23] Tigdar River is a huge river which was found in this wereda and selected as the study area for the assessment of small scale hydropower potential (SHP) using GIS and hydrological modeling (SWAT). The area is 19910.52ha andthe length is 38.3469 km longer. It’s out to let longitude 10.82343 and latitude 38.195833.The location of the Tigdar Riveris shown in the following figure (Figure 3.1).

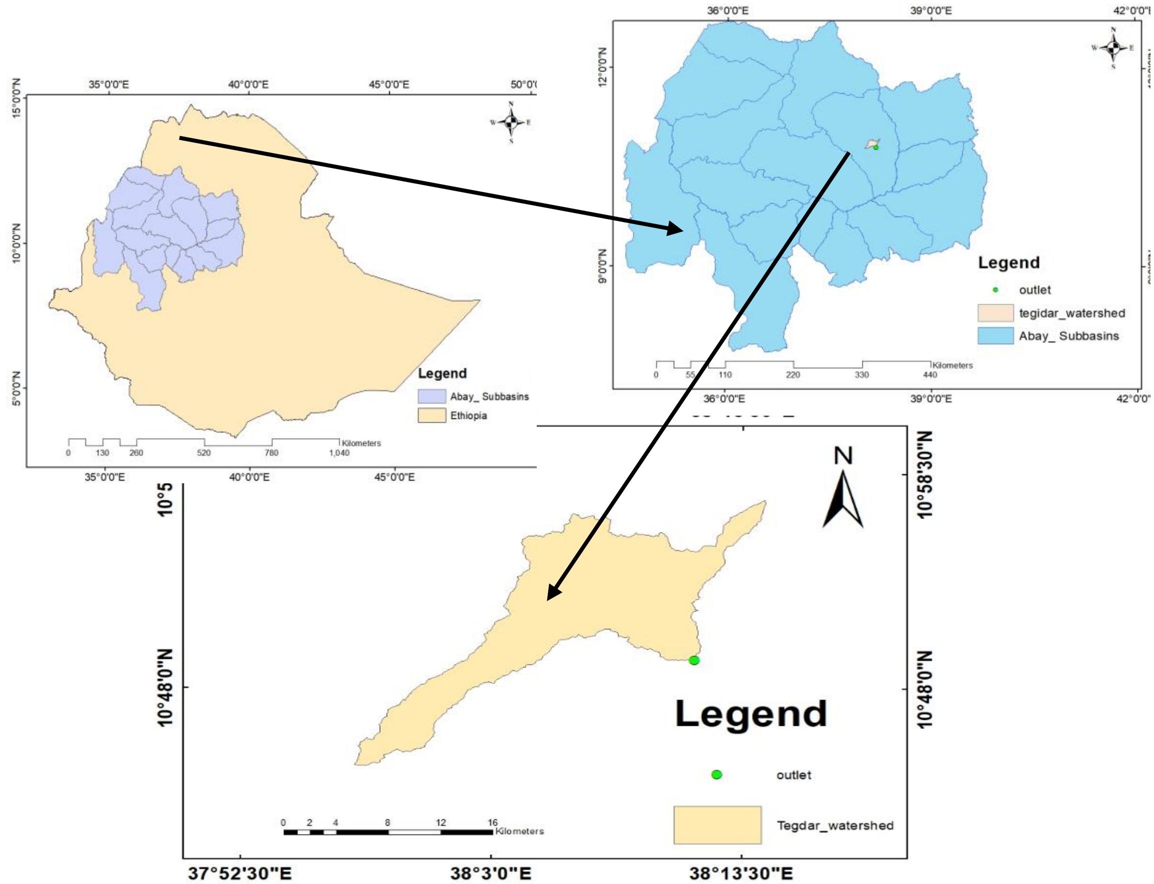

Figure 3.1: Tigdar river basin location

3.1 Data Collection and Preparation

This hydro potential assessment study using GIS application with SWAT2012 requires some specific data for simulation of flow rates. These data can be categorized as spatial thematic map data and discrete data corresponding to discrete location, including, climatic data, Discharge data, soil type and land use/cover data.

Table 3.1: List of necessary datasets in this study

No	Type-specific location. Spatial thematic map data includes 1.Digital Elevation Model (DEM), 2. Stream network data, 3. Land use map, and 4. Soil map. The input data of Data	Specification	Source	Desecration
1	flow Discharge	1station(2008-2020)	FDREABA	m^3s^{-1}
2	DEM	Resolution of 30m	Earth explorer.google.com	NASA SRTM Digital Elvation.tif.ovr
3	Land use		FDREABA	Land use classification (.ship file)
4	Soli type			Soil type (.ship file)
5	Rain fall	1station (2008-2020)	West Amhara methodology service center	In mm
6	Max tamp.	1station(2008-2020)		In ^{0}C
7	Min temp			In ^{0}c
8	Relative humidity	1station(2008-2020)		Fraction
9	Wind speed	1station(2008-2020)		m/s
10	Solar radiation	1tsation (2008-2020)		

3.2.Observed Discharge Measurement

The float method is used to measure the velocity and flow rate in a river by putting a floating object just beneath to reach a specified distance. The time taken for float object to travel from point startetime to end time is recorded over a known distance (L) to calculate the surface velocity as presented in Figure 3.2.. Thus, the discharge (Q) was calculated from the average stream velocity (V) and cross-sectional area (A):

$$Q=A.V \tag{2}$$

Q is the stream discharge (flow), V is the average stream velocity, and A is the cross-sectional area perpendicular to flow[31].

The float method (Figure 3.2) was used in this study to get a rough estimate of the Runoff River. The surface velocity ($V_{surface}$) of the river is measured using a floating object. The mean river velocity (V_{mean}) can then be calculated as follows:

$$V_{mean}=0.7.V_{surface} \tag{3}$$

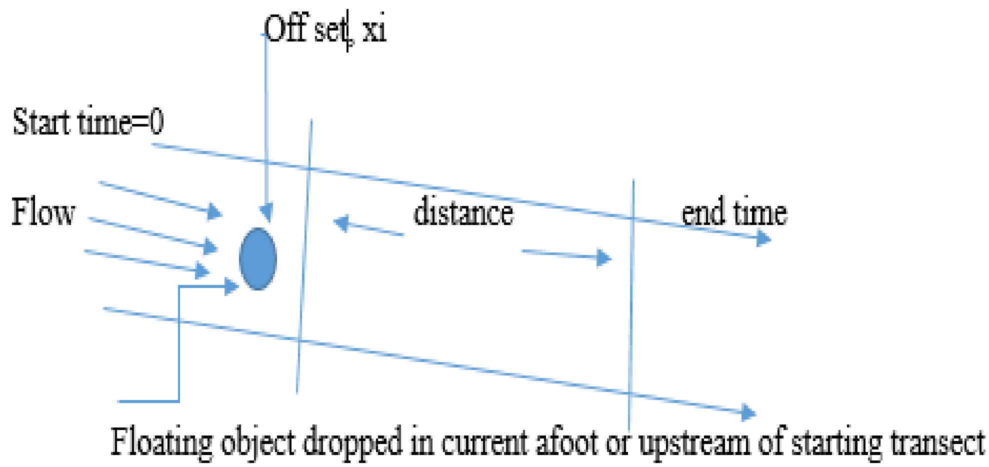

Figure 3.2: Float method setup for measuring the river surface velocity distribution

3.3.Data Analysis

Identifying sites and determining flows at selected sites have been the requirements for assessing hydropower potential on Tigdar River in the upper Abay basin. It was examined through simulations using the SWAT and dailyclimatic data from 2008 to 2020 (13years). DEM, digital stream, Land Use Land Cover/LULC/, soil type, and climatic data sets were used as inputsto the SWAT model for simulating daily flows at numerous points along the basin's rivers.

3.3.1. Data Quality Control

It involves for estimation of missing data. Consist of tests designed to ensure that hydrological data meet certain standards; it involves looking for errors in the acquired data sets and adequate length of data is essential for any hydrological analysis. The longer length of data, the more confidence on the reliability of the analysis[24].

3.3.1.1.Flow data

Flow data is one of the most important and predominant data for potential hydropower analysis of Tigdar River flow. Stream flow data are among the most valuable of all hydrological data because they represent all hydrologic factors.River flow data were required to evaluate the potential hydropower site.SWAT 2012 version and ArcGIS 10.6 software were used to estimate flows [26].The observed discharge of Tigdar was determined using the float method. Finally, by running the SWAT CUP model, the model's simulated flow, calibration, and validation were checked.

Tigdar River has a gauge station and a long periodof data. For the analysis of the hydropower scheme, its flow data is sufficient to manipulate the hydropower scheme, especially the run-off river type. The total available daily flow data at Tigdar station is 13years (2008-2020) (Figure 4). This data was used for the analysis of run-off hydropower potential sites. According to the FDREABA report, the number of missing data values is very small. As a result, the daily missing data were filled using the simple average method.

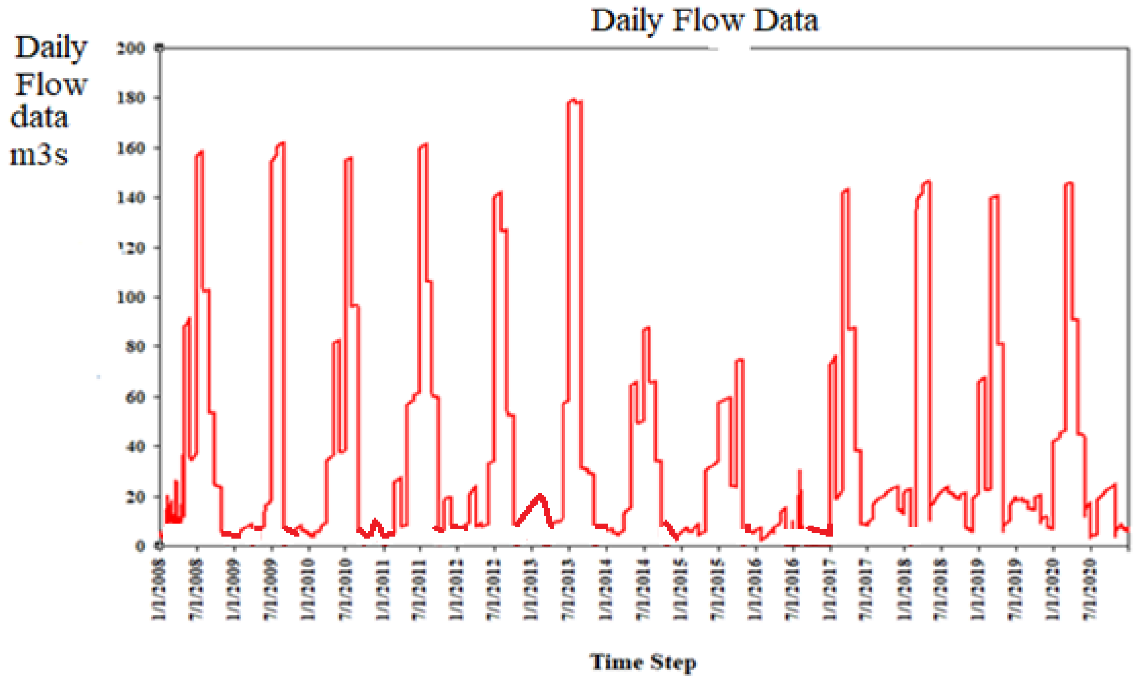

Figure 3.3: Daily Flow Data (source **FDRABA)**

3.3.2. Digital Elevation Model

The data source of DEM can be obtained from: explorer.earthengine.google.com Name NASA SRTM Digital Elevation. The data helps to recognize the elevation condition with 30m inter mission using the land's topography and distinguish the Watershed River's place. The digital elevation model corresponds to a regular grid of elevation, and each node of the grid shows an altitude value. Also, the resolution of the grid corresponds to the distance between neighbor nodes. The grid structure elevation data is stored in an array of grids. The data structure of a Grid shares many similarities with the file structure of computers: as two-dimensional arrays can be assigned to a row and column. Widely used Geographical Information System (GIS) software. ArcGIS was used for the processing of the satellite-derived Digital Elevation Model (DEM).

It was used to generate the stream map of the Tigdar River to select feasible stream reach site locations for potential hydropower development, which has enough flow for the generation of hydropower. The similarity of storage structures of the topological relations between the data points is recorded implicitly. As shown in Figure 3.4, the terrain features of the study area havea maximum value of 3940mand a minimum value of

2244m elevation.

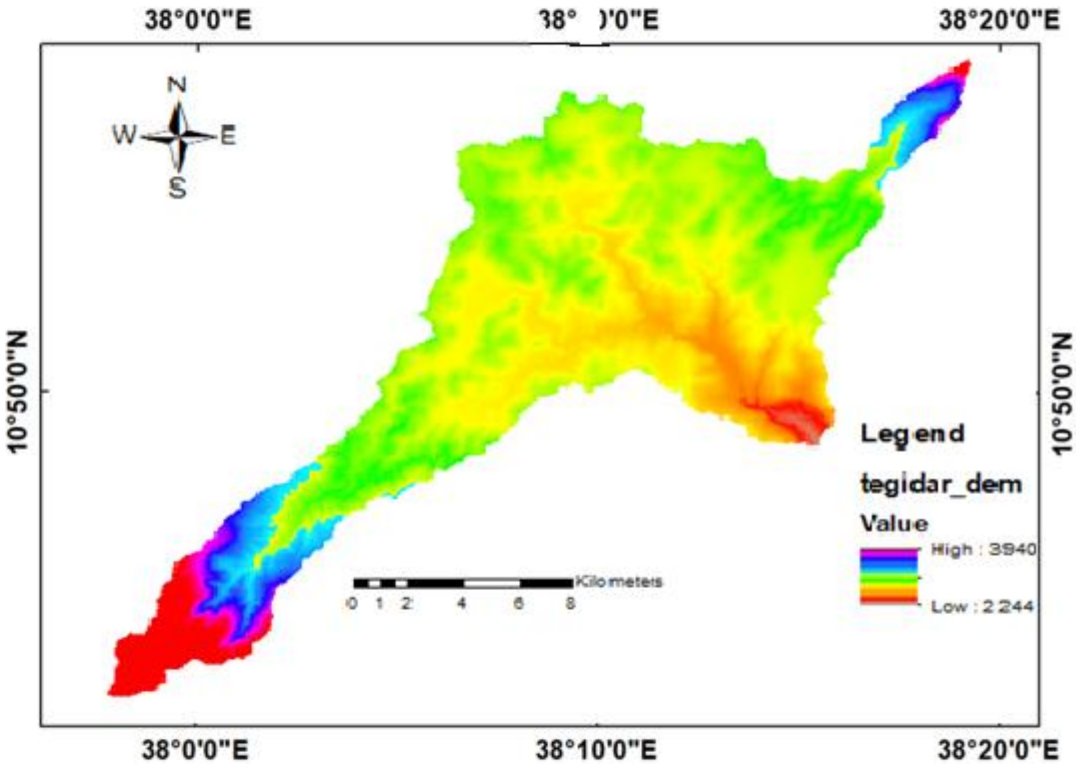

Figure 3.4: DEM for Tigdar watershed

Each class of the watershed is described by a complete set of statistics of terrain attributes, including elevation, slope, and graphical tools are used to ease understanding of the partition.

3.3.3. Land use/land cover

The land cover is the observed biophysical cover on the earth's surface. In contrast, land use is characterized by activities and inputs people undertaking on land cover type to produce, change or maintain it. LULC is one of the inputs of Arc SWAT, which is used to simulate hydrological data.Land use activity in the study area (Figure 3.5) is categorized into farming system activities. Most of the area in the watershed is covered by crop production. The land use ofthe agricultural practice is from top tobottom. The Tigdar land cover changes are caused by several natural and human driving forces. Natural effects like climate change are felt over a long period. The effects of human activities are instantaneous and often radical. It was impossible to obtain overall demographic data for the watershed studied here because of data compiled according to the administrative structure. Tigdar watershed covered by water (WATR) area

552.4ha,forest (FRST) area 1154.03ha, agriculture activity (AGRR) area 16957.29ha and pastoral activity (PASTR) area 1246.28ha (Figure 3.5).

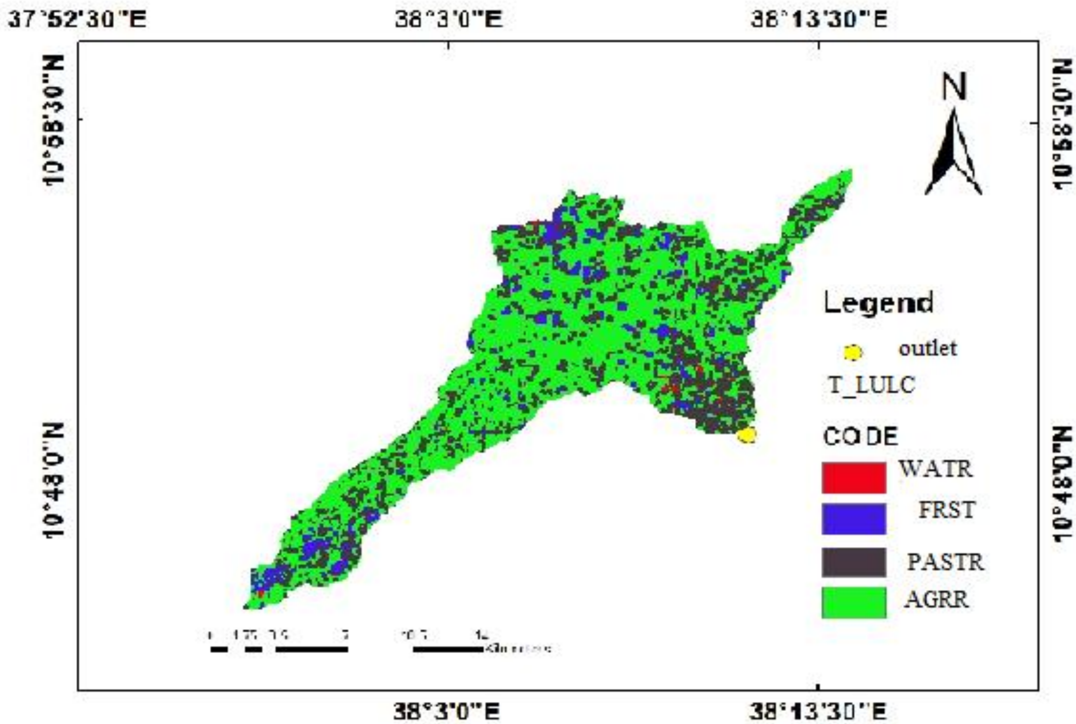

Figure 3.5: Land use/land cover of Tigdar watershed

3.3.4. Soil map of Tigdar River

The soil typedata source is found fromFDREABA. The soil properties include texture, hydronic conductivity, number of soil layer water capacity. It has its role in the hydrological cycle, and its significance is very high. The Tigdar watershed is covered by Eutricvertisols (Be50-2-3c-21) area11831.4ha, chromic luvisols (Be45-2a-16) area 578.43ha, HaplicAlisols (Bc9-2b-8) area5822.91 ha, Haplicluvisols (Be8-3c-24) area 52.11ha and Eurtic Lpeptosols(Bh11-1b-27) 2107.53ha. The soil data is used to define the HRUs, and the soil map of the Tigdar watershed is shown in Figure 3.6.

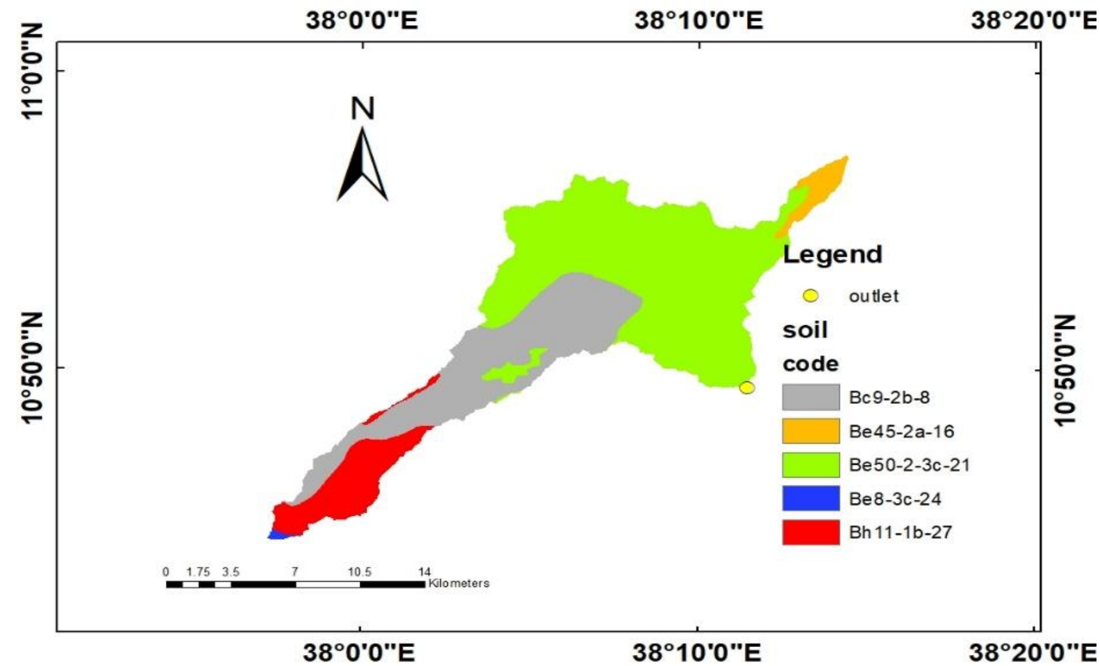

Figure 3.6: Soil type of Tigdar River

3.3.5. Climate Data

The SWAT requires meteorological data of solar radiation, wind speed, and relative humidity maximum and minimum temperature perception to simulate the Discharge flow in the watershed. In this study, 13 years of meteorological data were obtained fromthe West Amharameteorology service center recorded in one weather station (Debre Work, 408805 N,11788160 E) during a time boundary of 2008- 2020. The SWAT requires a specific format of meteorological data known as WGN user.To arrange the data in the WGN user format, an online Excel-based macro file named WGENmaker4 was used. WGEN maker4 arranges and calculates the weather station data in the WGN.xls user format as required by the Generate Arc SWAT.txt files.[29]. Firstly, 13 years maximum, minimum temperature (TMPMX, TMPMN), and mean total monthly perception (mmH_2O) (PCPMM)mon and standard division for daily perception in a month (mmH2O/day) (PCPSTD) were taken. The perception average and standard division were calculated by using two programs (pcpstat and dew02). To run PCP stat put in text format and run the program, and the first value in the file must have the value of January 1stand the last one of December 31st.If missing data in the measurement need to fill these days with no data values,then run the program[32]. After run the program we have got mean total monthly precipitation (mmH_2O)(PCP_MM)mon, standard division for dailyprecipitationin month (mmH2O/day)(PCPSTD)mon,skew coefficient for daily precipitation in month (PCPSKW)mon, probability of a wet day following a dry day in the month (PR_W1)mon, probability of a wet day following a wet day in the month (PR_W2)mon, average number of days of precipitation in month (PCPD)mon and maximum 0.5 hour rain fall in entire a period of record for month(mmH2O)(RAINHHM)mon, but RAINHHM can be calculated PCP_MM divided by two or(RAINHHM = PCP_MM/2).

The other data was average daily dew point temperature for each month (^{0}C) or relative humidity can be input (DEWPT)mon can be calculated by open dew02 program and to run the program daily maximum, minimum temperature and average daily humidity put in the txt format than run the program get dewpt of twelve months(Stefan et al.2003). Finally,WGEN user copy data was incorporated intothe SWAT 2012 version to simulatethe hydrological data of Tigdar River.

3.3.6. Flow accumulation of the study area

The flow accumulation tool in ArcGIS software calculates accumulated flow as the accumulated weight of all cells flowing into each downslope cell in the output raster. It is done using the Arc GIS hydrology toolbox, and it shows the drainage path based on the flow direction raster. The stream order of Tigdar River in different flow accumulation was identified by using Arc map10.6. The Flow Direction and Flow Accumulation tools were used more specificallyAccumulation flow calculation is based on the idea that water in a cell always flows to the comparatively steepest downslope neighbor cell out of the surrounding neighborhood cells [27]. The threshold value of less than 500 accumulated units is considered small streamflow that ismore likely to disappear due to natural processes like infiltration, evapotranspiration, and dry within short months [27].A threshold value of >=3000 accumulated flow units is chosen as the stream order in this study.

3.4. Criteria and Approach of Potential Site Identification

3.4.1. Criteria for Site Identification

I. Available flow

For the selection of the potential sites for hydropower, the following criteria were accepted. The accessibility of proper flow is to be ensured:

a) by considering first streams that have flow accumulation of 3000 cells or more, as determined from the flow accumulation map; and
b) as two second-order streams join to become a third-order stream, this will have sufficient runoff for connection of a powerhouse; thus, the flow accumulation map was studied along with the digitized drainage map to make sure that only streams of third-order or more are considered

II. Site spacing

a) The minimum distance between two successive sites should not be less than 1000 meters in ensuring a sufficient gap between the tailrace of one site and the diversion arrangement of the next site. This also ensures that the river ecosystem will have sufficient time to regenerate [2];and[28].

III. Head availability

a)head of >= 20 meters so that sufficient power is generated even for low flows[28]

3.4.2. Approaches for Potential Site Identification

Model Set up and configuration

In this study, the SWAT model was used to estimate components of the water balance in the watershed. Firstly, watershed delineation is needed to identify the potential site. The study catchment was delineated using the Soil, DEM interface, with 30-meter spatial resolution and SWAT2012.

After the catchment delineation process was done, the description of HRUs was continued for the SWAT2012 interface. Slope, land use/land cover, and soil maps are three spatial data sets and are important for the definition of HRUs. Then, all the required weather data were fed to the model. The weather generator tool in the Arc SWAT interface was allocated to fill for the case of inaccessibility of station data. This tool to enables us to produce the relative humidity, solar radiation, and wind speed from a long-term daily and maximum and minimum temperature and rainfall. The rainfall-runoff process was established to be estimated by the curve number (CN-method), and the Variable Storage Routing simulated the channel water routing. Next, all the above processes remained completed, the SWAT simulation was activated [33]. Through simulation, a two-year warming-up period was given. Including the two years warming-up period, the total simulation period was set to run from 2008 to 2020 (*i.e.*,13 years). Hence, 13 years of hydrologic variables were simulated for the study catchment (including the warmup periods). The major procedures in the simulation process are summarized in Figure 3.7

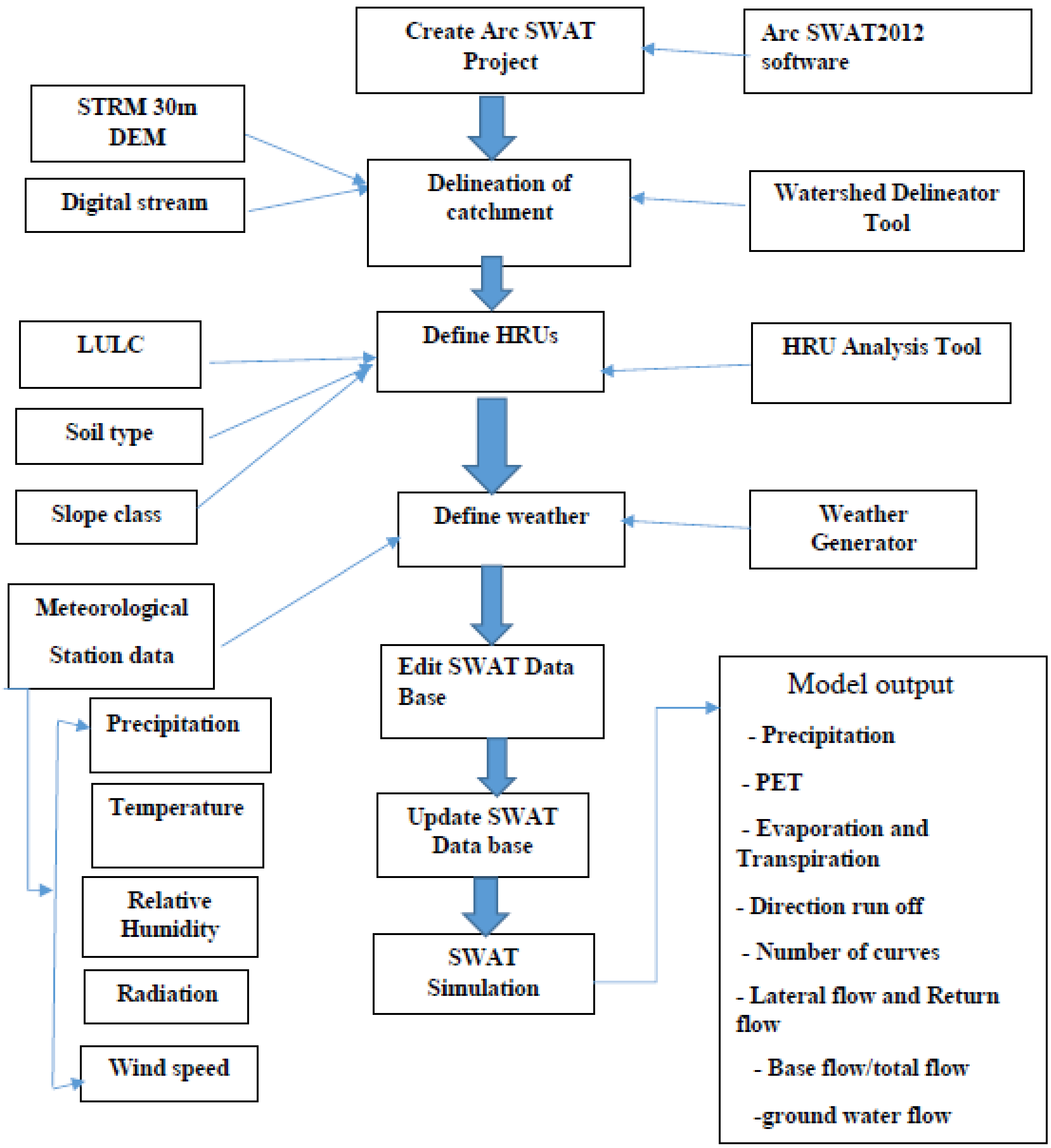

Figure 3.7: General frame modelling processing SWAT2012 to simulate the discharge

The SWAT 2012 used inputs to define the watershed and determine the hydrological definition. To simulate discharging and analyze the model's performance, the SWAT CUP model was employed. The relationship between simulated discharge and observed discharge was then investigated using calibration and validation. Finally, a potential site was discovered, and the amount of power created was calculated.The general procedure is summarized in Figure 3.8.

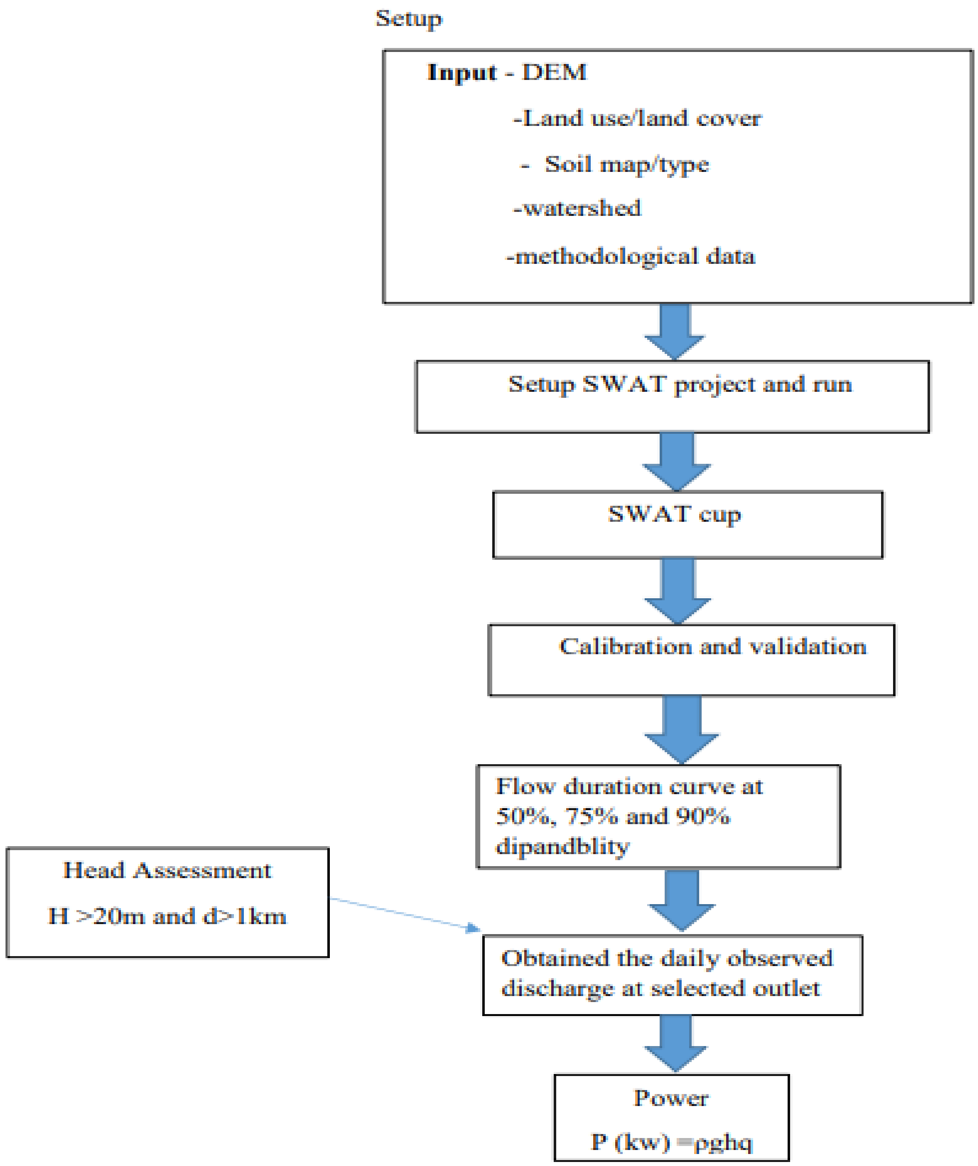

Figure 3.8: Flow chart for hydropowerpotential assessment.

3.5.Validation and Calibration of SWAT Model

SUFI-2 program of a semi-automated approach is used for calibration, validation, sensitivity, and uncertainty analysis. The uncertainty of the input parameters is described as uniform distributions, while the model output of uncertainty is quantified by the 95% prediction uncertainty (95PPU) r-factor and p-factor are statistical indicators and the main indices to govern the model's goodness-of-fit and uncertainty.The p-factor is the percentage of observed data connected by the 95% prediction uncertainty (95PPU). The r-factor is the average thickness of the 95PPU band divided by the standard deviation of the observed flow data. The P-factor ranges from zero (0) to one, and the r- factor range between zero and infinity[33]).In the ideal condition, where the simulation closely matches the observed data, the p-factor and r-factor tend to be 100% and 0, respectively. Still, these values cannot be realized for real cases due to the errors from different sources [34].

In this study, the Nash-Sutcliffe coefficient (NS) was used in the calibration and validation process. The coefficient of determination (R^2) was also used for the performance of the model. Equations (1and 2) were used to calculate the performance indices.

$$\mathbf{NS} = \mathbf{1} - \frac{\sum_i (Q_s - Q_{si}) i^2}{\sum_i (Q_{oi} - Q_o)^2} \tag{4}$$

$$\mathbf{R^2} = \frac{\sum_{i[}(Q_{s,i} - Q^-{}_s)(Q_{oi} - Q^-{}_o)]^2}{\sum_i (Q_{si} - Q^-{}_s)^2 \sum_i (Q_{oi} - Q^-{}_o)^2} \tag{5}$$

Q is a variable (*e.g.*, discharge), *o*and *s* stand for average measured and simulated variables, and s*i*is the*oi*measured or simulated data.

4. Result and Discussion

Hydropower generation has considerable attention because it is a renewable energy source and suitable means of providing electricity. In this study, hydrological models have been used to identify stream order, potential sites, evaluate the model performance, characterized the potential site andestimate the power of thepotential sites. The following results were obtained.

4.1 Stream order

The stream order technique was assigning a numeric order to linka stream network.It is used to describe the hierarchy of streams from the top to the bottom of a catchment and the number of stream supplies to the main river. The stream order was identified based on flow accumulation and the number of tributaries flowing into the stream,givingthe higher possibility to harvest more water. The analysis was done basedon Strahler's criteria(Korkovelos *et al.*, 2018).The stream order of TigdarRiver in different flow accumulation is shown in Figure 4.1.

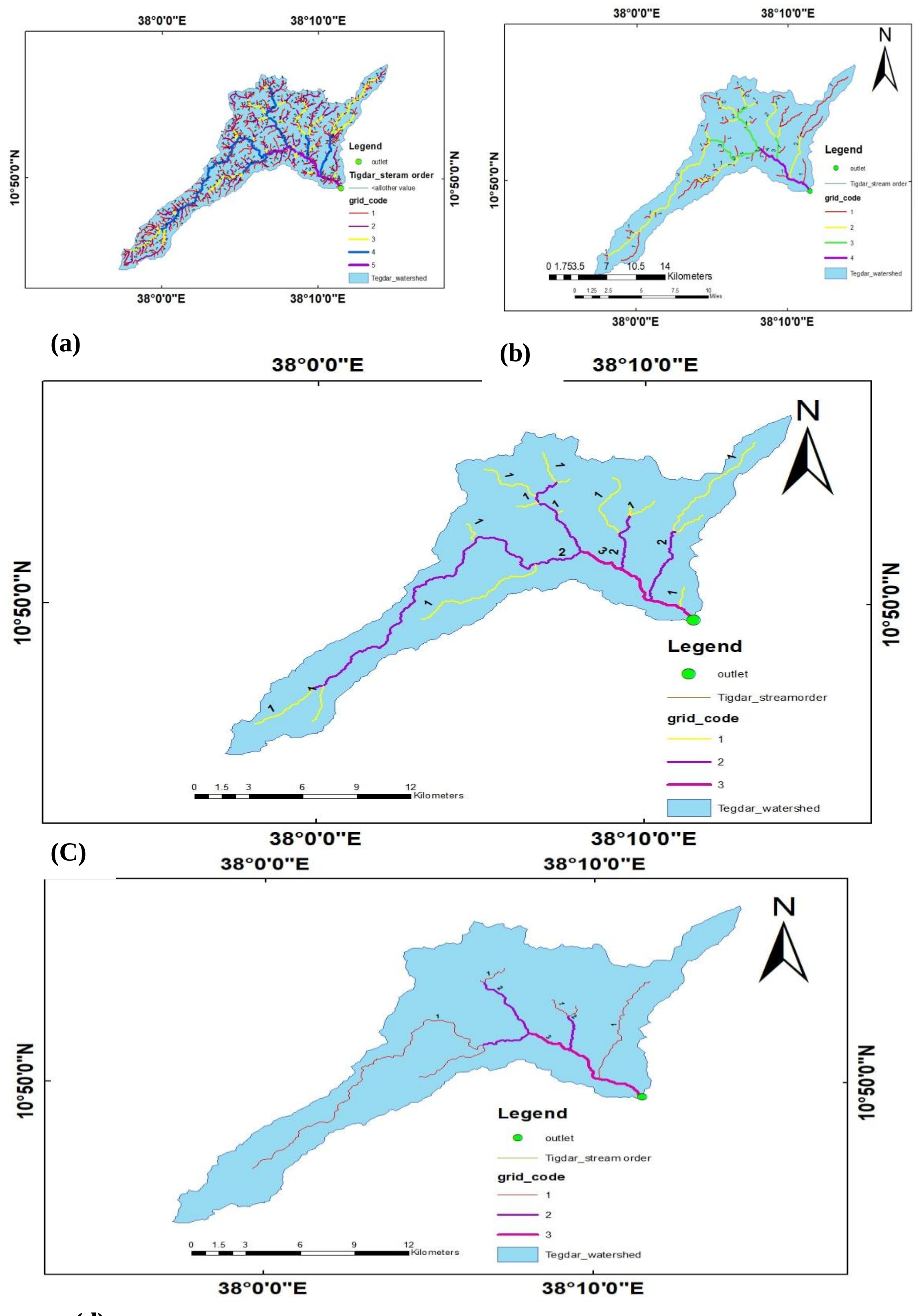

Figure 4.1: Tigdar river stream order in different flow accumulation

As revealed by[10], whentwo N^{th} order stream meets, the resultant stream becomes $(N+1)^{th}$ order stream.Similarly, when a higher $((N+1)^{th})$ order stream meets the lower order stream, the resultant streambecomes the highest order stream.

Accordingly, in the Tigdar watershed, when one stream is coded as 1(Figure 4.1c) and the main river meets, theresultant stream order number is assigned as stream order number 1 (purple color). When a 1^{st} stream order meets another two 1streams, the resultant stream isassigned as stream order number 2. Similarly, when the 2^{nd} stream order meets four 1 streams, the resultant stream order is assigned as stream order number 3 (pink color), which is the last higher stream order in the study area. Higher streamorders (3^{rd})are considered for selectingpotential hydropower sites to ensure the sufficiency of flows in the watershed streamflow.

The stream order of the Tigdar River was identified in this study at a threshold value of >=3000 flow accumulation (Figure 4.1c). This enables us to obtain the best stream orders, as confirmed by[9]. The number of stream orders may be reduced if the threshold value of >= 10,000 flow accumulation is used (Figure 4.1d). In addition, when the threshold flow accumulation values (>= 100 and >=1000) are fill in the Arc GIS Software, several mini streams which might be dried in the dry season are displayed as shown in Figures4.1(a) and 10(b).

4.2 Delineation of Watershed into Sub-Basins and HRUs

To delineate the watershed into sub-basin, DEM, LULC, soil type,slope, and Digital streams are used. In this study, the arc SWAT topographic measurements of each sub-basin are reported. SWAT model, satellite data and GIS tools were utilized to identify the outlet ofthe basin. In the Tigdar watershed, eight sub-basinswere identified within 38.3469km length and 19910.11ha area(Figure 4.2).

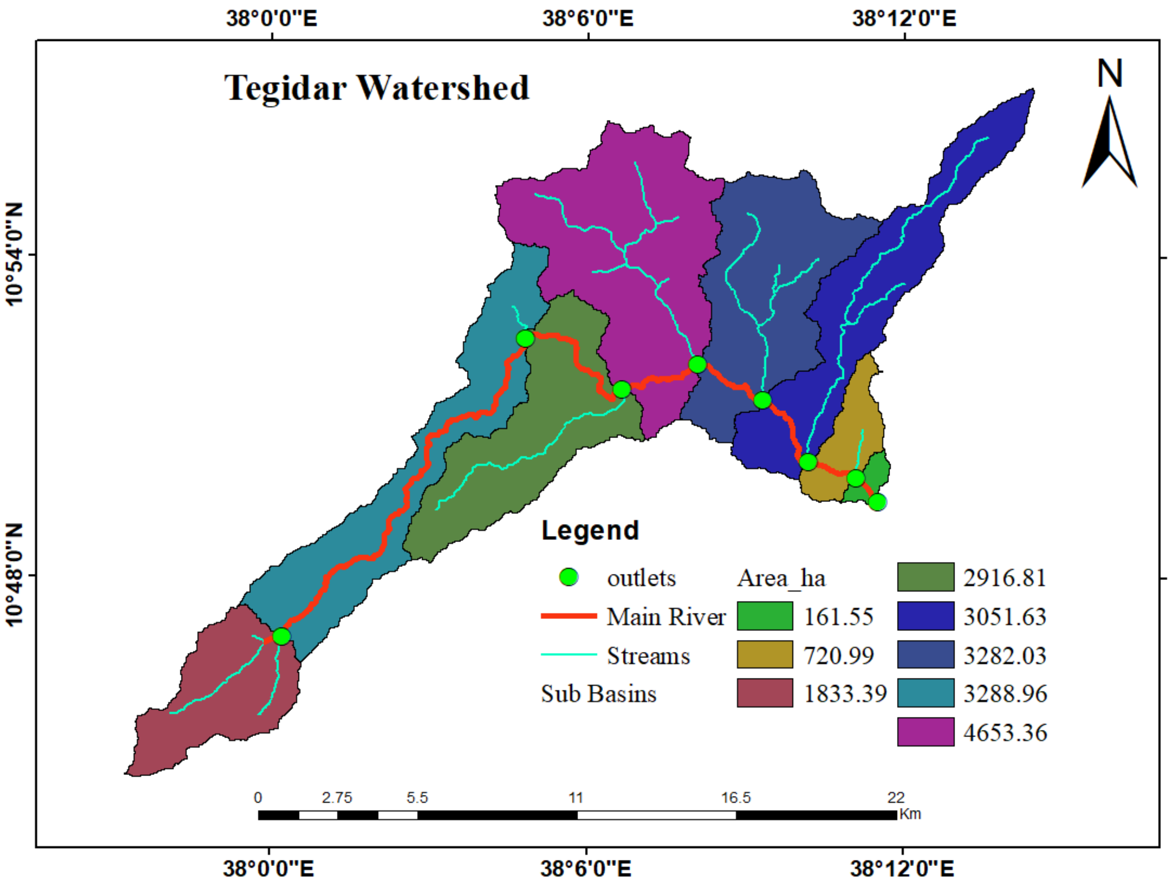

Figure 4.2: Tigdar River Watershed

Table 4.1 illustrates the hydraulic geometries of subbases in the watershed. A river's hydraulic geometry deals with differences in waterway characteristics caused by discharge variations. Despite sub-basin 8, sub-basins 2, 3, and 1 have the highest slope, indicating the availability of more heads for a given length, respectively. It also indicates the availability of potential sites in the catchment downstream.The width and depth values are also consistent with the river's bed slope. Even though there is a high slope in sub-basin 8, there are fewer streams and the possibility of low water accumulation.

Table 4.1: Hydraulic Geometry

Outlet Name	distance(m)	Width(m)	Depth(m)	Area(ha)	Latitude	Longitude	Max.Elva	Min Elva.	Slope
1	1205.95	30.905	1.08	161.55	10.827468	38.187915	2309	2248	5.05
2	1916.107	30.54	1.07	720.99	10.834207	38.17763	2349	2309	2.1
3	3154.63	27.75	1.01	3051.63	10.850233	38.161329	2455	2349	3.4
4	3017.06	24.4	0.9	3282.03	10.860348	38.148466	2490	2455	1.16
5	3224.9	18.9	0.78	4653.36	10.861954	38.118085	2548	2490	1.8
6	5438.01	14.99	0.67	2916.81	10.865701	38.097966	2586	2548	0.69
7	16613.15	12.8	0.6	3288.96	10.48234	38.055237	2828	2586	1.45
8	3758.45	5.84	0.356	1833.39	10.772338	37.992176	3318	2828	13.03

4.3 Calibration and Validation of SWAT CUP

The model calibration is the adjustment of model parameters within a suggested range so that the model output matches the observed data as closely as possible. The calibration tool of Arc SWAT allows the adjustment of different parameters through user interference. The algorithm (SUFI-2) of the SWAT Calibration Uncertainty Program (SWAT-CUP) tool was active for the calibration of parameters used. In this study, the SWAT model was validated and calibrated for the flow data of Tigdar River near Gindeweyin station (station no1120).The data for the flow was available from 2008 to 2020. The flow data for 2008-2016 were used to calibrate the model and from2017-2020 used for validation.

To examine the relative changes in model output with respect to changes in model input variables, sensitivity analysis must be performed[18].The effect that model parameters have on the output is determined by sensitivity analysis, reducing the number of calibration parameters.According to[2]research, to identify input parameters that have the greatest influence on model output, a careful study of input parameters and their sensitivity is required before calibration.Nine sensitive parameters were identified as having a significant influence on streamflow control in the watershed.The sensitivity analysis results of nine parameters with their relative minimum and maximum sensitivity values areshown in Table 4.2 below.

Table 4. 2: Sensitive parameters for calibration and validation

Parameters	**Definition**	**Min value**	**Max value**
ALPHA_Bank	Base flow alpha factor for bank storage	0	1
DIS_STREAM	Average distance to stream	0	1000
CN2.mgt	Curve number for soil water condition	35	55
GW_DELAY.gw	Ground water delay(days)	0	200
GW.REVAP. Gw	Ground water “revap”for the main channel	0.02	0.2
REVAPMN. Gw	Threshold depth of water in the shallow aquifer for “revap”to occur(mm)	0	500
CH_N2	Manning “n” value for the main channel	-0.01	0.3
SOL_Z	Depth from soil surface to bottom of layer	0	3500
ALPHA_BF. Gw	Base flow alpha factor (days)	0	1

The SWAT-CUP model is calibrated and validated using several input parameters. To calibrate the model, the above parameters (Table 4.2) are the only input parameters with medium, high, and very high sensitive values that significantly affect the model output.Because parameters with low sensitivity values have little effect on model output, they are ignored during the calibration process. The remaining parameters were ignored because they were discovered to be small, sensitive, and less. They have no significant effect on model output and can be dropped during model calibration.As a result, the model was calibrated using only nine medium, high, and very high sensitive parameters.

The sensitive parameters were used within an acceptable range to determine the best suitable observed and simulated discharge. Figure 4.3 depicts the observed (red color solid line) and simulated (green color break line) series for model calibration and validation.

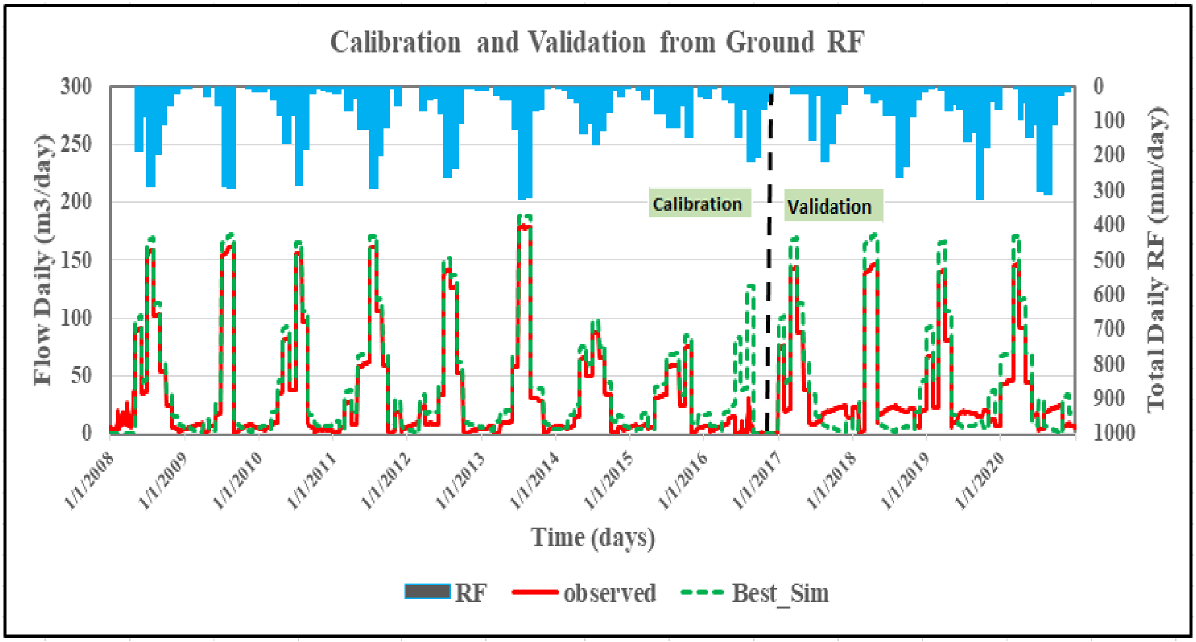

Figure 4.3: Calibration and validation of Tigdar River observed and simulated flow data

The determination coefficient (R^2) and Nash-efficiency Sutcliff's (ENS) were used to assess the relationship between simulated and observed data sets. The calibration and validation models were the most correlated between simulated and observed data sets, as shown in Figure 4.3.To accept the calibration model as representative, the validation model must be computed for isolated and independent data sets to ensure its reliability[3]. Calibration and validation were performed using measured flow data from 2008 to 2016 and four years from 2017 to 2020, respectively (Table 4.3).

In this study, the values of R^2 and E_{NS} were found in a very good performance of the model (>=0.75, Table 2.4) and agreement with [20] with R^2 (0.85) and E_{NS} (0.78) values. The p-factor and r-factor values are also within the acceptable ranges. The result demonstrates a very close relationship between observed/measured/ and simulated modeled discharges, and the model hasthe best performance.

Table 4.3: Statistical indexes for calibration and validation from 2008-2020

Statistical Evaluation Criteria	**Calibration (2008-2016)**	**Validation (2017-2020)**
R^2	0.91	0.91
NSE	0.87	0.78
P-factor	0.14	0.01
r-factor	0.00	0.00

4.4 Identification and Characterization of Potential Sites

4.4.1 Identification of Potential Sites

Physical observation aided by a Global Positioning System (GPS)was used to identify potential sites of the Tigdar watershed. A site is identified as a potential site when a head of greater than 20 meters in the stream and a distance of 1000 meters or more between two sites (Table 9). The result is in agreement with the findings of [18], which is described in method section 3.5 for the identification of potential sites

Head is the pressure created by the elevation difference between the upper surface and down the surface. It was measured using GPS during a field visit to the watershed (Figure 4.4).

Figure 4.4: Picture of Head at Tigdar River

Based on the criteria (Section 3.5), three potential sites were identified in the watershed, as shown in Table 4.4. Minimum and Maximum heads were found at Site 1 and Site 3. The minimum and maximum elevation values are also in line with the value of head at each site.

Table 4.4: GPS reading of Potential sites at Tigdar River

Sites	Latitude	Longitude	Maximum Elv. (m)	Minimum Elv. (m)	Head (m)
Site1	10.826332	38.189239	2487	2463	24
Site 2	10.83363	38.177417	2678	2652	29
Site 3	10.850672	38.162278	2742	2681	61

The potential sites are shown by blue dots(Figure 4.5).Potential site 1found in sub-basin one, potential site 2was found in sub-basin two and potential site 3 was found in sub-basinthree.Sub-basin one, two, and three are the light blue traces (right to left) linked to the main river (red color).

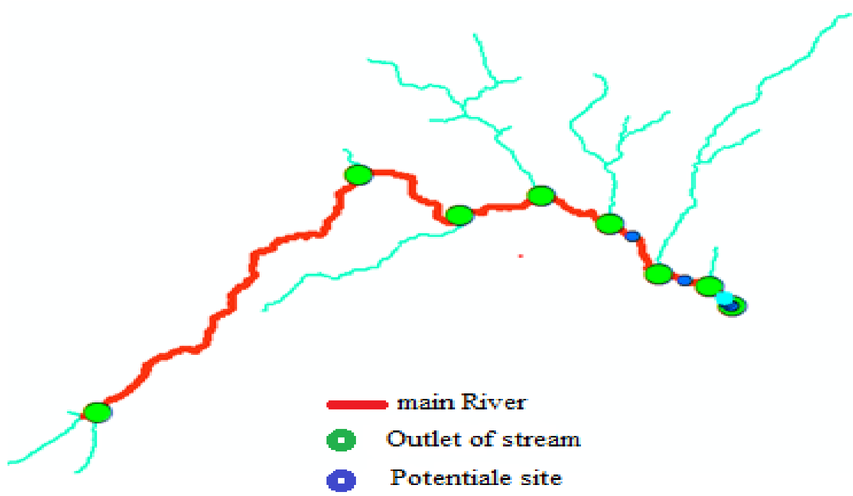

Figure 4.5: Potential Sites at each Sub-basins of Tigdar Watershed

The location of potential sit one from the community 19.6 km, sit two 11km and sit three 3km from begido sub city.

4.4.2 Characterization of Potential Sites

4.4.2.1. Flow Duration Curves

Delineation of the watershed, calibration and validation of the SWAT model are the pre-requisites for identifying potential sites. After calibrating and validating the model, it was used to estimate daily river flow in each of the potential sites identified using the criteria outlined in Method Section 3.5.In the Tigdar watershed, three potential sites (blue dots) were identified.

Flow duration analysis was performed on the selected hydropower sites using the FDC 2.1 software. The flow duration curve depicts the percentage of time that a stream flows that is likely to equal or exceed a specified value of interest[36]. It can show the percentage of time river flow that can be expected to exceed a design flow of some specified value after the model has simulated time-based water discharge data.The flow duration curve at each potential site represents the percentage of time that streamflow is likely to equal or exceed an interesting value for hydropower generation.Daily rainfall and temperature data from 2008 to 2020 created flow duration curves for all identified hydropower locations and sub-basins.

In this study, only available natural sites where power could be generated without a reservoir were identified as potential sites.The figure below (Figure 4.6) depicts the amount of discharge obtained from simulation results for all imported time-series for the percentage of time river flow can be expected to exceed a design flow of some specified value with potential sites one, two and three that can be considered.

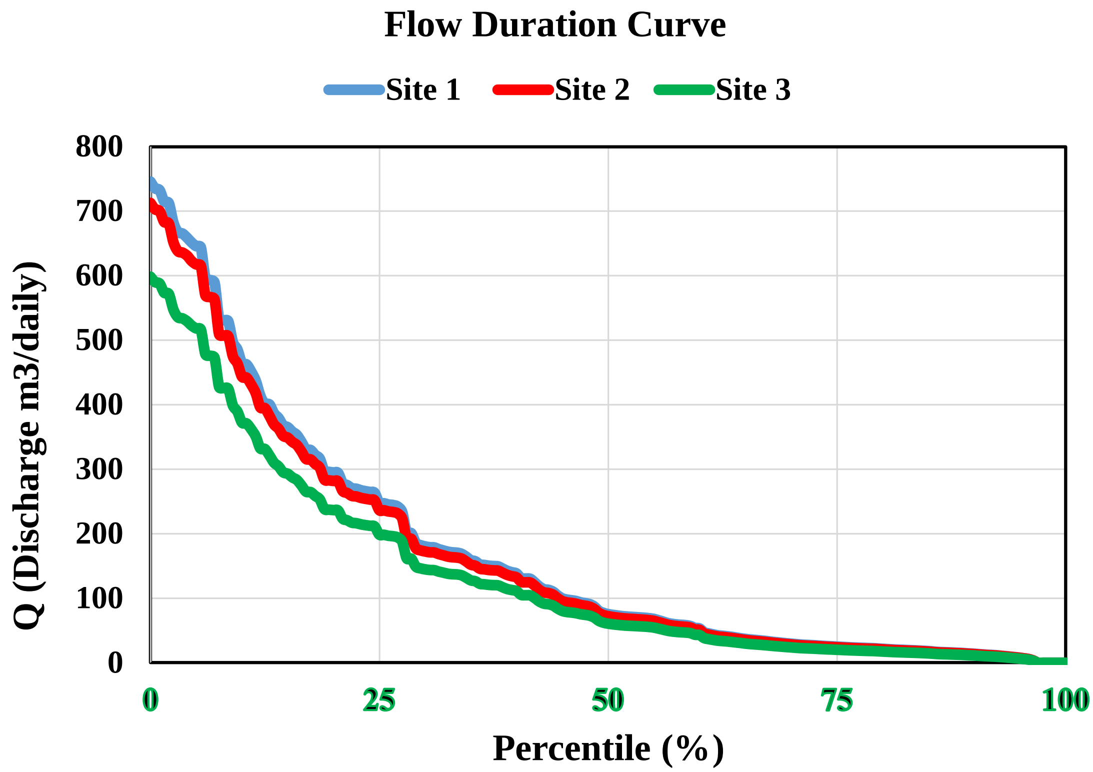

Figure 4.6: Flow exceeded probability curve for potential sites 1 (blue line color), 2 (red line color) and 3 (green line color) at Tigdar River

According to[33],the above curves show the percentageof time/percentile/ that flow equals or exceeds various values during the recording time; forexample, Q(75, daily) is the flow that is reached or exceeded statistically in 75% of the time, i.e.,inan average year at 75 percent of 365 days.FDC does not account for variations in head independent stream flow and does not describe the seasonal distribution of streamflow. On the other hand, these curves are useful for evaluating the power output of the run of a river and other power projects wherethe head varies directly with the flow [9].

4.4.2.2.Selection of Design Discharge for the Potential Site

During hydropower development, the potential capacity of the proposed site has to be taken into consideration since the river flow is affected by seasonal variations.As a result, minimum flow analysis is required to predict dependable capacity; average flow analysis is important for energy output considerations, and maximum flow analysis is critical from design or installed capacity.

The design flow is chosen based on the available flow at the site in the watershed; the flow is designed approximately half of the time (Q_{50}). Q_{50}, Q_{75}, and Q_{90} are thinking about visualizing the flow condition for each of the duration curves created for the site. The meaning of Q_{50} is available to discharge in the river 50% of the time.

Table 4.5: Simulated Daily discharge at selected percentile for the selected site in m3/s obtained from FDC of each potential site

Number	No. of sites in Selected Sub-basin	Discharge m3/s) at 0.5 dependability	Discharge m3/s) at 0.75 dependability	Discharge m3/s) at 0.9 dependability
1	1(1)	75.41	25.06	14.01
2	1(2)	72.23	23.97	13.44
3	1(3)	60.65	20.17	11.31

These percentile values were chosen because percentages are important in hydropower plant size. These percentile values are based on mean daily flow data for the available site.

4.5. Prediction of the Dependable Potential Site Capacity

4.5.1. Estimation of Hydropower Potential

To predict dependable or firm plant capacity, minimum flows are required. Long time Series River flows daily data was collected for the computation of water availability. The firm flow of rivers is specified by the flow duration curve, which is typically set by users between 90% and 100% [9]. According to the Ministry of New and Renewable Energy (MNRE, 2008andPandey *et al.*, 2015) the hydropower generation is estimated by considering three levels of dependability, 90%, 75%, and 50%. Water availability for hydropower is estimated in this study based on a 90% dependable flow. The 90% of flow denotes the number of river flows available 90% of the time, which is the flow that exists during the driest season.However, the installed capacity of a hydropower station increases when there is an increase in flow during a rainy season to meet maximum power generation.

The discharge of the River in each potential site was determined using observed and simulated daily flow data.

i) Measurement of Observed Discharge

River discharge is an important asset regularly monitored along with several of Ethiopia's major rivers and streams. The discharge (Q) was calculated from the average stream velocity (V) and cross-sectional area (A) using the float method, as described in the method section in equations (2 and 3).Table 4.6 shows the discharge of potential sites in the Tigdar watershed.

Table 4.6: Cross sectional areas and velocity profile measurement of Tigdar River

Sites	**Width (w) in m**	**Average Depth(d) in m**	**Distance travel(L) in m**	**Time (T) in sec**	**Velocity**		**Area (A) m^2**	**Discharge (Q) m^3/s**
					Surface Velocity (V_{su})in m/s	**Mean velocity in m/s**		
Site1	13.83	0.584	20	13.66	1.46	1.028	8.76	8.303
Site2	13.92	0.536	20	12.94	1.54	1.078	7.461	8.043
Site3	12.43	0.776	20	18.8	1.064	0.774	9.65	7.469

Potential sites 1 and 3 had the highest and lowest discharges, respectively.Table 4.6 shows the amount of discharge obtained from observed results for all imported time-series for 50%, 75%, and 90% of time river flow.

Table 4.7: Time dependable observed discharge amount obtained from FDC of each potential site

Sites name	**Dependability of 50%**	**Dependability of 75%**	**Dependability of 90%**
Site1	8.739	8.034	7.65
Site2	7.608	6.038	5.598
Site3	6.899	5.368	5.261

The amount of observed discharge obtained from the 50%, 75%, and 90% flow duration curves for Site 1 is greater than the observed discharge amount obtained from potential Sites 2 and 3, ensuring that maximum hydropower may be produced from Site 1.

i) **Determination of Efficiency (η) and Turbine Types**

In this study, Francis Turbine and Kaplan Turbine were used in Tigdar River based on the available head determined by river elevation in GPS readings.If the head (m) is less than 45m, the Kaplan turbine is used, if the head (m) is between 45-250m, the France turbine is used, and if the head (m) is greater than 250m, the Pelton turbine is used[37]. Based on the above head interval, the efficiency of the Francis turbine and the Kaplan turbine is 90%.

In this study, the hydropower of a potential site in the Tigdar River is estimated by taking the average of the observed and simulated discharge of the SWAT model, which has 90% dependability (Table 4.8).

Table 4.8: Average simulated and observed discharge FDC 90% dependability

Sites Name	Head (m)	Simulated dischargeFDC 90%	Observed discharge FDC 90% dependability	Average simulated and observed discharge 90% Dependability
Site1	24	14.01	7.65	10.83
Site2	29	13.44	5.598	9.519
Site3	61	11.31	5.261	8.285

Maximum discharge was found at Potential site 1 of the Tigdar watershed in more cases, with 90% dependability. This ensures the production of large amounts of hydropower from the remaining potential sites.

ii) Power Production Capacity in Selected Hydropower Potential Sites of Tigdar Watershed.

The amount of power produced by a hydro-power plant during a specific period is referred to as hydropower. Energy is the amount of work done over time or the capacity to do work. Electricity is a type of energy that can be measured in joules, but it is usually expressed in megawatt-hours (MWh), kilowatt-hours (KWh), or gigawatt-hours (GWh). The electrical power produced from each potential site in the watershed is presented in Table 4.9.

Table 4.9: Hydropower Potential of Tigdar Watershed

Site Name	**Types of Turbine**	**Head (m)**	**Discharge (m3/s)**	**Gravity (m/s^2)**	**Density (kg/m^3)**	**Efficiency (%)**	**Power (kW)**
Site1	Kaplan	24	10.83	9.81	1000	90	2294.83
Site2	Kaplan	29	9.519	9.81	1000	90	2437.25
Site3	Francis	61	8.285	9.81	1000	90	4462.04
Sum							9194.093 kw

Using equation (1), the maximum and minimum power production capacities of hydropower sites 3 and 1 are 4462.04KW and 2294.83 KW, respectively. Tigdar watershed has a total power production capacity of 9194.093KW (9.2 MW). The high value of the head is associated with potential site 3's maximum power production capacity.

This research aims to estimate the hydropower potential of the Tigdar watershed. As a result, based on the study's objective, the final result shows that the selected River hydropower sites are feasible (in the range of small-scale hydropower) based on their installed capacity.

5. Conclusion and Recommendations

5.1.Conclusion

Hydropower is one of the most reliable renewable energy sources.Compared to other renewable energy sources, hydropower has low operating and maintenance costs, contributes to sustainable energy development, is environmentally friendly, has a high efficiency, and plays an important role in reducing the environmental pollution.

There is a huge amount of water resource in Ethiopia. However, more than 70% of the population does not have access to electricity. Therefore, the largest basins and lakes in the country should be studied and used for power generation.Furthermore, the small hydropower's location must have a good head and water flow rate to produce a sufficient amount of power, and it must also be close to the location where the energy will be used.Streamflow data is important in determining the maximum power derivable from any flowing river because it represents an integration of all hydrologic factors.

The research aimed to identify the potential site and estimate the hydropower generated from the Tigdar watershed.Arc GIS and SWAT model are effective tools in the identification of suitable sitesfor hydropower plants.Daily flow data is more preferred than monthly and annual flow data for the identification of potential sites.The calibration and validation models were found to be the most correlated between simulated and observed data sets.

Three potential sites have been identified in the Tigdar watershed. The flow duration curve is useful for evaluating the power output of a run of the river. The water availability in the driest season for hydropower is estimated in this study based on a 90% dependable flow. The discharge of the River in each potential site was determined using observed and simulated daily flow data. Maximum discharge was found at potential site 1 of the Tigdar watershed in more cases, with 90% dependability. Maximum power would be generated from potential site 3 compared to other sites. About 9.2MW will be generated from the watershed. If a hydropower plant project is developed, the surrounding rural communities will have access to electricity, thereby alleviating energy crises.

5.2.Recommendations

The demand and supply of electricity in Ethiopia are unbalanced due to inefficient resource use and economic issues. Better access to energy must be increased and supplied to the rural community to bring about meaningful change in economic development. Hydropower generation has considerable attention because it is a renewable energy source and suitable means of providing electricity.

This study aimed to assess the potential hydropower sites in the Tigdar watershed to reduce the energy crisis in the surrounding community. This type of potential assessment technique is essential because it provides clear information on how the water resource can be effective to power generation since no study has been made before.

Tigdar River has a high power potential with a high head of up to 61m and good flow conditions. As a result, I recommend that the local government or other institutions looking for details and findings to implement the hydropower construction and installation study.

Additional studies such as head measurement using a DEM, turbine design and speed, should be carried out during the hydropower potential assessment.

According to the findings of this study, many watersheds and lakes in our country has not been studied and are not being used for power generation. As a result, the government and non-governmental organizations should use their full potential to address the community's electricity crisis by researching and implementing large hydropower projects in each area. This improves the living standards of the community and upgrades the development of the country as a whole.

Reference

[1] E. Arthur *et al.*, "Journal of Hydrology : Regional Studies Potential for small hydropower development in the Lower Pra River Basin , Ghana," *J. Hydrol. Reg. Stud.*, vol. 32, no. August, p. 100757, 2020, doi: 10.1016/j.ejrh.2020.100757.

[2] W. Dilnesa, "GIS and Hydrological Model Based Hydropower Potential Assessments of Temcha Watershed," *J. Energy Technol. Policy*, vol. 10, no. 5, pp. 9–16, 2020, doi: 10.7176/jetp/10-5-02.

[3] N. Rospriandana and M. Fujii, "Assessment of small hydropower potential in the Ciwidey subwatershed, Indonesia: A GIS and hydrological modeling approach," *Hydrol. Res. Lett.*, vol. 11, no. 1, pp. 6–11, 2017, doi: 10.3178/hrl.11.6.

[4] Umaru Garba Wali, "Estimating Hydropower Potential of an Ungauged Stream," *Int. J. Emerg. Technol. Adv. Eng.*, vol. 3, no. 11, pp. 592–600, 2013.

[5] V. Sammartano, L. Liuzzo, and G. Freni, "Identification of potential locations for run-of-river hydropower plants using a GIS-based procedure," *Energies*, vol. 12, no. 18, pp. 1–20, 2019, doi: 10.3390/en12183446.

[6] Y. Gao and D. Long, "Intercomparison of remote sensing-based models for estimation of evapotranspiration and accuracy assessment based on SWAT," vol. 4869, no. July, pp. 4850–4869, 2008, doi: 10.1002/hyp.

[7] A. Ajanovic and R. Haas, "On the long-term prospects of power-to-gas technologies," *Wiley Interdiscip. Rev. Energy Environ.*, vol. 8, no. 1, pp. 1–16, 2018, doi: 10.1002/wene.318.

[8] X. Cai, F. Ye, and F. Gholinia, "Application of artificial neural network and Soil and Water Assessment Tools in evaluating power generation of small hydropower stations," *Energy Reports*, vol. 6, pp. 2106–2118, 2020, doi: 10.1016/j.egyr.2020.08.010.

[9] V. Singh, "Flow Duration Curve," *Introd. to Tsallis Entropy Theory Water Eng.*, pp. 303–326, 2015, doi: 10.1201/b19113-16.

[10] S. Saad and A. Y. Hatata, "S. Saad, A. Y. Hatata and M. M. El-Saadawi," vol. 43, no. 3, pp. 10–18, 2018.

[11] D. M. Degefu, W. He, and J. H. Zhao, "Hydropower for sustainable water and

energy development in Ethiopia," *Sustain. Water Resour. Manag.*, vol. 1, no. 4, pp. 305–314, 2015, doi: 10.1007/s40899-015-0029-0.

[12] D. Egré and J. C. Milewski, "The diversity of hydropower projects," *Energy Policy*, vol. 30, no. 14, pp. 1225–1230, 2002, doi: 10.1016/S0301-4215(02)00083-6.

[13] B. van der Zwaan, A. Boccalon, and F. Dalla Longa, "Prospects for hydropower in Ethiopia: An energy-water nexus analysis," *Energy Strateg. Rev.*, vol. 19, pp. 19–30, 2018, doi: 10.1016/j.esr.2017.11.001.

[14] A. Teshome, "Assessment of Hydropower Potential Using Geospatial Technology in a Case Study of Guna- Tana Landscape Upper Abay Basin , Ethiopia," pp. 1–19.

[15] S. Abolhosseini, A. Heshmati, and J. Altmann, "A Review of Renewable Energy Supply and Energy Efficiency Technologies," *IZA Discuss. Pap.*, no. 8145, 2014.

[16] J. K. Arthur, "Assessment of a typical small hydropower site for rural," *Master Sci. Renew. Energy Technol. KNUST*, 2014.

[17] A. Bartle, "Hydropower potential andn development activities," *Fuel Energy Abstr.*, vol. 44, no. 4, p. 241, 2003, doi: 10.1016/s0140-6701(03)83046-1.

[18] A. Pandey, D. Lalrempuia, and S. K. Jain, "Evaluation du potentiel hydroélectrique utilisant la technologie spatiale et le modèle SWAT pour la rivière Mat, dans le sud Mizoram, Inde," *Hydrol. Sci. J.*, vol. 60, no. 10, pp. 1651–1665, 2015, doi: 10.1080/02626667.2014.943669.

[19] A. Kumar and M. Freitas, "Hydropower," no. May 2017, 2012.

[20] N. Pokharel, K. Basnet, B. Sherchan, and D. Thapaliya, "Assessment of Hydropower Potential using SWAT modeling and Spatial Technology in the Seti Gandaki River, Kaski, Nepal," vol. 8, no. 7, pp. 87–102, 2020.

[21] B. C. Kusre, D. C. Baruah, P. K. Bordoloi, and S. C. Patra, "Assessment of hydropower potential using GIS and hydrological modeling technique in Kopili River basin in Assam (India)," *Appl. Energy*, vol. 87, no. 1, pp. 298–309, 2010, doi: 10.1016/j.apenergy.2009.07.019.

[22] A. Balasubramanian, "DIGITAL ELEVATION MODEL (DEM) IN GIS by

Prof . A . Balasubramanian Centre for Advanced Studies in Earth Science , University of Mysore , Mysore," no. September, 2017, doi: 10.13140/RG.2.2.23976.47369.

[23] D. Tessema, "DESIGN OF MICRO HYDRO POWER SYSTEM ON TEMIE RIVER BY :," vol. 7, no. 3, pp. 1095–1205, 2019.

[24] F. Ali, C. Srisuwan, K. Techato, A. Bennui, and T. Suepa, "Theoretical Hydrokinetic Power Potential Assessment," *Energies*, pp. 1–13, 2020.

[25] P. Punys, A. Dumbrauskas, A. Kvaraciejus, and G. Vyciene, "Tools for Small Hydropower Plant Resource Planning and Development: A Review of Technology and Applications," pp. 1258–1277, 2011, doi: 10.3390/en4091258.

[26] X. Cai, F. Ye, and F. Gholinia, "Application of artificial neural network and Soil and Water Assessment Tools in evaluating power generation of small hydropower stations," *Energy Reports*, vol. 6, pp. 2106–2118, 2020, doi: 10.1016/j.egyr.2020.08.010.

[27] X. Dai, "Dam site selection using an integrated method of AHP and GIS for decision making support in Dam site selection using an integrated method of AHP and GIS for decision making support in Bortala , Northwest China By," no. 14, 2016.

[28] A. Pandey, D. Lalrempuia, S. K. Jain, A. Pandey, D. Lalrempuia, and S. K. Jain, "Assessment of hydropower potential using spatial technology and SWAT modelling in the Mat River , Assessment of hydropower potential using spatial technology and," vol. 6667, no. March 2016, 2015, doi: 10.1080/02626667.2014.943669.

[29] J. Arnold, D. Moriasi, P. Gassman, and M. White, "SWAT : Model use , calibration , and validation," 2012.

[30] D. Moriasi, J. Arnold, and M. W. Van Liew, "Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations," no. May 2007, 2013, doi: 10.13031/2013.23153.

[31] Y. Tian, F. Zhang, Z. Yuan, Z. Che, and N. Zafetti, "Assessment power generation potential of small hydropower plants using GIS software," *Energy Reports*, vol. 6, pp. 1393–1404, 2020, doi: 10.1016/j.egyr.2020.05.023.

[32] A. Q. Guide, “Weather Database,” no. June, 2016.

[33] D. H. Kouchi, K. Esmaili, A. Faridhosseini, S. H. Sanaeinejad, D. Khalili, and K. C. Abbaspour, “Sensitivity of calibrated parameters and water resource estimates on different objective functions and optimization algorithms,” *Water (Switzerland)*, vol. 9, no. 6, pp. 1–16, 2017, doi: 10.3390/w9060384.

[34] A. G. Mengistu, L. D. van Rensburg, and Y. E. Woyessa, “Techniques for calibration and validation of SWAT model in data scarce arid and semi-arid catchments in South Africa,” *J. Hydrol. Reg. Stud.*, vol. 25, no. May, p. 100621, 2019, doi: 10.1016/j.ejrh.2019.100621.

[35] A. Korkovelos *et al.*, “A Geospatial Assessment of Small-Scale Hydropower Potential in Sub-Saharan Africa,” doi: 10.3390/en11113100.

[36] I. Butera and R. Balestra, “Estimation of the hydropower potential of irrigation networks,” *Renew. Sustain. Energy Rev.*, vol. 48, pp. 140–151, 2015, doi: 10.1016/j.rser.2015.03.046.

[37] O. J. Mdee, C. Z. Kimambo, T. K. Nielsen, and J. Kihedu, “Measurement methods for hydropower resources : a review Measurement methods for hydropower resources : a review,” no. January, 2018.

Appendices

Appendix 1: Daily flow data Report from the period of 2008-2020.

						2008						
Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	5.40	2.70	18.30	9.40	71.96	35.72	153.20	103.30	54.57	25.09	6.50	0.92
2	5.40	4.60	14.90	9.40	83.98	34.30	156.40	101.90	53.27	24.21	5.78	1.38
3	5.40	7.20	14.90	11.90	87.31	34.28	156.70	101.90	53.17	24.10	5.59	1.58
4	5.40	10.60	13.40	11.90	87.99	34.37	156.90	101.90	53.14	24.05	5.51	1.72
5	5.40	11.90	11.90	9.40	88.19	34.49	157.00	101.90	53.15	24.02	5.44	1.82
6	3.90	14.90	8.20	9.40	88.33	34.62	157.10	102.00	53.16	23.99	5.39	1.92
7	3.30	20.10	11.90	7.20	88.45	34.73	157.20	102.10	53.15	23.97	5.34	2.01
8	3.30	16.50	10.60	7.20	88.55	34.86	157.20	102.10	53.16	23.95	5.28	2.10
9	3.30	11.90	11.90	5.40	88.65	34.98	157.30	102.10	53.18	23.94	5.24	2.19
10	3.90	11.90	9.40	9.40	88.76	35.08	157.40	102.20	53.19	23.93	5.19	2.28
11	3.90	9.40	9.40	7.20	88.87	35.20	157.50	102.20	53.19	23.91	5.15	2.38
12	3.90	9.40	11.90	9.40	89.00	35.31	157.60	102.30	53.20	23.89	5.09	2.47
13	3.90	13.40	11.90	11.90	89.12	35.42	157.60	102.30	53.21	23.87	5.05	2.57
14	3.90	9.40	11.90	11.90	89.25	35.55	157.70	102.30	53.19	23.85	5.00	2.66
15	4.60	3.90	11.90	10.60	89.36	35.63	157.80	102.40	53.19	23.84	4.95	2.76
16	3.90	6.30	9.40	16.50	89.51	35.75	157.80	102.40	53.21	23.82	4.90	2.86
17	3.30	9.40	11.90	11.90	89.65	35.85	157.90	102.40	53.20	23.80	4.84	2.95
18	2.70	7.20	9.40	13.40	89.79	35.95	158.00	102.40	53.21	23.78	4.79	3.05
19	1.80	9.40	8.20	11.90	89.92	36.05	158.10	102.50	53.22	23.75	4.75	3.14
20	1.80	9.40	9.40	9.40	90.10	36.16	158.20	102.50	53.22	23.74	4.69	3.24
21	3.90	9.40	9.40	11.90	90.20	36.26	158.20	102.50	53.23	23.73	4.65	3.33
22	3.90	10.60	14.90	26.50	90.30	36.36	158.30	102.60	53.21	23.71	4.59	3.43
23	3.90	9.40	16.50	36.80	90.50	36.46	158.30	102.60	53.22	23.66	4.55	3.53
24	3.90	13.40	24.20	28.80	90.60	36.57	158.40	102.60	53.22	23.63	4.49	3.62
25	3.90	13.40	26.50	31.30	90.80	36.66	158.50	102.70	53.23	23.61	4.44	3.72
26	3.90	11.90	22.10	24.20	90.90	36.75	158.50	102.70	53.21	23.59	4.39	3.81
27	2.70	16.50	16.50	18.30	91.10	36.84	158.60	102.70	53.22	23.59	4.33	3.90
28	2.70	16.50	13.40	14.90	91.20	36.93	158.60	102.70	53.21	23.58	4.28	4.00
29	2.70	16.50	9.40	11.90	91.40	37.01	158.70	102.80	53.22	23.55	4.23	4.09
30	3.90		7.20	11.90	91.50	37.08	158.70	102.80	53.21	23.53	4.19	4.18
31	3.90		7.20		91.70		158.80	102.80		23.51		4.27
						2009						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	3.82	5.86	7.60	1.98	6.14	10.10	150.10	160.10	5.29	3.52	6.81	6.48
2	3.79	6.07	7.65	0.32	6.74	13.84	153.80	160.30	0.48	3.65	6.88	6.23
3	3.84	6.18	7.70	0.52	6.91	15.68	154.30	160.30	0.20	3.78	6.95	6.13
4	3.89	6.26	7.75	0.79	6.97	16.14	154.40	160.40	0.44	3.90	7.03	6.07

5	3.96	6.32	7.80	0.92	7.00	16.29	154.60	160.50	0.58	4.03	7.10	6.02
6	4.03	6.38	7.85	0.99	7.00	16.37	154.70	160.60	0.68	4.15	7.17	5.98
7	4.09	6.43	7.90	1.04	7.00	16.42	154.80	160.70	0.76	4.28	7.24	5.95
8	4.15	6.48	7.94	1.08	7.00	16.47	154.90	160.80	0.84	4.40	7.31	5.94
9	4.21	6.54	7.99	1.13	7.00	16.54	155.00	160.80	0.93	4.52	7.37	5.92
10	4.26	6.59	8.03	1.18	7.00	16.56	155.10	160.90	1.01	4.64	7.44	5.90
11	4.32	6.64	8.08	1.24	7.00	16.64	155.20	161.00	1.10	4.76	7.50	5.88
12	4.38	6.69	8.12	1.28	7.01	16.68	155.40	161.10	1.20	4.87	7.56	5.86
13	4.45	6.75	8.16	1.35	7.02	16.74	155.50	161.10	1.30	4.99	7.62	5.83
14	4.48	6.80	8.20	1.40	7.04	16.81	155.60	161.20	1.41	5.10	7.68	5.80
15	4.53	6.86	8.24	1.46	7.06	16.89	155.70	161.30	1.51	5.21	7.74	5.77
16	4.58	6.91	8.29	1.53	7.08	16.96	155.80	161.30	1.63	5.32	7.80	5.74
17	4.64	6.97	8.32	1.60	7.10	17.04	155.90	161.40	1.74	5.43	7.86	5.71
18	4.68	7.02	8.36	1.67	7.13	17.11	156.00	161.50	1.86	5.53	7.91	5.67
19	4.72	7.07	8.40	1.73	7.15	17.20	156.10	161.50	1.98	5.64	7.96	5.64
20	4.76	7.13	8.44	1.81	7.18	17.29	156.20	161.60	2.11	5.74	8.01	5.60
21	4.80	7.18	8.48	1.89	7.21	17.38	156.30	161.70	2.23	5.84	8.06	5.56
22	4.84	7.24	8.51	1.97	7.25	17.47	156.50	161.70	2.36	5.94	8.11	5.51
23	4.88	7.29	8.55	2.04	7.28	17.57	156.50	161.80	2.48	6.03	8.15	5.48
24	4.91	7.34	8.58	2.11	7.31	17.66	156.60	161.80	2.61	6.13	8.20	5.43
25	4.94	7.40	8.61	2.19	7.35	17.76	156.70	161.90	2.74	6.22	8.25	5.40
26	4.98	7.45	8.65	2.27	7.39	17.84	156.80	161.90	2.87	6.31	8.29	5.36
27	5.00	7.50	8.68	2.35	7.43	17.93	156.90	162.00	3.00	6.40	8.34	5.32
28	5.04	7.55	8.72	2.43	7.46	18.02	157.00	162.10	3.13	6.49	8.37	5.28
29	5.06	7.06	8.75	2.50	7.50	18.11	157.10	162.10	3.26	6.58	8.41	5.23
30	5.09		8.78	2.58	7.54	18.20	157.20	162.10	3.39	6.66	8.45	5.19
31	5.14		8.81		7.58		157.30	162.20		6.74		5.15

2010

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4.65	5.47	7.06	33.27	79.86	38.78	151.70	97.70	9.78	0.16	3.00	2.84
2	4.54	5.66	7.85	34.13	81.14	37.58	154.70	96.20	7.09	0.73	2.83	2.77
3	4.48	5.71	8.08	34.33	81.34	37.48	155.10	96.10	6.70	0.99	2.79	2.75
4	4.43	5.73	8.18	34.43	81.42	37.49	155.10	96.20	6.57	1.17	2.82	2.75
5	4.38	5.72	8.25	34.51	81.50	37.51	155.20	96.20	6.50	1.31	2.87	2.74
6	4.34	5.73	8.28	34.60	81.57	37.54	155.20	96.20	6.44	1.44	2.93	2.73
7	4.29	5.72	8.32	34.67	81.64	37.57	155.20	96.20	6.40	1.56	3.00	2.73
8	4.25	5.72	8.37	34.74	81.69	37.60	155.30	96.20	6.35	1.68	3.06	2.74
9	4.20	5.72	8.42	34.81	81.76	37.63	155.30	96.20	6.31	1.80	3.12	2.74
10	4.15	5.73	8.44	34.88	81.82	37.64	155.30	96.30	6.26	1.92	3.18	2.73
11	4.11	5.73	8.48	34.96	81.88	37.66	155.30	96.30	6.23	2.04	3.23	2.72
12	4.07	5.73	8.52	35.03	81.94	37.70	155.40	96.30	6.17	2.16	3.28	2.72
13	4.02	5.74	8.56	35.09	82.00	37.72	155.40	96.30	6.12	2.29	3.33	2.71
14	3.98	5.74	8.63	35.17	82.05	37.74	155.40	96.30	6.06	2.42	3.37	2.70

15	3.93	5.75	8.67	35.24	82.12	37.76	155.40	96.30	6.01	2.54	3.41	2.69
16	3.89	5.75	8.73	35.30	82.17	37.79	155.50	96.40	5.95	2.67	3.45	2.68
17	3.85	5.77	8.77	35.39	82.23	37.80	155.50	96.40	5.90	2.80	3.49	2.68
18	3.80	5.78	8.83	35.44	82.28	37.81	155.50	96.40	5.85	2.93	3.51	2.67
19	3.76	5.79	8.88	35.51	82.33	37.83	155.60	96.40	5.80	3.06	3.55	2.65
20	3.72	5.81	8.94	35.57	82.40	37.84	155.60	96.40	5.72	3.19	3.58	2.64
21	3.68	5.82	8.99	35.65	82.44	37.87	155.60	96.40	5.67	3.32	3.60	2.63
22	3.65	5.83	9.05	35.71	82.49	37.90	155.70	96.40	5.60	3.44	3.63	2.63
23	3.60	5.84	9.10	35.77	82.54	37.93	155.70	96.50	5.55	3.57	3.65	2.61
24	3.57	5.86	9.17	35.84	82.59	37.94	155.70	96.50	5.49	3.70	3.68	2.60
25	3.53	5.87	9.22	35.91	82.65	37.98	155.80	96.50	5.43	3.83	3.69	2.59
26	3.49	5.89	9.27	35.97	82.70	38.01	155.80	96.50	5.37	3.95	3.71	2.58
27	3.45	5.90	9.34	36.03	82.75	38.03	155.80	96.50	5.31	4.08	3.72	2.57
28	3.41	5.93	9.39	36.09	82.80	38.05	155.80	96.50	5.25	4.19	3.74	2.55
29	3.38	5.30	9.44	36.15	82.86	38.07	155.80	96.50	5.19	4.32	3.75	2.54
30	3.35		9.50	36.21	82.89	38.08	155.90	96.50	5.13	4.44	3.76	2.53
31	3.32		9.55		82.93		155.90	96.50		4.56		2.52
2011												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	0.14	3.96	24.20	8.36	55.42	60.43	157.50	107.30	61.18	3.58	18.05	1.72
2	0.32	4.35	25.66	7.72	56.99	60.56	160.10	106.00	59.89	1.39	19.16	2.84
3	0.39	4.47	25.98	7.65	57.24	60.61	160.40	105.90	59.78	0.92	19.37	3.16
4	0.43	4.53	26.13	7.66	57.34	60.67	160.40	105.90	59.75	0.70	19.45	3.32
5	0.45	4.57	26.16	7.69	57.42	60.70	160.50	105.90	59.74	0.56	19.42	3.42
6	0.49	4.60	26.24	7.73	57.46	60.75	160.50	106.00	59.74	0.44	19.39	3.49
7	0.52	4.63	26.27	7.78	57.51	60.79	160.60	106.00	59.74	0.33	19.37	3.56
8	0.54	4.64	26.30	7.83	57.56	60.82	160.60	106.00	59.73	0.22	19.33	3.62
9	0.56	4.67	26.32	7.87	57.59	60.87	160.60	106.00	59.74	0.12	19.30	3.68
10	0.58	4.70	26.37	7.91	57.63	60.91	160.70	106.10	59.73	0.01	19.26	3.74
11	0.61	4.73	26.42	7.94	57.68	60.93	160.70	106.10	59.73	0.10	19.25	3.81
12	0.63	4.76	26.45	7.97	57.73	60.97	160.70	106.10	59.73	0.22	19.21	3.88
13	0.65	4.79	26.50	8.02	57.79	61.02	160.80	106.10	59.72	0.34	19.21	3.95
14	0.67	4.83	26.55	8.06	57.83	61.06	160.80	106.10	59.72	0.45	19.17	4.03
15	0.69	4.86	26.63	8.09	57.87	61.08	160.80	106.20	59.72	0.58	19.19	4.10
16	0.72	4.90	26.67	8.12	57.91	61.12	160.90	106.20	59.72	0.70	19.18	4.18
17	0.75	4.93	26.73	8.15	57.96	61.16	160.90	106.20	59.72	0.83	19.18	4.27
18	0.79	4.97	26.79	8.18	58.01	61.19	160.90	106.20	59.71	0.96	19.19	4.35
19	0.80	5.01	26.85	8.21	58.05	61.22	161.00	106.20	59.70	1.09	19.20	4.43
20	0.83	5.05	26.92	8.24	58.10	61.26	161.00	106.20	59.70	1.22	19.20	4.52
21	0.86	5.10	26.97	8.27	58.15	61.31	161.00	106.30	59.69	1.36	19.21	4.61
22	0.88	5.13	27.04	8.30	58.20	61.33	161.10	106.30	59.69	1.49	19.22	4.70
23	0.91	5.18	27.10	8.32	58.25	61.37	161.10	106.30	59.68	1.62	19.24	4.78
24	0.92	5.21	27.17	8.34	58.28	61.41	161.10	106.30	59.67	1.75	19.25	4.87

25	0.94	5.27	27.24	8.36	58.34	61.43	161.20	106.30	59.66	1.89	19.27	4.96
26	0.97	5.30	27.30	8.38	58.38	61.48	161.20	106.30	59.66	2.02	19.29	5.05
27	0.99	5.36	27.37	8.41	58.43	61.52	161.20	106.30	59.65	2.15	19.31	5.14
28	1.02	5.39	27.44	8.43	58.46	61.55	161.30	106.40	59.64	2.28	19.33	5.23
29	1.05		27.51	8.44	58.51	61.59	161.30	106.40	59.64	2.41	19.35	5.32
30	1.07		27.56	8.46	58.55	61.64	161.30	106.40	59.64	2.54	19.39	5.41
31	1.10		27.63		58.61		161.40	106.40		2.67		5.50
						2012						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	5.59	7.90	18.85	8.14	7.87	32.08	137.40	126.50	54.53	3.86	1.31	3.17
2	5.68	7.95	20.61	7.65	7.85	32.98	140.20	126.20	52.58	2.01	1.41	3.20
3	5.77	8.01	21.05	7.64	7.88	33.17	140.60	126.20	52.41	1.61	1.50	3.24
4	5.85	8.06	21.29	7.70	7.91	33.24	140.70	126.20	52.39	1.43	1.60	3.28
5	5.94	8.11	21.40	7.78	7.95	33.29	140.70	126.30	52.40	1.32	1.70	3.33
6	6.02	8.15	21.51	7.86	7.98	33.33	140.80	126.30	52.40	1.23	1.80	3.38
7	6.11	8.20	21.61	7.96	8.02	33.37	140.80	126.30	52.39	1.14	1.88	3.42
8	6.19	8.25	21.70	8.04	8.05	33.40	140.90	126.40	52.40	1.06	1.97	3.47
9	6.27	8.29	21.79	8.12	8.09	33.44	140.90	126.40	52.41	0.99	2.06	3.51
10	6.35	8.38	21.88	8.21	8.12	33.48	141.00	126.40	52.42	0.90	2.14	3.55
11	6.43	8.48	21.97	8.30	8.15	33.52	141.10	126.50	52.41	0.82	2.23	3.59
12	6.51	8.61	22.07	8.37	8.18	33.55	141.10	126.50	52.44	0.74	2.32	3.63
13	6.59	8.77	22.17	8.45	8.21	33.60	141.20	126.50	52.42	0.64	2.40	3.67
14	6.66	8.84	22.29	8.52	8.24	33.63	141.20	126.60	52.41	0.57	2.48	3.71
15	6.75	8.94	22.40	8.59	8.26	33.69	141.30	126.60	52.41	0.47	2.55	3.74
16	6.84	9.03	22.51	8.67	8.28	33.73	141.30	126.60	52.41	0.38	2.63	3.78
17	6.91	9.08	22.61	8.75	8.32	33.80	141.40	126.70	52.41	0.29	2.72	3.81
18	6.98	9.14	22.74	8.80	8.33	33.84	141.40	126.70	52.41	0.19	2.79	3.84
19	7.05	9.18	22.84	8.88	8.35	33.88	141.50	126.70	52.43	0.09	2.86	3.87
20	7.12	9.20	22.94	8.94	8.37	33.95	141.50	126.80	52.42	0.01	2.95	3.90
21	7.18	9.22	23.06	9.00	8.41	34.00	141.60	126.80	52.41	0.10	3.02	3.93
22	7.25	9.24	23.18	9.06	8.43	34.04	141.60	126.80	52.40	0.20	3.09	3.96
23	7.31	9.26	23.30	9.11	8.45	34.08	141.60	126.80	52.39	0.30	3.16	3.98
24	7.40	9.28	23.42	9.16	8.46	34.14	141.70	126.90	52.40	0.40	3.22	4.01
25	7.46	9.30	23.53	9.22	8.48	34.17	141.80	126.90	52.40	0.49	3.30	4.03
26	7.54	9.32	23.65	9.27	8.50	34.21	141.80	126.90	52.39	0.58	3.38	4.05
27	7.60	9.38	23.76	9.33	8.52	34.25	141.80	127.00	52.39	0.68	3.43	4.08
28	7.67	9.41	23.89	9.38	8.54	34.28	141.90	127.00	52.37	0.77	3.49	4.10
29	7.72	9.43	23.99	9.43	8.55	34.32	141.90	127.00	52.38	0.88	3.56	4.12
30	7.79		24.11	9.48	8.57	34.36	142.00	127.00	52.38	0.97	3.61	4.14
31	7.85		24.23		8.59		142.00	127.00		1.07		4.17
						2013						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	3.92	5.60	0.90	7.87	9.46	55.43	174.70	174.70	177.70	35.18	30.51	1.76

2	3.91	5.85	0.28	8.20	9.49	56.91	177.80	177.80	177.70	31.32	30.48	0.49
3	3.92	5.97	0.08	8.33	9.53	57.14	178.20	178.20	177.70	30.95	30.47	0.15
4	3.93	6.05	0.00	8.41	9.58	57.24	178.30	178.30	177.80	30.88	30.44	0.03
5	3.94	6.10	0.03	8.48	9.63	57.31	178.30	178.30	177.80	30.88	30.43	0.15
6	3.96	6.15	0.07	8.55	9.67	57.37	178.40	178.40	177.90	30.84	29.05	0.25
7	3.97	6.19	0.09	8.61	9.72	57.42	178.50	178.50	177.90	30.84	28.99	0.34
8	3.98	6.24	0.09	8.68	9.75	57.47	178.50	178.50	177.90	30.84	28.97	0.43
9	4.00	6.28	0.10	8.74	9.80	57.52	178.60	178.60	178.00	30.84	28.94	0.52
10	4.01	6.32	0.13	8.80	9.84	57.56	178.60	178.60	178.00	30.82	28.93	0.62
11	4.02	6.37	0.14	8.86	9.88	57.62	178.70	178.70	178.00	30.83	28.89	0.71
12	4.03	6.42	0.17	8.93	9.92	57.66	178.70	178.70	178.10	30.81	28.88	0.81
13	4.04	6.47	0.20	8.99	9.96	57.71	178.80	178.80	178.10	30.80	28.86	0.90
14	4.05	6.52	0.23	9.05	10.00	57.76	178.90	178.90	178.10	30.80	28.86	1.01
15	4.07	6.57	0.27	9.11	10.04	57.81	178.90	178.90	178.20	30.78	28.83	1.11
16	4.07	6.62	0.31	9.17	10.08	57.86	178.90	178.90	178.20	30.76	28.81	1.21
17	4.08	6.67	0.35	9.23	10.11	57.91	179.00	179.00	178.20	30.77	28.80	1.32
18	4.09	6.73	0.38	9.30	10.15	57.96	179.10	179.10	178.30	30.75	28.77	1.42
19	4.10	6.78	0.42	9.35	10.19	58.01	179.10	179.10	178.30	30.72	28.76	1.53
20	4.10	6.83	0.47	9.41	10.21	58.05	179.20	179.20	178.30	30.69	28.74	1.63
21	4.11	6.89	0.51	9.47	10.25	58.11	179.20	179.20	178.30	30.69	28.73	1.75
22	4.12	6.94	0.56	9.53	10.28	58.16	179.30	179.30	178.40	30.67	28.72	1.85
23	4.12	7.00	0.60	9.58	10.31	58.21	179.30	179.30	178.40	30.66	28.70	1.96
24	4.13	7.05	0.66	9.63	10.34	58.27	179.40	179.40	178.40	30.66	28.68	2.07
25	4.13	7.10	0.70	9.69	10.38	58.32	179.40	179.40	178.50	30.62	28.67	2.18
26	4.14	7.16	0.75	9.75	10.41	58.39	179.50	179.50	178.50	30.61	28.66	2.28
27	4.14	7.21	0.81	9.80	10.44	58.45	179.50	179.50	178.50	30.57	28.63	2.39
28	4.15	7.27	0.85	9.85	10.47	58.54	179.60	179.60	178.50	30.55	28.61	2.50
29	4.16		0.91	9.90	10.49	58.60	179.60	179.60	178.50	30.54	28.60	2.60
30	4.16		0.95	9.95	10.51	58.66	179.70	179.70	178.50	30.52	28.56	2.71
31	4.16		1.00		10.54		179.70	179.70	178.60		28.56	

2014

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	3.06	5.29	4.17	13.33	62.86	49.83	85.81	66.17	35.26	3.65	5.59	2.18
2	3.27	5.16	4.70	13.66	64.36	49.43	86.83	65.65	34.36	2.36	5.90	2.75
3	3.42	5.12	4.86	13.77	64.60	49.43	86.95	65.60	34.25	2.06	5.95	2.96
4	3.56	5.10	4.97	13.85	64.71	49.46	86.99	65.62	34.23	1.91	5.94	3.08
5	3.68	5.08	5.03	13.92	64.79	49.50	87.04	65.62	34.21	1.82	5.91	3.17
6	3.80	5.07	5.10	13.98	64.85	49.54	87.06	65.64	34.21	1.74	5.86	3.25
7	3.91	5.05	5.17	14.04	64.92	49.58	87.10	65.65	34.21	1.67	5.82	3.32
8	4.03	5.04	5.22	14.09	64.98	49.62	87.12	65.67	34.18	1.60	5.78	3.38
9	4.14	5.03	5.26	14.15	65.03	49.66	87.15	65.68	34.16	1.53	5.74	3.45
10	4.26	5.01	5.31	14.21	65.09	49.71	87.18	65.70	34.18	1.46	5.69	3.51
11	4.37	4.99	5.37	14.26	65.15	49.74	87.21	65.71	34.16	1.39	5.66	3.58

12	4.48	4.97	5.43	14.31	65.20	49.77	87.23	65.71	34.15	1.32	5.62	3.66
13	4.59	4.96	5.48	14.38	65.26	49.81	87.26	65.74	34.15	1.25	5.59	3.73
14	4.70	4.94	5.53	14.43	65.32	49.85	87.28	65.74	34.14	1.18	5.56	3.80
15	4.81	4.91	5.60	14.48	65.38	49.88	87.31	65.75	34.13	1.10	5.53	3.88
16	4.92	4.89	5.66	14.54	65.45	49.90	87.34	65.76	34.13	1.02	5.50	3.96
17	5.03	4.87	5.72	14.59	65.49	49.94	87.36	65.77	34.11	0.94	5.47	4.04
18	5.13	4.85	5.76	14.64	65.55	49.96	87.39	65.78	34.09	0.86	5.45	4.11
19	5.23	4.83	5.82	14.69	65.61	50.00	87.42	65.79	34.09	0.78	5.43	4.20
20	5.34	4.81	5.88	14.74	65.66	50.04	87.45	65.81	34.07	0.71	5.42	4.27
21	5.44	4.79	5.95	14.80	65.72	50.08	87.47	65.82	34.07	0.63	5.40	4.35
22	5.54	4.76	6.01	14.85	65.77	50.13	87.52	65.82	34.06	0.54	5.37	4.43
23	5.64	4.74	6.07	14.89	65.83	50.17	87.51	65.84	34.02	0.47	5.34	4.51
24	5.74	4.72	6.12	14.94	65.88	50.22	87.54	65.83	34.02	0.39	5.32	4.59
25	5.83	4.70	6.17	14.98	65.94	50.26	87.54	65.85	34.01	0.30	5.30	4.68
26	5.93	4.68	6.24	15.03	65.98	50.29	87.57	65.86	34.02	0.22	5.29	4.75
27	6.02	4.65	6.30	15.07	66.04	50.32	87.59	65.87	33.99	0.14	5.26	4.83
28	6.11	4.62	6.35	15.12	66.08	50.34	87.63	65.87	33.97	0.06	5.25	4.91
29	6.20	4.12	6.40	15.16	66.13	50.37	87.64	65.86	33.98	0.02	5.25	4.99
30	6.29		6.46	15.22	66.19	50.40	87.66	65.87	33.97	0.10	5.25	5.07
31	6.37		6.51		66.24		87.69	65.88		0.18		5.14
2015												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	5.33	6.13	5.98	3.98	28.21	32.06	56.65	58.79	25.03	72.94	3.20	4.77
2	5.46	5.90	6.66	4.70	29.87	32.17	57.35	58.86	23.97	74.38	0.56	5.52
3	5.57	5.82	6.86	4.90	30.25	32.25	57.48	58.92	23.83	74.53	0.04	5.69
4	5.66	5.80	6.99	4.97	30.39	32.32	57.55	58.95	23.81	74.56	0.20	5.73
5	5.75	5.80	7.06	5.00	30.47	32.40	57.60	58.97	23.80	74.61	0.35	5.70
6	5.83	5.80	7.14	5.02	30.52	32.48	57.67	59.01	23.78	74.60	0.46	5.66
7	5.91	5.80	7.21	5.02	30.57	32.55	57.72	59.04	23.77	74.62	0.57	5.62
8	5.99	5.81	7.28	5.03	30.61	32.62	57.77	59.07	23.78	74.63	0.67	5.57
9	6.07	5.81	7.35	5.04	30.65	32.69	57.82	59.10	23.78	74.62	0.77	5.53
10	6.15	5.82	7.42	5.05	30.69	32.76	57.87	59.13	23.77	74.63	0.87	5.49
11	6.23	5.81	7.50	5.06	30.74	32.84	57.92	59.15	23.77	74.64	0.98	5.45
12	6.30	5.81	7.56	5.08	30.79	32.91	57.97	59.18	23.76	74.64	1.09	5.42
13	6.38	5.80	7.63	5.10	30.84	32.97	58.02	59.20	23.77	74.65	1.20	5.38
14	6.45	5.79	7.69	5.12	30.89	33.04	58.06	59.24	23.75	74.66	1.32	5.36
15	6.53	5.78	7.77	5.16	30.96	33.10	58.12	59.26	23.74	74.66	1.44	5.35
16	6.60	5.76	7.85	5.19	31.02	33.17	58.16	59.29	23.74	74.68	1.56	5.32
17	6.67	5.75	7.91	5.22	31.08	33.24	58.21	59.31	23.72	74.68	1.69	5.32
18	6.75	5.73	8.00	5.26	31.15	33.31	58.25	59.33	23.72	74.70	1.82	5.30
19	6.83	5.71	8.08	5.29	31.21	33.37	58.29	59.35	23.71	74.73	1.95	5.30
20	6.91	5.70	8.14	5.33	31.28	33.43	58.34	59.37	23.71	74.75	2.08	5.29
21	6.99	5.68	8.22	5.37	31.35	33.49	58.38	59.40	23.69	74.76	2.21	5.29

22	7.06	5.65	8.29	5.41	31.43	33.55	58.41	59.42	23.68	74.76	2.34	5.29
23	7.12	5.63	8.37	5.45	31.50	33.63	58.47	59.46	23.67	74.76	2.48	5.29
24	7.19	5.61	8.43	5.50	31.57	33.68	58.52	59.46	23.66	74.77	2.61	5.30
25	7.25	5.59	8.52	5.55	31.65	33.75	58.54	59.49	23.65	74.79	2.75	5.31
26	7.31	5.56	8.58	5.59	31.72	33.81	58.59	59.51	23.65	74.81	2.88	5.31
27	7.39	5.54	8.65	5.64	31.79	33.87	58.61	59.52	23.63	74.82	3.01	5.33
28	7.46	5.51	8.72	5.69	31.88	33.93	58.65	59.55	23.62	74.84	3.15	5.34
29	7.53	5.06	8.79	5.74	31.95	33.99	58.69	59.56	23.60	74.84	3.28	5.35
30	7.60		8.86	5.78	32.02	34.05	58.73	59.58	23.59	74.86	3.41	5.37
31	7.66		8.93		32.10		58.76	59.60		74.88		5.38

2016

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	6.47	1.96	4.38	4.85	13.09	0.18	2.14	5.46	0.54	0.41	0.18	0.09
2	6.51	2.50	4.59	7.16	13.29	0.29	0.34	12.05	0.48	0.22	0.18	0.09
3	6.52	2.67	4.72	7.73	13.39	0.31	2.15	20.16	0.42	0.18	0.18	0.09
4	6.55	2.74	4.82	7.91	13.47	0.31	5.65	30.26	0.90	0.23	0.17	0.09
5	6.56	2.79	4.90	7.99	13.54	0.32	0.41	18.26	0.30	0.20	0.15	0.11
6	6.59	2.83	4.98	8.03	13.62	0.36	10.25	26.24	0.26	0.15	0.15	0.09
7	6.60	2.85	5.06	8.06	13.69	0.36	1.03	29.24	0.21	0.10	0.15	0.12
8	6.64	2.88	5.13	8.08	13.76	0.31	0.35	15.26	0.28	0.87	0.15	0.11
9	6.64	2.92	5.21	8.10	13.84	0.24	2.56	16.25	0.21	0.82	0.15	0.09
10	6.67	2.95	5.29	8.13	13.91	0.26	0.65	18.26	0.45	0.73	0.15	0.09
11	6.70	2.99	5.36	8.15	13.98	0.28	2.26	15.26	0.15	0.64	0.15	0.09
12	6.72	3.02	5.44	8.19	14.05	0.28	0.54	14.23	0.21	0.57	0.15	0.08
13	6.74	3.07	5.52	8.23	14.12	0.35	1.25	22.37	0.13	0.49	0.12	0.07
14	6.76	3.10	5.60	8.26	14.19	0.34	0.42	8.56	0.15	0.46	0.12	0.07
15	6.78	3.15	5.68	8.30	14.26	0.46	2.37	7.69	0.13	0.40	0.12	0.07
16	6.81	3.19	5.76	8.35	14.32	0.56	0.47	6.24	0.10	0.40	0.12	0.07
17	6.82	3.23	5.83	8.40	14.39	0.45	0.42	7.46	0.09	0.37	0.12	0.07
18	6.85	3.27	5.91	8.45	14.46	0.25	3.27	8.27	0.09	0.31	0.12	0.07
19	6.88	3.32	5.99	8.51	14.52	0.45	0.36	5.07	0.10	0.29	0.11	0.07
20	6.90	3.37	6.07	8.56	14.58	0.46	0.45	3.25	0.07	0.29	0.11	0.07
21	6.93	3.41	6.14	8.63	14.65	0.54	1.05	2.53	0.10	0.27	0.11	0.07
22	6.95	3.47	6.22	8.69	14.71	0.61	0.59	3.85	0.07	0.27	0.12	0.06
23	6.96	3.51	6.30	8.75	14.78	0.65	4.02	6.45	0.14	0.34	0.11	0.06
24	6.99	3.56	6.37	8.82	14.83	0.64	1.54	3.45	0.39	0.27	0.09	0.06
25	7.01	3.61	6.45	8.88	14.89	0.45	0.56	2.56	0.15	0.22	0.09	0.07
26	7.03	3.66	6.52	8.95	14.95	0.56	3.02	2.32	0.18	0.22	0.09	0.06
27	7.05	3.72	6.59	9.01	15.01	0.46	0.54	3.15	0.45	0.20	0.11	0.05
28	7.08	3.77	6.67	9.08	15.07	0.36	1.03	5.26	0.16	0.18	0.09	0.05
29	7.09	3.82	6.74	9.14	15.13	0.46	0.62	4.26	0.13	0.18	0.12	0.05
30	7.11		6.81	9.21	15.18	0.48	1.24	3.27	0.15	0.18	0.11	0.05
31	7.12		6.88		0.27		0.51	2.16		0.18		56.71

2017												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	68.73	19.04	21.83	143.55	87.55	37.96	8.28	11.06	19.52	20.34	22.90	17.23
2	72.06	19.03	137.95	88.05	87.55	9.84	8.26	16.17	19.07	20.39	22.95	15.57
3	72.74	19.12	141.15	86.65	39.32	8.96	8.75	16.63	19.04	21.11	23.00	14.73
4	72.94	19.24	141.45	86.65	38.02	8.85	9.47	16.83	19.09	21.32	23.05	14.46
5	73.08	19.37	141.65	86.65	37.92	8.80	9.66	16.97	19.14	21.43	23.10	14.33
6	73.20	19.48	141.75	86.65	37.89	8.77	9.74	17.07	19.21	21.51	23.15	14.26
7	73.30	19.61	141.85	86.75	37.90	8.74	9.81	17.17	19.28	21.57	23.19	14.21
8	73.40	19.73	141.95	86.85	37.91	8.72	9.86	17.26	19.34	21.63	23.24	14.17
9	73.51	19.83	141.95	86.85	37.90	8.70	9.91	17.35	19.40	21.68	23.28	14.12
10	73.62	19.95	142.05	86.85	37.91	8.69	9.97	17.44	19.46	21.73	23.33	14.07
11	73.75	20.06	142.15	86.95	37.93	8.68	10.01	17.53	19.51	21.79	23.37	14.01
12	73.87	20.17	142.25	86.95	37.94	8.66	10.06	17.63	19.57	21.84	23.41	13.97
13	74.00	20.30	142.35	87.05	37.94	8.64	10.10	17.72	19.63	21.89	23.45	13.90
14	74.11	20.38	142.35	87.05	37.95	8.62	10.16	17.82	19.70	21.94	23.49	13.85
15	74.26	20.50	142.45	87.05	37.96	8.60	10.20	17.91	19.73	22.00	23.54	13.79
16	74.40	20.60	142.55	87.15	37.94	8.59	10.25	18.01	19.78	22.05	23.57	13.72
17	74.54	20.70	142.55	87.15	37.94	8.57	10.30	18.11	19.83	22.11	23.61	13.65
18	74.67	20.80	142.65	87.15	37.96	8.55	10.35	18.20	19.89	22.16	23.65	13.58
19	74.85	20.91	142.75	87.15	37.95	8.53	10.41	18.30	19.93	22.22	23.69	13.52
20	74.95	21.01	142.85	87.25	37.96	8.50	10.46	18.39	19.97	22.27	23.73	13.44
21	75.05	21.11	142.95	87.25	37.97	8.49	10.50	18.49	20.01	22.32	23.76	13.36
22	75.25	21.21	142.95	87.25	37.97	8.48	10.56	18.58	20.05	22.38	23.80	13.28
23	75.35	21.32	143.05	87.35	37.98	8.46	10.60	18.68	20.09	22.43	23.83	13.21
24	75.55	21.41	143.05	87.35	37.96	8.41	10.66	18.78	20.13	22.49	23.86	13.14
25	75.65	21.50	143.15	87.35	37.97	8.38	10.70	18.87	20.16	22.54	23.90	13.06
26	75.85	21.59	143.25	87.45	37.97	8.36	10.76	18.97	20.19	22.59	23.93	12.98
27	75.95	21.68	143.25	87.45	37.98	8.34	10.81	19.06	20.23	22.65	23.97	12.90
28	76.15	21.76	143.35	87.45	37.96	8.34	10.86	19.15	20.25	22.70	24.00	12.82
29	76.25		143.35	87.45	37.97	8.33	10.92	19.25	20.29	22.75	24.03	12.75
30	76.45		143.45	87.55	37.96	8.30	10.97	19.34	20.31	22.80	24.06	12.67
31	20.47		143.45		37.97		11.02	19.43		22.85		21.39
2018												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	21.99	1.41	2.95	142.05	146.85	18.64	21.91	23.70	20.40	18.60	7.40	18.02
2	22.16	0.43	134.85	144.85	146.95	18.77	21.99	21.73	19.90	18.57	7.17	18.88
3	22.22	0.89	138.55	145.05	9.96	18.90	22.06	21.48	19.79	20.72	7.07	19.08
4	22.25	1.04	139.05	145.05	14.77	19.03	22.13	21.38	19.73	20.91	7.00	19.18
5	22.25	1.12	139.15	145.15	15.45	19.15	22.20	21.32	19.67	20.96	6.97	19.26
6	22.25	1.17	139.35	145.25	15.69	19.28	22.28	21.27	19.63	20.98	6.93	19.35
7	22.25	1.22	139.45	145.35	15.83	19.40	22.35	21.23	19.58	20.97	6.88	19.42
8	22.25	1.29	139.55	145.45	15.93	19.53	22.42	21.20	19.54	20.98	6.83	19.49

9	22.25	1.31	139.65	145.55	16.01	19.65	22.49	21.19	19.50	20.97	6.81	19.56
10	22.25	1.39	139.75	145.55	16.09	19.77	22.56	21.17	19.45	20.97	6.77	19.63
11	22.26	1.43	139.85	145.65	16.18	19.89	22.62	21.15	19.40	20.97	6.73	19.71
12	22.27	1.49	139.95	145.75	16.26	20.00	22.69	21.13	19.36	20.98	6.69	19.78
13	22.29	1.56	140.15	145.85	16.35	20.12	22.75	21.11	19.32	20.98	6.62	19.84
14	22.31	1.64	140.25	145.85	16.45	20.24	22.81	21.08	19.27	20.98	6.58	19.92
15	22.33	1.71	140.35	145.95	16.55	20.35	22.87	21.05	19.23	20.99	6.52	19.99
16	22.35	1.79	140.45	146.05	16.66	20.46	22.93	21.02	19.18	20.99	6.48	20.05
17	22.38	1.86	140.55	146.05	16.76	20.57	22.99	20.99	19.14	21.00	6.42	20.14
18	22.40	1.95	140.65	146.15	16.88	20.68	23.05	20.96	19.10	21.00	6.37	20.19
19	22.43	2.04	140.75	146.25	16.99	20.78	23.11	20.92	19.05	21.01	6.31	20.26
20	22.46	2.13	140.85	146.25	17.11	20.89	23.16	20.89	19.01	21.03	6.26	20.32
21	22.50	2.22	140.95	146.35	17.23	20.99	23.21	20.85	18.97	21.04	6.20	20.40
22	22.53	2.32	141.05	146.45	17.36	21.09	23.26	20.81	18.93	21.06	6.15	20.46
23	22.56	2.41	141.25	146.45	17.48	21.19	23.31	20.76	18.90	21.07	6.08	20.52
24	22.60	2.51	141.25	146.55	17.61	21.28	23.36	20.73	18.85	21.08	6.03	20.59
25	22.64	2.59	141.35	146.55	17.73	21.38	23.40	20.68	18.82	21.09	5.98	20.66
26	22.68	2.68	141.45	146.65	17.86	21.47	23.45	20.65	18.78	21.11	5.91	20.72
27	22.71	2.77	141.55	146.65	17.99	21.56	23.50	20.61	18.74	21.12	5.86	20.78
28	22.75	2.86	141.65	146.75	18.12	21.65	23.54	20.57	18.70	21.14	5.81	20.84
29	22.79		141.75	146.85	18.25	21.74	23.58	20.53	18.66	21.15	5.75	20.90
30	22.83		141.85	146.85	18.38	21.83	23.62	20.48	18.63	21.18	5.70	20.96
31	5.15		141.95		18.51		23.66	20.44		8.19		64.61
						2019						
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
1	65.89	22.33	22.83	140.65	81.25	10.12	19.69	19.01	17.77	14.18	10.41	6.89
2	66.09	22.23	136.45	82.45	81.25	15.41	19.81	18.09	15.11	14.15	10.73	7.53
3	66.17	22.24	139.45	80.95	5.47	15.98	18.25	18.02	14.93	19.21	10.88	7.60
4	66.25	22.26	139.85	80.85	8.16	16.24	18.08	18.00	14.86	19.60	10.91	7.59
5	66.32	22.29	139.85	80.95	8.55	16.42	18.04	18.00	14.82	19.72	10.99	7.56
6	66.39	22.32	139.95	80.95	8.68	16.56	18.07	17.99	14.80	19.78	11.02	7.52
7	66.44	22.35	139.95	80.95	8.75	16.69	18.12	17.98	14.76	19.82	11.05	7.47
8	66.51	22.38	139.95	80.95	8.81	16.81	18.18	17.98	14.73	19.85	11.07	7.42
9	66.57	22.39	140.05	80.95	8.85	16.93	18.25	17.99	14.71	19.88	11.12	7.38
10	66.63	22.41	140.05	80.95	8.90	17.05	18.31	17.99	14.69	19.89	11.17	7.34
11	66.69	22.45	140.05	81.05	8.94	17.17	18.37	17.98	14.67	19.92	11.20	7.31
12	66.75	22.47	140.05	81.05	8.99	17.29	18.43	17.97	14.64	19.95	11.25	7.28
13	66.80	22.49	140.15	81.05	9.02	17.41	18.48	17.97	14.62	19.98	11.30	7.23
14	66.87	22.51	140.15	81.05	9.08	17.54	18.53	17.96	14.60	20.01	11.38	7.19
15	66.92	22.54	140.15	81.05	9.13	17.67	18.58	17.95	14.58	20.04	11.42	7.16
16	66.98	22.55	140.15	81.05	9.19	17.79	18.62	17.94	14.56	20.08	11.48	7.13
17	67.03	22.56	140.25	81.15	9.24	17.92	18.66	17.93	14.53	20.11	11.54	7.10
18	67.08	22.58	140.25	81.15	9.30	18.05	18.70	17.93	14.50	20.15	11.60	7.07

19	67.15	22.59	140.25	81.15	9.35	18.18	18.74	17.92	14.46	20.18	11.67	7.04
20	67.19	22.62	140.35	81.15	9.40	18.31	18.76	17.90	14.45	20.22	11.72	7.01
21	67.24	22.65	140.35	81.15	9.45	18.44	18.80	17.89	14.42	20.26	11.79	6.98
22	67.29	22.68	140.35	81.15	9.53	18.57	18.83	17.88	14.39	20.30	11.85	6.95
23	67.34	22.69	140.45	81.15	9.58	18.69	18.85	17.88	14.37	20.35	11.92	6.93
24	67.40	22.73	140.45	81.25	9.65	18.82	18.88	17.86	14.34	20.38	11.99	6.91
25	67.45	22.76	140.45	81.25	9.70	18.95	18.90	17.85	14.33	20.43	12.05	6.89
26	67.50	22.78	140.55	81.25	9.76	19.08	18.92	17.84	14.31	20.46	12.12	6.87
27	67.55	22.80	140.55	81.25	9.82	19.20	18.94	17.83	14.28	20.52	12.19	6.84
28	67.61	22.82	140.55	81.25	9.88	19.33	18.96	17.82	14.26	20.55	12.26	6.82
29	67.64		140.55	81.25	9.94	19.44	18.97	17.80	14.23	20.61	12.31	6.81
30	67.68		140.55	81.25	10.00	19.57	18.99	17.79	14.20	20.64	12.38	6.79
31	23.53		140.65		10.06		19.00	17.78		8.96		40.17

2020

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	41.74	45.31	142.25	92.05	91.15	11.67	17.92	16.97	20.84	23.10	5.36	7.11
2	41.99	45.36	144.85	90.75	45.93	13.86	2.80	18.09	20.93	23.15	5.80	7.60
3	42.09	45.42	145.15	90.65	44.64	14.33	3.91	18.41	21.02	23.20	6.04	7.61
4	42.17	45.45	145.15	90.65	44.53	14.55	4.12	18.57	21.10	23.25	6.15	7.55
5	42.21	45.50	145.25	90.65	44.50	14.69	4.20	18.67	21.19	23.31	6.26	7.47
6	42.26	45.54	145.25	90.75	44.49	14.81	4.17	18.74	21.27	23.36	6.36	7.39
7	42.31	45.57	145.35	90.75	44.49	14.92	4.14	18.81	21.36	23.40	6.45	7.29
8	42.34	45.62	145.35	90.75	44.49	15.03	4.12	18.87	21.44	23.45	6.54	7.21
9	42.38	45.66	145.35	90.75	44.48	15.13	4.08	18.93	21.52	23.50	6.63	7.13
10	42.43	45.68	145.45	90.85	44.49	15.24	4.05	18.99	21.60	23.54	6.72	7.04
11	42.48	45.72	145.45	90.85	44.48	15.35	4.01	19.06	21.68	23.63	6.82	6.95
12	42.54	45.77	145.45	90.85	44.48	15.47	4.00	19.13	21.76	23.73	6.92	6.88
13	42.58	45.81	145.55	90.85	44.48	15.59	3.96	19.20	21.84	23.86	7.04	6.80
14	42.62	45.83	145.55	90.85	44.47	15.70	3.96	19.28	21.91	24.02	7.15	6.73
15	42.66	45.87	145.55	90.95	44.47	15.83	3.92	19.35	22.00	24.09	7.26	6.66
16	42.71	45.91	145.65	90.95	44.47	15.95	3.94	19.43	22.08	24.19	7.36	6.58
17	42.76	45.94	145.65	90.95	44.47	16.08	3.93	19.51	22.16	24.28	7.49	6.50
18	42.80	45.97	145.65	90.95	44.47	16.21	3.93	19.60	22.23	24.33	7.59	6.45
19	42.85	46.01	145.75	90.95	44.46	16.34	3.94	19.68	22.30	24.39	7.69	6.37
20	42.90	46.06	145.75	90.95	44.45	16.47	3.95	19.77	22.37	24.43	7.81	6.31
21	42.95	46.08	145.75	91.05	44.45	16.61	3.95	19.86	22.43	24.45	7.93	6.25
22	43.00	46.12	145.85	91.05	44.44	16.74	3.96	19.95	22.50	24.47	8.05	6.19
23	43.03	46.16	145.85	91.05	44.44	16.87	3.97	20.03	22.56	24.49	8.17	6.14
24	43.09	46.18	145.85	91.05	44.43	17.00	3.99	20.12	22.65	24.51	8.28	6.09
25	43.13	46.23	145.95	91.05	44.42	17.14	4.00	20.21	22.71	24.53	8.40	6.03
26	43.18	46.27	145.95	91.05	44.41	17.27	4.02	20.30	22.79	24.55	8.51	5.98
27	43.21	46.30	145.95	91.05	44.41	17.40	4.04	20.39	22.85	24.57	8.64	5.92
28	43.26	46.34	146.05	91.15	44.40	17.53	4.06	20.48	22.92	24.63	8.74	5.87

29	43.30	46.39	146.05	91.15	44.39	17.66	4.08	20.57	22.97	24.66	8.86	5.82
30	43.36		146.05	91.15	44.39	17.79	4.10	20.66	23.04	24.68	8.98	5.77
31	45.18		146.15		44.39		4.14	20.75		3.60		7.38

Appendix 2: Measurement of head, depth, width and length of Tigdar River.