ASSESSING POTENTIAL LAND AND SURFACE WATER RESOURCES AVAILABLE AND SUITABLE FOR IRRIGATED AGRICULTURE IN THE WAMI SUB-BASIN MOROGORO

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGEE OF MASTER OF SCIENCE IN LAND USE PLANNING AND MANAGEMENT OF SOKOINNE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

2021

ABSTRACT

Assessing potential land and water resources suitable for surface irrigation is essential for proper planning of their utilization types. The assessment has a great role in satisfying subsistence requirements, increasing agricultural production and hence reducing poverty. Despite efforts made by various stakeholders to improve agricultural productivity by increasing irrigated areas, Tanzania is still facing a daunting task of reaching the one million hectare target of irrigated area. This indicates that land and water resources are not presently effectively utilized. This study was initiated with the objective of assessing the land and water resources suitable for irrigated agriculture along with the extent of small-scale irrigation in the Wami sub-basin. Geographical Information System (GIS) based on Multi Criteria Decision Analysis (MCDA) was used along with various spatial tools including a model builder which was used to create geo-referenced maps of land and water resources. Ten layers (irrigation suitability factors) were used in the analysis for identification of potential land suitable for irrigated agriculture. Results indicate that, based on the suitability factors about 841.39 km^2 (3.11% of the total area), is highly suitable for surface irrigation, about 18,244.41 km^2 (67.51%), is moderately suitable and 7939.87 km^2 (29.38%), is marginally suitable for surface irrigation. Furthermore, results shows that the extent of small-scale irrigation is about 1958.87 km^2. Moreover, results indicates that, approximately 1958 km^2 of land assumed to represent the extent of small-scale irrigated areas in Morogoro region including Dakawa and Mvomero in particular. As such, the exploration of various resources as observed in this study, including land, soil and water was well demonstrated by the integration of GIS-Based Multi Criteria Decision Analysis (MCDA), and the weighted overlay technique for land suitability analysis.

DECLARATION

I, CHARLES JOHN MALEKELA, do hereby declare to the Senate of Sokoine University of Agriculture, that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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ACKNOWLEDGMENTS

Primarily, I would like thank our almighty God for being able to complete this project with success. His hand upon me, protection, mercies, grace and blessings strengthen my wellbeing in successfully accomplishment of this project. Indeed he is so faithful.

My sincere appreciation goes to my supervisors Prof. Boniface P. Mbilinyi and Dr. Winfried Mbungu for their constructive ideas, support and technical advice during the whole period of my research work. Their patience, motivation, sacrificed time, guidance and immense knowledge collectively lead me to write this thesis. I cannot imagine having better advisors and mentors for my masters' research work.

My sincere thanks go to the Tanzania Meteorological Authority (TMA) that provided an opportunity for me to go for postgraduate studies and for funding my masters' studies through the Global Framework for Climate Services (GFCS).

My heartfelt appreciation goes to my lovely family; my darling wife Monica Mutoni Malekela and my lovely sons, Kenny Charles Malekela and Liam-Saviour Malekela for their unending patience, blessing and support during the whole period of my studies. My deepest appreciation goes to my late father Mr. John Clemence Malekela and my loving mother Mrs. Bernadetha Christian Mbwana for blessed memories and for their irreplaceable parental guidance and support in seeing that I am achieving the best level of education.

Last but not least, I would like to extend my sincere thanks to the entire staff members of the Department of Engineering Sciences and Technology both academic and technical staff who contributed in the journey of my studies at Sokoine University of Agriculture. My appreciation also goes to my colleagues, Wilfred G. Mkongera, and Grace E. Gowele for their moral support in making the work better.

DEDICATION

To God Almighty and my family: my wife and sons, my parents and siblings, who are the great support to the education I am honoured to acquire today. Thank you for being part of my life.

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LIST OF ABBREVIATION AND SYMBOLS

%	Percentage
μ	Discrepancy term
^0C	Degree Celsius
A	Area of the Basin
AHP	Analytical Hierarchy Process
CDO	Climate Data Operator
CEC	Cation Exchange Capacity
CSV	Comma Separated Values
DEM	Digital Elevation Model
DN	Digital Number
ET_0	Evapotranspiration
FAO	Food and Agriculture Organization
GIS	Geographical Information System
ISRIC	International Soil Reference and Information Centre
Km^2	Square kilometre
LULC	Land Use Land Cover
M/s	Meter per second
M^3/s	Cubic meter per second
Max	Maximum
MCDA	Multi Criteria Decision Analysis
Min	Minimum
MJ/m2	Mega Joule per square meter
mm	Millimetre
NAFORMA	National Forestry Resources Monitoring and Assessment

NDVI	Normalized Difference Vegetation Index
NetCDF	Network Common Data Form
NRCS	Natural Resources Conservation Services
OLI	Operational Land Imager
P	Precipitation
Q	River discharge
QGIS	Quantum Geographical Information System
RCMRD	Regional Centre for Mapping of Resources for Development
S/n	Serial number
SD	Standard Deviation
SOC	Soil Organic Carbon
SOCS	Soil Organic Carbon Stock
TIRS	Thermal Infrared Sensor
TMA	Tanzania Meteorological Authority
TOA	Top of Atmosphere
URT	United Republic of Tanzania
USDA	United State Department of Agriculture
USGS	United State Geological Survey
V	Storage Expressed as a Volume (m^3)
WRBWO	Wami Ruvu Basin Water Office
ΔS	Change in Water Storage
λ	Lambda

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Irrigation plays a great role in satisfying subsistence requirements, increases in food security, ensuring the production of much needed dietary supplements such as vegetables, fruits and pulses (Burney *et al*., 2013; Kahimba *et al*., 2015; Woodhouse *et al*., 2017). Irrigation is the agricultural practice by farmers, which enables them to improve and raise the level of production and consequently the livelihood outcomes (Palamuleni *et al.*, 2013). Irrigation development is essential in enhancing agricultural productivity, food self-sufficiency, security and creation of employment (Hatibu *et al*., 2002; URT, 2009). Irrigation as opposed to weather dependent rain-fed agriculture is considered important in the efforts to reduce poverty of rural communities and sustainable development (Smith, 2004; Tesfaw, 2018).

Increasing agricultural production and productivity is one of the major strategies in reducing poverty and enhancing livelihoods of the majority of the poor. However, rain-fed agriculture is susceptible to variability and is highly unreliable for the sustainability of farming activities which are major economic activities of the majority of the population in rural areas (Cooper *et al*., 2008). Smallholder farmers are often faced with crop failures due to prolonged dry spells and frequent droughts (Vogels *et al*., 2019). Sustainable crop production and development are expected through optimal use of available resources particularly land and water and risks are minimized when irrigation is utilized. Tesfaw (2018), suggested that small-scale irrigation farming has played a vital role in enabling food production by lowering the risk of crop failure and sustaining households and food security status. Indeed, it has contributed in poverty alleviation (Eneyew *et al*., 2014).

Mwakalila *et al*., 2004), reported increased incomes and reduced poverty for smallholder incomes who practiced irrigation compared to those who entirely depended on rain-fed agriculture. In general, adoption of small-scale irrigation systems has played a role in reducing farmer’s vulnerability to weather conditions, making production and incomes more stable (Salazar *et al*., 2016). The National Irrigation Policy (2009), recognizes the role irrigation needs to play in the socio-economic development and the fight against poverty in Tanzania (URT, 2009).

Despite efforts made by various stakeholders to improve agricultural productivity by increasing irrigated areas, Tanzania is still facing a daunting task of reaching the one million ha target of irrigated area. Out of approximately 2.1 million hectares of land identified as highly suitable for irrigation. Indeed, recent data shows only 461 326 ha of the highly suitable area and less than 2% of the total potential area for irrigation is currently irrigated (URT, 2009). This indicates that land and water resources are not presently effectively utilized.

Development efforts of irrigation infrastructures and facilities may be hindered by the lack of information on potential land and water resources (URT, 2009). On the other hand, in order to meet demands for food requirements, and minimize the risks of crop failure, smallholder farmers have engaged in traditional irrigation, where conditions permit. Proper planning of irrigation development requires favorable elevation and availability of information on land and water resources (Frenken, 1997), as well as other socio-economic factors such as availability of good markets, roads and communication infrastructures.

Thus, proper assessment of land suitability, water availability and other biophysical factors necessary for irrigation development is a vital process. As such, various researches incorporated geographic information system (GIS) with Multi-Criteria Decision Analysis (MCDA) for land suitability evaluation (Elaalem, 2013; Muema, 2016). GIS based Multi Criteria Decision Analysis (MCDA) is concerned with the allocation of land to suit a specific objective on the basis of a variety of attributes that the selected areas should possess (Elaalem, 2013).

Wami sub-basin in the Wami Ruvu Bain is endowed with fertile agricultural landscapes, and a good network of rivers and water resources. However, agricultural productivity in the Wami sub-basin has highly dependent on the expansion of new farms at the expenses of the natural lands such as forests and woodlands (Ngana *et al*., 2010). Unpredictable rainfall that is unevenly distributed across the sub-basin is yet another challenge that confront agriculture which is the predominant activity in rural areas (Ngana *et al*., 2010).

On the other hand, increasing population (Colin *et al*., 2014), intensify the pressure on agricultural resources in order to meet the food demands of the growing population (Muema, 2016). The situation is made worse with the use of simple technologies and poor farming practices used by smallholder farmers that do not only result in low incomes but also proliferate environmental degradation affecting rivers and water sources (Ngana *et al*., 2010). As irrigation is an essential tool in poverty alleviation (Burney and Naylor, 2012), its development is considered a priority in socio-economic development.

However, lack of information on where irrigation would be suitable without compromising sustainability of the natural resources and ecosystems has been a major issue. Smallholder farmers faced with the need to increase income and ensure food security in their householders have ventured into irrigation using traditional methods and large plantations have been opened up in several areas within the sub-basin, often not informed about the suitability of the areas for the enterprises. This has caused problems in the water resources resulting in drying up of rivers especially during the dry season and other environmental distresses. These issues call for proper management of land and water resources at the basin and assessment of suitability of the areas for irrigation is of paramount importance. Therefore, this research intends to use geospatial techniques in assessing potential land and surface water resources suitable for irrigation and the extent of irrigated agriculture in the Wami sub-basin in Morogoro region.

1.2 Problem Statement and Justification of the Study

In Tanzania agriculture has remained unpredictable and of low productivity due to the continued dependence on erratic, unreliable and non-uniformly distributed rainfall (URT, 2009). On one hand, poor farming practices by smallholders' farmers and the use of simple technologies are mentioned as a contributing factor to the low incomes for communities and environmental degradation which include land and water resources (Ngana *et al*., 2010). Furthermore, increasing population (Colin *et al*., 2014), creates pressure on agricultural resources in order to meet the food demands of the growing population (Muema, 2016). Moreover, other studies suggest the absence of adequate data base for irrigation development as one among the constraints facing the irrigation sector in Tanzania (URT, 2009). As such, the available data base ignores current extent of areas in use by informal smallholders (Beekman *et al*., 2014). On the other hand, the current data on irrigation potential is not well realized due to the various reasons such as limited financial resources (Nyomora, 2015), thus, there is an urgent need for an agreed common approach for assessing irrigation potential. Indeed, this research expect to come up with information on potential land for implementing irrigated agriculture that will be useful for decision makers, investors and natural resources managers as well as smallholder farmers in planning future interventions as well as management. Mapped extent of small-scale irrigation in the Wami sub-basin will be useful information for natural and water resource managers in planning interventions activities for sustainable management of the catchments.

1.3 Objectives

1.3.1 Overall objective

The overall objective of the study is to assess the available land resources potential of river catchments of Wami sub-basin in order to improve and sustain irrigated agriculture in the Wami sub-basin.

1.3.2 Specific objectives

i. To assess surface water availability for irrigation in the Wami sub-basin
ii. To identify and map the potential land suitable for irrigation using GIS-based Multi Criteria Decision Analysis (MCDA) in the Wami sub-basin.
iii. To identify the extent of small-scale irrigation in the Wami sub-basin using Remote Sensing Indices and Field data.

1.4 Research Questions

1. What extent of surface water is available for irrigation practices?
2. What amount of potential land is suitable for irrigated agriculture?
3. What extent of land currently used for small-scale irrigation?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Description of Key Terms

Land is an essential natural resource comprising all elements of physical and biological environment such as climate, relief, soils, hydrology and vegetation that influence land use (Elsheikh and Abdalla, 2016). The indicators of land characteristics and qualities determine land suitability for a defined use (Al-Mashreki *et al.*, 2010). Indeed, the evaluation of land-use suitability aims at pinpointing the most suitable spatial pattern for future land uses rendering to the specific requirements of some activities (Malczewski, 2004).

Surface water resources is known as that part of the surface water stock which can be drawn on for various uses of water. Water accumulated or flowing on the surface of the earth is considered as surface water (Wijesekera, 2010). This include the water on the surface that exposed to the atmosphere which can originate from rains, lakes, rivers, creeks, wetlands or from ground water (Sohan, 2017). As such, surface water can either be permanent (perennial), semi-permanent (ephemeral), or man-made structures.

Irrigation means application of water in the amounts necessary to bring soil to the desired moisture level prior to crop planting (URT, 2009). Irrigation has been thought to have an important role in increasing agricultural productivity (Oates *et al*., 2017). Mandal *et al* (2017) reported that irrigation has noticeably influence to rural populations which include poverty alleviation, food security and improved the quality of life.

2.2 Irrigation Water Quality

Water quality is a great concern to every living organism including plants and animals (Hopkins *et al*., 2007: Zaman *et al*., 2018). The concentration and composition of the soluble salts in water is the one which determine water quality for various purposes. As such, the quality of irrigation water differs in various regions, countries and location basing on the mechanism at which water is extracted and used, rainfall intensity and consequent aquifers restore (Zaman *et al*., 2018). The impacts of irrigation water on plants and soil depends on the water, soil, crop and other environmental conditions such as climate, natural vegetation and land forms. As irrigation water damage plants directly, others damage soil structures. It is applicable in dry areas and during the periods of insufficient rainfall.

2.3 Irrigated Agriculture

Irrigated agriculture is one of the most critical human activities sustaining civilization (Downgert, 2010). In Tanzania, irrigation is critically vital to deal with the erratic rainfall, especially in the context of climate change and hence in ensuring that the national achieves a reliable and sustainable crop production and poverty reduction (URT, 2009; URT, 2016). A study by Schaefer and Dietrich (2015), suggests the fact that, water demand already exceeds water availability, thus limiting food production and agricultural development.

A study of gravity-fed furrow irrigation in Tanzania (Beekman, 2014), has pointed at a continued expansion of up 4% annually of informal irrigated area by smallholders during the period 1995-2005. On one hand, sustainable irrigation development found to be a heart to improve food security and livelihood. Indeed, irrigated agriculture assumed to reduce significant production threats related with unreliable rainfall and thus raise farmer incomes (URT, 2009).

2.4 Performance of Irrigation Sector in Tanzania

The performance of irrigated agriculture in Tanzania is re-counted with insufficient achievement. Most of the irrigation schemes that customary depended on improvement support, their performance steadily deteriorated due to unsuitable system design, ineffective management, low irrigation effectiveness and poor operations and maintenance, which resulted into their abandonment (URT, 2009). Previous studies in the Wami sub-basin reported that, irrigated agriculture is practiced in wetter districts such as Kilosa and Mvomero in Morogoro Region through the use of permanent water sources (Ngana, *et al*., 2010). As such, this study intend to support the development of surface irrigation through exploring, improving and sustaining water resources, land suitability and irrigated agriculture in the Wami sub-basin.

2.5 Land Suitability Classification

Land suitability is defined as the fitness of a given type of land for a well-defined use. The land may be well-thought-out in its present condition or after improvement for its definite use. Thus, the method of land suitability classification is the assessment and grouping of particular areas of land in terms of their suitability for well-defined uses (FAO, 1976).

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively in sequence of decreasing degrees of suitability within the order. Within the order suitable, the number of classes is not specified however number should be kept to the minimum necessary to meet interpretative aims, utmost five classes should be used.

The classes include the following;

- S1 – Highly suitable (>80%)
- S2 – Moderately suitable (60% - 80%)
- S3 – Marginally suitable (40% - 60%)
- N1 – Marginally not suitable (20% - 40%)
- N2 – Permanently not suitable (<20%)

Highly suitable – This is the land that has no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits.

Moderately suitable – This is the land that have limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, though still attractive, will be appreciably inferior to that expected on Class S1 land.

Marginally suitable – This is the land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity of benefits, or increase required inputs, that this expenditure will be only marginally justified.

Marginally not suitable – This is the land that have limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner.

Permanently not suitable – This is the land that have limitations which appear so severe as to preclude any possibility of successful use of the land in the given manner (FAO, 1976).

2.6 Irrigation Criteria

2.6.1 Slope

Slope is the inclination of a surface and is normally expressed in a percentage. Slope is very essential for soil formation and management because of its influence on runoff, drainage, erosion and choice of irrigation types. The slope of the land has great influence on selection of the irrigation methods. Basing on FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation. Whilst, slopes which are greater than 8%, are not generally recommended (FAO, 1999).

Table 1: Slope suitability classification for irrigation

Serial number	Slope (%)	Factor Rating
1	0 – 2	S1
2	2 – 5	S2
3	5 – 8	S3
4	>8	N

Source: FAO, 1996

2.6.2 Soils

Agricultural deeds have a direct consequence on soils' physical, chemical, and biological properties. These creates serious environmental problems such as soil degradation, waterlogging, salinization/alkalization and contamination (Abd-Elmabod *et al.,* 2019). Thus, the assessment of soils properties for irrigation involves the examination of soil properties that are permanent in nature and cannot be changed or modified. Such properties include texture, depth, drainage, salinity and alkalinity, electrical conductivity, calcium carbonate and slope (Rezania *et al,* 2009: Muema, 2016).

2.6.3 Land use Land cover

The land use land cover pattern of a region is an outcome of natural and socio-economic factors, and their utilization are considered a central component for managing natural resources and monitoring environmental changes (Nath *et al*., 2018). Study by Naschen *et al.* (2019), reported an increasing trend of conversion of natural land cover into arable land, drivers of the change being human activities such as population growth, economic development, and globalization. The term Land use land cover change refers to the human modification of the terrestrial surface of the earth as well as the study of land surface change, they are the most prominent form of global environmental changes as they occur at spatial and temporal scales (Roy and Arijit Roy, 2012: Nath *et al.*, 2018). Thus, land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil and artificial structures, whereas land use is defined as the social and economic purposes and contexts for and within which lands are managed (Roy and Arijit Roy, 2012).

2.7 Overview of GIS and Remote Sensing Application

Geographical Information Systems (GIS), is a tool designed to capture, store, query, retrieve, manipulate, analyze, map and display geographically referenced data (Church, 2002: Muema, 2016). As a tool, GIS is used for management and decision making in various aspects such as water resources for agricultural and conservation purposes (Acharya, 2014). Likewise, valuation of land suitability potential for agriculture is undertaken through close examination of the indicators of land characteristics and qualities by using Geographical Information Systems (Al-Mashreki *et al*., 2010).

Moreover, GIS techniques allows modeling of water demand with different scenarios of soil, crop, weather and irrigation data (Acharya, 2014). Indeed, GIS-based approaches and techniques are capable of capturing important irrigation suitability criteria such as topography, climate, soil, land use pattern, water availability, and agricultural practices and infrastructures i.e. road networks (Wagesho, 2004). As such, studies by (Al-Mashreki *et al*., 2010: Chandio *et al.*, 2013) reported that, GIS is powerful in resource investigation which include management, evaluation and analysis of data to derive useful results for land development activities.

A study by Golmehr (2009), suggest the fact that remote sensing technique is the most efficient scientific tool in connection with ground truth and toposheet for gathering spatial information and very useful in identification, classification and mapping of land use units. Moreover, with linkages to GIS data layer, GPS data, and other functionality, remote sensing technology offers collection and analysis of data from ground-based, atmospheric and Earth-orbiting platforms. In totality, this has made remote sensing a valuable source of land-use information (Rogan and Chen, 2003).

2.7.1 GIS- Based Multi Criteria Decision Analysis

Many decision problems have led to the integration of GIS and Multi-Criteria Decision Analysis (Muema, 2016). As such, the integration of GIS using the multi criteria decision analysis approach (MCDA) provides an environment to the decision makers in citing areas using land suitability analysis procedures (Chandio *et al.*, 2012: Muema, 2016).

Multi Criteria Decision Analysis technique gather methods and processes for constructing decision problems, planning, appraising and ranking alternative decisions (Malczewski, 2006). Many different data types ranked from most suitable to least suitable and then standardized into suitability indices are reported as an input of the MCDA technique (Michael *et al.,* 2005). MCDA technique is capable of simplifying decision making, in circumstances where several clarifications are available, and various criteria are to be considered while decision makers are in conflict (Hamadouche *et al.*, 2014: Linkov *et al.,* 2004). As such, Analytical Hierarchy Process (AHP), has been reported as a major tool in Multi Criteria Decision Analysis (Chandio *et al.*, 2013). MCDA process involve a number of steps as reported by Muema (2016). These include defining the problem or goal, data collection, determination of the criteria, generation of the criteria maps, determining weight for each criterion, standardization of the criterion, aggregation of the criteria, validation of the results and generation of the suitability map.

2.7.2 Weighted overlay analysis

Normally, GIS techniques are used to analyze different factors in trying to solve various geographical glitches. For instance, finding an optimal site for irrigation requires weighing of factors such as slope, soil, land cover and distance from water sources. Thus, a method like weighed overlay which is one method of modeling suitability that apply a common measurement scale of values to diverse and dissimilar inputs so as to create an integrated analysis has to be deployed (Muema, 2016). Weighted overlay analysis involves the series of process in the ArcGIS environment which include assigning weight in the suitability analysis to each of the raster which target to control the influence of dissimilar criteria in the suitability model, reclassification of values in the raster in accordance to common suitability scale, derivation of suitability values by overlaying and multiplying each raster cell’s suitability values by its layer weight and then totaling the values which are going to be written to a new cells in an output layer(Stauder, 2014). Indeed, the weighed overlay analysis is achieved by combining all thematic layers and assigning ranks accordingly based on the multi-influencing factors of the particular features (Rahul *et al.*, 2018).

CHAPTER THREE

3.0 MATERIALS AND METHOD

3.1 Materials

3.1.1 Description of the study area

The study was carried out in Wami sub-basin within Morogoro Region. Wami sub-basin is located between Latitude 5° – 7° South and Longitude 36° – 39° East (Figure 1). The total area of Wami sub-basin is 43,000 km^2, and lies within an altitudinal gradient of approximately 2260 meters. Approximately, 75% of total household income in the basin is earned from agriculture. The agricultural activities carried out in the Wami sub-basin are mostly depended on rain-fed agriculture which is largely practiced in the semi-arid areas in Dodoma, Mpwapwa and Kongwa and irrigation schemes that are found in wetter districts such as Kilosa and Mvomero in Morogoro Region (Ngana *et al.,* 2010). Dodoma, Mpwapwa, Kongwa, Kilosa and Mvomero Districts are major Livestock centers in the Wami sub-bain.

Wami sub-basin falls under bimodal rainfall pattern, with long rains falling between March to June (*Masika* rains) and short rains falling between November to December (*Vuli* rains). Dry periods normally observed from July to October. Average annual rainfall across the Wami sub-basin is estimated to be varying between 550 – 750 mm in the highlands near Dodoma, 900 – 1000 mm in the middle areas near Dakawa and between 900 – 1000 mm at the river's estuary.

The Wami sub-basin is among the basins with a high potential for irrigated agriculture. The main problem and issues facing sub-basin include water resources, socio-economic, conflict, policy and law enforcement, management and administration (Ngana *et al.*, 2010).

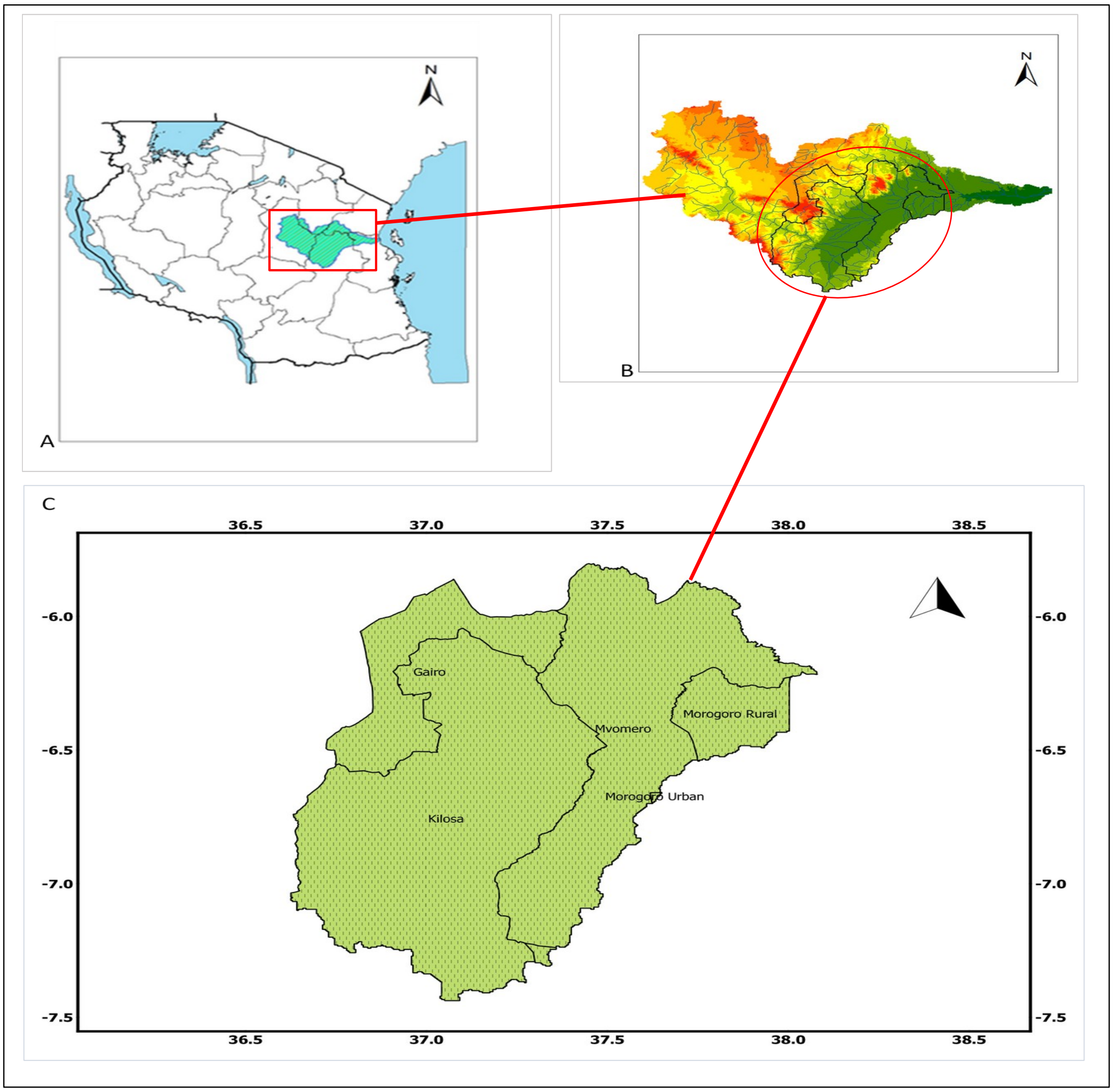

Figure 1: Map showing Wami sub-basin within Morogoro Region (in green) in Tanzania

3.1.2 Data collection methods

3.1.2.1 Geospatial data

Spatial data for rivers and roads network used in this study were extracted from DIVA-GIS (www.diva-gis), which is a free computer program for mapping and geographical data analysis (Geographical Information Systems). Whereas, Land use land cover data used was extracted from landsat-8 OLI obtained from United State Geological Survey (USGS). Also, Geo-spatial data for soil chemical and physical properties in the Wami sub-basin (Table 2), were obtained from (ISRIC-World Soil Information-https://www.isric.org/explore/soilgrids, (International Soil Reference and Information Center-ISRIC).

Table 2: Geospatial data

	Spatial data	Available depth	Units	Mass fraction
Physical properties	TZA_waterline_dcw.shp	-	-	-
	TZA_roads.shp	-	-	-
	TZA_cov.shp	-	-	-
	TZA_river.shp	-	-	-
	Bulk density	100 cm	Kg/m^3	%
	Clay content	100 cm	0-2 µm	%
	Silt content	100 cm	2-50 µm	%
	Sand content	100 cm	500-2000 µm	%
	Coarse content	100 cm	-	%
Chemical properties	CEC	100 cm	%	
	SOC	-	g/kg	
	Soil PH	PH X 10 in water	%	
	Depth to the rock	R- horizon to	-	
	Absolute depth	200cm	-	
	SOCS	100 cm	Tones/ha	
		-		

3.1.2.2 Satellite data

Landsat satellite images (Landsat 8 OLI/TIRS C1 level-1), from 1st January 2019 to 30th June 2020, with varying cloud cover ranges were used in this study (See Table 3). These data were obtained from United States Geological Survey (USGS).

Table 3: List of Landsat-8 OLI images used

No.	Path/Row	Acquisition date	Spatial Resolution	Cloud Cover Range	Season
1	168/66	11.0.8.2020 13.08.2020	30 meter	0% - 12%	Dry
2	168/65	12.08.2020 13.08.2020	30 meter	0% - 7%	Dry
3	168/64	12.08.2020 13.08.2020	30 meter	0% - 9%	Dry
4	167/66	10.08.2020 13.09.2020	30 meter	0% - 14%	Dry
5	167/65	08.08.2020 10.09.2020	30 meter	0% - 9%	Dry
6	166/65	15.08.2020	30 meter	0% - 19%	Dry

3.1.2.3 Rainfall data

Satellite rainfall data were obtained from early warning explorer under USGS through (https://data.chc.ucsb.edu/products/CHIRPS2.0/global_daily/netcdf/p05/by_month/).These are the rainfall estimates from the rain gauge and satellite abbreviated as CHIRPS. The word CHIRPS stands for -Climate Hazards Group Infrared Precipitation with Station data, which blends three different products to create the rainfall estimate, which include station data, infrared data and climate data.

3.1.2.4 Evaporation data

Daily evaporation data for Morogoro Meteorological station were obtained from Tanzania Meteorological Authority (TMA).

3.1.2.5 Evapotranspiration data

The daily data for maximum and minimum temperature, dew point temperature, sunshine and wind run, for Morogoro Meteorological station was used to calculate evapotranspiration. These data were obtained from Tanzania Meteorological Authority (TMA), in Dar es Salaam.

3.1.2.6 Hydrological data

Stream flow data of the study area (Dakawa and Mandera gauging stations), were obtained from Wami Ruvu Basin Water Office (WRBWO), in Morogoro.

3.1.2.7 Normalized Difference Vegetation Index (NDVI) data

Satellite imagery obtained from Landsat-8 was used to calculate Normalized Difference Vegetation Index (NDVI). These data are freely accessible through the USGS earth explorer (United States Geological Survey). .

Table 4: Water balance analysis datasets

Data type	Source	Units	Temporal Resolution	Spatial Resolution	Start date	End date
Rainfall		mm	Monthly		01.01.2010	31.12.2019
Evaporation		mm				
Sunshine		MJ/m^2				
Windrun	TMA	m/s	Daily	Nil	01.01.2019	31.12.2019
Dew point		^0C				
Max. temp		^0C				
Min. temp		^0C				
Stream flow		m^3/s			01.01.2010	31.12.2018

3.2 Methods

3.2.1 Assessment of surface water availability for irrigation

Water balance model simulation

The water balance at land surface within Wami Sub-basin was estimated basing on general hydrologic equation. This equation is basically a statement of the law of conservation of mass which is expressed as;

Inflow = Outflow + Change in storage……………………………….…………….. (1)

The volumetric water balance per unit area was transformed and expressed as;

$$P = E_T + Q + \Delta S + \mu \quad \text{.......... (2)}$$

Where P is the precipitation, E_T is the actual evapotranspiration, Q is the river discharge from the basin, ΔS is the change in water storage expressed as a mean depth and μ is the discrepancy term. All the terms in equation (2) above are dependent except precipitation.

The daily rainfall data in Network Common Data Form (NetCDF), format (item 3.1.2.3), were decoded and then merged using Climate Data Operator (CDO). These data were opted due to the inappropriate observation data of study area in the TMA offices. Thus, pre-processing was performed using CDO to obtain area total rainfall on monthly basis (in the Wami sub-basin). Subsequently, Mean amount of the precipitation was computed as the arithmetic mean of the monthly precipitation data.

$$\underline{P} = \frac{1}{n}\sum_{i=1}^{n} Pi \quad \text{.......... (3)}$$

Where; $\underline{P}$ is the mean precipitation for sub-basin, P_i is the mean precipitation for the same period at the i^th station, and n is the number of stations used to compute mean precipitation.

Then, transformations between depth and volume of water in recommended units was done basing on equation number 4;

$$V = 1000.A.S \ldots\ldots (4)$$

Where; S is a storage expressed as a "mean depth" in (mm), V is the same storage expressed as a volume (m^3), and A is the area of the basin in Km^2.

Moreover, Penman Monteith method was used to estimate evapotranspiration. This was achieved by inserting the daily climatic data within Penman Monteith features found in the Instat+ software for processing. Afterwards, average evapotranspiration ($\underline{E}$), over the basin was computed as the arithmetic mean of ET_0 output obtained using Penman Monteith method.

$$\underline{E} = \frac{1}{n}\sum_{i=1}^{n} Ei \ldots\ldots (5)$$

Where; $\underline{E}$ is the mean ET_0 for the Wami sub-basin, E_i is the mean ET_0 for the same period at the i^th^ station, n is the number of stations used to compute the mean.

Furthermore, having observed flow (Q_{obs}), of the study areas (such as. Dakawa and Mandera watersheds within Wami sub-basin), calculated flow(Q_c), will be obtained upon using the assumption made by Jiang *et al* (2011), that is; the storage change (ΔS), was assumed to be insignificant for a full year period, then average annual water balance equation was simplified as equation 6;

$$P - ET_0 = Q \ldots\ldots (6)$$

Additionally, GIS was used for spatial mapping of the location of the existing surface water sources and irrigation schemes in the Wami sub-basin. Then, an overlay of elevation map of the Wami sub-basin, surface water resource, including rivers network and irrigation schemes will be produced.

3.2.2 Identifying and mapping potential land suitable for irrigation using GIS-based multi criteria decision analysis (MCDA)

3.2.2.1 Data collection and criteria (factors/constraints) determination

Seven criteria were chosen basing on data availability and their significances to the surface irrigation methods. This includes biophysical data comprising of climate data, Topography data (Slope and Elevation), Soil data (texture, depth and PH), and land use/land cover data. Likewise, Roads and River networks as socio-economic data were used in this study. These data were obtained from various sources. Climate data were obtained from Tanzania Meteorological Authority (TMA), other sources were; Earth Explorer – USGS for (Topographic data), ISRIC for (Soil data), and some other data were extracted from DIVA – GIS. Moreover, satellite images from Landsat-8 were downloaded from USGS. These images were used to generate land use/cover of the study area. About 166 Landsat-8 images were evaluated for image processing, the target was to get images with cloud cover less than 10, 15 and 19%. As such, several clouds free images were downloaded, alternatively clouds percentage values were specified on the downloading portal. However, it was not possible to get the desired images. In that regard, images with higher cloud cover (10< cloud cover < 20), were used (Table 3).

3.2.2.2 Generation of Criteria Maps Using GIS

The biophysical and socio-economic factors were used to identify the criteria and constraints basing on their significances and data availability. Afterwards, Geographical Information System was used to process spatial data so as to generate criteria maps including Digital Elevation Mode (DEM), Elevation, Rainfall, Slope, Soil, River, Roads and LULC maps of the study area.

3.2.2.3 Determination of Weights for each Criterion Using AHP Process.

Seven criteria were defined and arranged in order. Then, each criterion was assigned its weight basing on its importance on acquiring potential land suitable for irrigation. The fundamental scale of number ranging from 1 to 9 by 1 was used to assign the weights (Analytical Hierarchy Process-AHP), as inverted by Saaty (Hamadouche *et al.*, 2014).The essence of using AHP was to make pairwise matrix comparison between the criteria so as to reduce the complexity as suggested by Saaty (1980), as illustrated in Table 5.

Table 5: Shows pairwise comparison matrix.

Definition	Index	Definition	Index
Equal important	1	Equal important	1/1
Equally or slightly more important	2	Equally or slightly less important	1/2
Slightly more important	3	Slightly less important	1/3
Slightly to much more important	4	Slightly to way less important	1/4
Much more important	5	Way less important	1/5
Much to far more important	6	Way to far less important	1/6
Far more important	7	Far less important	1/7
Far more important to extremely more important	8	Far less important to extremely less important	1/8
Extremely more important	9	Extremely less important	1/9

Source: Saaty (1980).

3.2.2.4 Standardization of the criteria measurements units (reclassification)

In the meantime, all criteria possess different scale of measurements as they are obtained from various sources. Thus, these scales of measurements must be harmonized so as to attain the uniformity and comparability (Quintana *et al.,* 2008: Effat and Hassan, 2013). As such, all criteria used in this particular case were standardized (reclassified) so as to attain uniformity by neutralizing scores dimensions along with their measurements units.

Thereafter, the criteria were combined (weighted overlay), and finally the whole AHP model (see item 3.2.2.5), was validated and executed to generate a suitability map for irrigated agriculture.

(a) Reclassifying Slope

Slope was extracted from digital elevation model (DEM)-30 meter resolution, then reclassified, and sliced the values into four equal intervals in GIS field. The numerical values were assigned to demarcate the areas with highly suitable ranges of slopes (areas with the lowest percentage value of slope denoted by 4), to the least suitable ranges of slopes (areas with the steepest percentage value of slope denoted by 1), and ranked the values in between linearly based on the AHP process proposed by Saaty (1980).

(b) Reclassifying Soil Depth

Soil depth was extracted, reclassified, and divided its values into four equal intervals in GIS environment using AHP techniques. Afterwards, the numerical values were assigned so as to demarcate the areas with highly suitable ranges of soil depths (areas with the highest value of soil depth denoted by 4), to the least suitable ranges of soil depths (areas with the lowest value of soil depth denoted by 1), and ranked the values in between linearly as suggested by Saaty’s AHP process (1980). The class ranges were arranged in decreasing order of depth level i.e. from very deep, deep, moderately deep and shallow.

(c) Reclassifying Soil Drainage

The soil drainage was extracted, reclassified, and sliced into four equal intervals in GIS field using AHP techniques. Subsequently, the numerical values were assigned so as to delineate the areas with highly suitable ranges of soil drainage (areas with the highest value of soil drainage denoted by 4), to the least suitable ranges of soil drainage (areas with the lowest value of soil drainage denoted by 1), and ranked the values in between linearly using the AHP process by Saaty (1980).

(d)Reclassifying Soil texture

The soil textural classes were extracted, reclassified, and sliced into four equal intervals in GIS environment using AHP techniques. Thereafter, numerical values were assigned to delineate the areas with well-textural value of soil suitable ranges of soil texture (areas with well-textural value of soil texture represented by 4), to the poorly-textural soil suitable ranges of soil texture (areas with poorly-textural value of soil represented by 1), and ranked the values in between linearly using the AHP process by Saaty (1980).

(e) Reclassifying Soil PH

Soil PH data was extracted, reclassified, and sliced into four equal intervals using GIS. Then, numerical values were assigned to delineate the areas with highest soil suitable ranges of soil PH (areas with highly value of soil PH indicated by 4), to the least soil suitable ranges of soil PH (areas with lowest value of soil PH indicated by 1), and ranked the values in between linearly using the AHP process by Saaty (1980).

(f) Reclassifying Road

To begin with, the Road data file (in a vector format), was loaded to the GIS field and converted to raster format. Then, the output data file (raster format), was loaded to the Model builder of ArcMap 10.7 GIS software. Then, the Model builder was validated and run so as to create Euclidean distance output and Euclidean direction output in the raster format as observed in Figure 2.

Afterwards, Euclidean distance and Euclidean direction output were reclassified and sliced into four equal intervals using GIS. Then, the numerical values were assigned to delineate the area which are located close to the roads for easily accessibility in terms of labour movement, input and output of farm materials and products. As such, closest suitable range of Euclidean Road distance (0 – 2 km), will be indicated by 4), to the farthest distance range (5 – 10 km), values of Euclidean Road distance will be indicated by 1, and ranked the values in between linearly using the AHP process by Saaty (1980). Finally, the model was validated and run to create proximity distance to the Road.

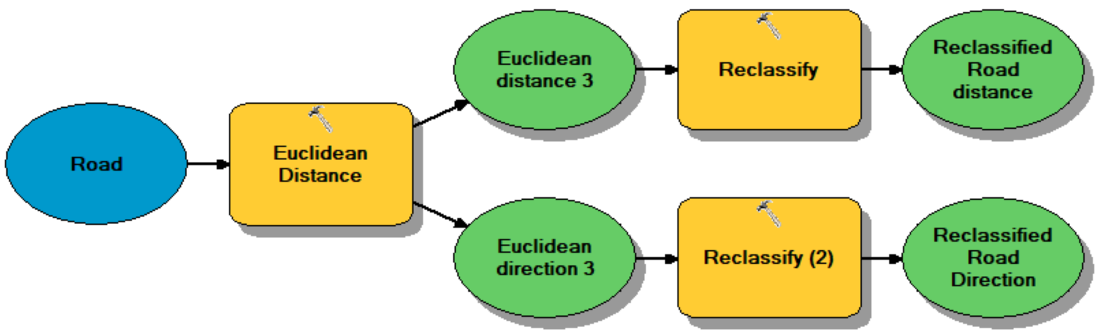

Figure 2: Proximity to the Road Model in the Wami sub-basin

(g) Reclassifying River

Basing on the assumption that, irrigated areas should be situated as close as possible to the rivers (taking into consideration a buffer zone for the safety of water resources), thus, the river data file (in a vector format), was loaded to the GIS field and converted to raster format. Then, the output data file (raster format), was loaded to the Model builder of ArcMap 10.7 GIS software. Euclidean distance output and Euclidean direction output (in the raster format) were created as observed in (Figure 3), after validating and run the model. Subsequently, Euclidean distance to the river output and Euclidean direction to the river output were reclassified and divided into four equal intervals using GIS software.

Then, the numerical values were assigned to establish the area with closest suitable range of Euclidean River distance(0 – 2 km), will be indicated by 4), to the farthest distance range (5 – 10 km), value of Euclidean River distance will be indicated by 1), and ranked the values in between linearly using the AHP process by Saaty process (1980). Finally, the model was validated and run to create Euclidean distance and direction to the River.

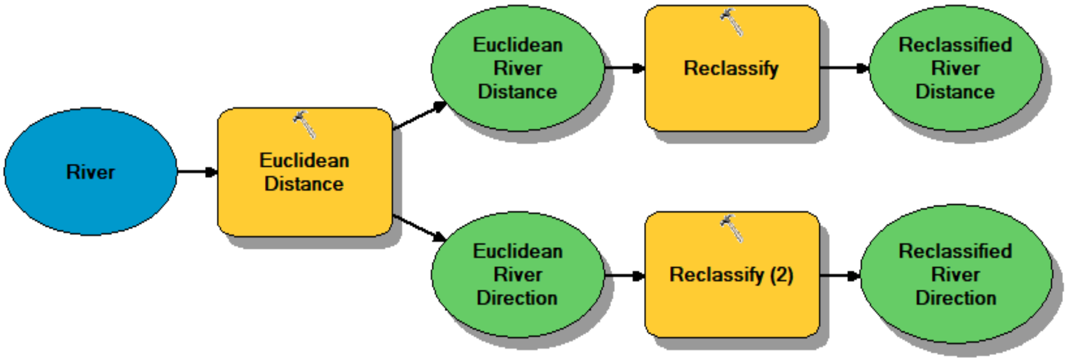

Figure 3: Proximity to the Rivers Model in the Wami sub-basin

3.2.2.5 Model Generation for Suitability Identification

The model inputs data sets were captured, re-arranged and pre-processed before subjected to the model builder. The rainfall data sets were kept in tabular format (comma separated values- csv), whereas, the digital elevation model (DEM)-30 metres cell resolution was processed using geographical information systems (GIS) to generate slope and elevation. Satellite data from landsat-8 OLI images acquired from January 2019 to June 2020 were subjected to the GIS environment for the atmospheric correction, and later mosaicked images were used to generate land cover map of the study area upon using supervised classification. This classification was enhanced using National Forest Resources Monitoring and Assessment (NAFORMA), a report of 2015. Moreover, roads and river data sets obtained from DIVA-GIS were subjected to the Geographical Information Systems (GIS) for conversion from vector to raster format. Afterwards, all data sets were introduced to the Model Builder environment of ArcMap 10.7 for suitability map execution as observed in Figure 4.

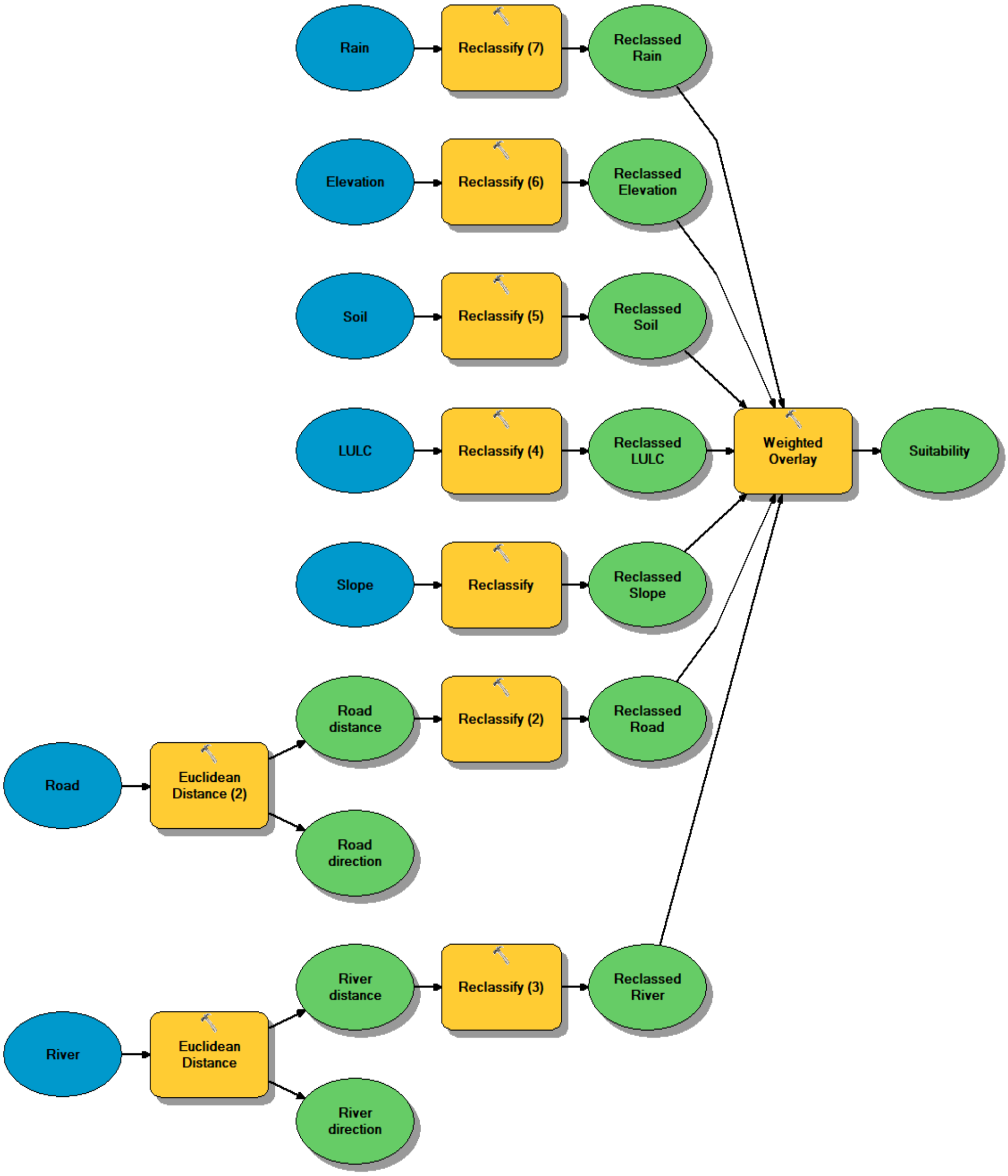

Figure 4: Weighted overlay model for suitability identification

3.2.3 Identifying the Extent of Small-Scale Irrigation Using Remote Sensing Indices Derived From Landsat- 8 OLI

3.2.3.1 Remote Sensing Data and Pre-processing

Three methods were used in data collection of the study area. Ground truthing, Google earth explorer and satellite image process. Ground truthing data was collected on 6th October 2020 using Garmin GPSmap 62s and smartphone. Inclusively, 166 points were taken (31 for small-scale irrigated areas and 135 for other land covers), and Dakawa irrigation scheme was visited. On the other hand, geocoding method that use Path and Row was used to obtain satellite data from Landsat Collection 1 Level- 1 (Landsat-8 OLI/TIRS C1 Level -1). Different dated 6 Level United State Geological Survey images were downloaded between August and early September 2020 from the USGS's Earth Explorer data portal. Through the whole process of selecting the remote sensing data, special attention was given to images which does not have cloud or fog over the study area. However, other imagery with cloud cover greater than 10% but less than 17% were incorporated due the availability of the data. Surface reflectance images were used in this study so as to generate more accurate results.

Each image obtained was subjected to QGIS 2.18 software for the pre-processing before deriving indices. This include radiometric corrections in which Landsat-8 images were converted from a digital number (DN) to top-of-atmospheric (TOA) reflectance, transformation and brightness temperature. The atmospheric correction of images was executed in order to attain surface reflectance data.

3.2.3.2 Remote Sensing Generation of NDVI data

The Normalized Difference Vegetation Index (NDVI), model was created. This model is made available for vegetation index (greenness detection), as described by Al-Doski *et al.* (2013).

3.2.3.3 Four steps image analysis

(a) To compute the NDVI from the mosaicked and clipped sub-basin layer.

The Normalized Difference Vegetation Index (NDVI), model was created. The NDVI classes were calculated based on threshold ranges between -1 to 1. Five classes of interest were highlighted. NDVI values less than -0.1 indicates the availability of water. NDVI values from -0.1 to less than 0.2 indicate bare land. NDVI values from 0.2 to 0.4 indicates shrubs and grassland (sparse vegetation), NDVI values from 0.4 to 0.6 indicates moderate vegetation, and values from 0.6 to 1 represents dense vegetation as suggested by Mzava *et al.* (2019).

Afterwards, the ground truthing points obtained from the field were randomly coded by number 1, 2, 3, 4 and 5 assumed to represents the classified NDVI as 1 representing water, 2 representing bare land, 3 indicates shrubs and sparse vegetation, 4 representing moderate vegetation and 5 representing dense vegetation.Then, Microsoft excel was used to create a control chart to determine the quality of NDVI classification process. The variables such as standard deviation (STD), mean central line (CL), of the NDVI classification process, upper control limit (UCL), and lower control limit (LCL), of the NDVI classification process were created using Microsoft excel.

(b) To perform accuracy assessment using error matrix and field data

Error matrix was developed based on classified NDVI and reference points data collected from the study area (ground truthing points), and google earth as well. Then, next step was to calculate error of omission, error of commission, users' accuracy, producers' accuracy, overall accuracy and kappa coefficient based on calculated values within error matrix table.

(c) To identify surface water features found within 1.5 km buffer zone.

Unsupervised classification was performed based on surface water sources found within 1.5 km buffer zone, and five classes were created. Afterwards, reclassification was performed to create two classes, of which first class represented water bodies (indicated by 1), and the other four classes (indicated by 2). The aim was to isolate water bodies from the rest of other classes such as bare land, scattered, moderate and dense vegetation. The new map in raster format was created. Then, the map was converted to vector format so as to acquire water bodies in vector format.

(d) To identify irrigated areas within the buffer zone using NDVI classes.

Despite the fact that NDVI signals were too weak to be recognized within landsat-8 imagery given at 30-meter resolution, the calculated NDVI classes were used to identify irrigation areas based on their threshold ranges between -1 to 1, Moreover, the research done by Hatibu *et al.* (2002), was used to justify the results obtained from this study.

3.2.3.4 Accuracy assessment

The objective of performing the accuracy assessment was to counter check how effective NDVI were able to delineate the small-scale irrigated fields. This is due to the fact that land use maps resulting from the satellite imagery encounter some errors due to the numerous factors as stated by Mandal and Satpathy (2018).

Error matrix (a square array of numbers), was developed based on classified NDVI generated from remotely sensed data (in a row), and reference points data (in a column), collected from the study area (ground truthing points), and google earth as well. Then, next step was to calculate user’s accuracy corresponding to error of commission (inclusion), and producer's accuracy corresponding to error of omission (exclusion), overall accuracy and kappa coefficient based on calculated values within error matrix table.

$$\text{User's accuracy} = \frac{\textit{Number correctly identified} \in \textit{a given map class}}{\textit{Number claimed} ¿} \textit{be} \in \textit{that map class} ¿$$

Likewise;

$$\text{Producer's accuracy} = \frac{\textit{Number correctly identifi ed} \in \textit{reference plots of a given class}}{\textit{Number of actually} \in \textit{tat reference class}}$$

And;

$$\text{Kappa coefficient} = \frac{\textit{Observed}(\textit{total})\,\textit{accuracy} - \textit{Random}(\textit{chance})\,\textit{accuracy}}{1 - \textit{Random}(\textit{chance})\,\textit{accuracy}}$$

Then;

$$\text{Overall accuracy} = \frac{\textit{Total correct}\,(\sum \textit{of the major diagonal})}{\textit{Total number of samples} \in \textit{the error} ¿¿}$$

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter provides the summary of the findings based on the collected data, analysis and the discussion of the research study assessing potential land and surface water resources available and suitable for irrigated agriculture in the Wami sub-basin Morogoro region. The chapter is sliced into sections and subsections which include assessment of surface water availability for irrigation (water balance model simulation was used), identification and mapping of the potential land for surface irrigation using GIS-Based Multi Criteria Decision Analysis (MCDA) method and identifying the extent of the Small-scale irrigation in the Wami sub-basin (Morogoro in particular), using remote sensing indices and field data.

4.1 Availability of Surface Water Resources for Irrigation

Water balance model simulation

Basing on assumption that storage change was insignificant over a full year period (equation 7 that is; $P - ET_0 = Q$), stream flows (Q) were simulated for Dakawa and Mandera catchments respectively. In Dakawa, the maximum flow recorded was 3200.4 m^3/s, with base flow being 0.0m^3/s (based on observed data sets at Dakawa), implying that there were no water flowing in the river during the dry season. Also, the observed mean flow was found to be 553.3m^3/s (direct flow), equivalent to 51.11 mm per month, whereas the calculated mean flow was found to be 64.34 mm. The mean difference of 13.23 mm per month between the observed stream flow (Q_{obs}) and (Q) simulated stream flow was observed in Dakawa. The computed mean difference of 13.23 mm account for an average of 92.0% of the annual precipitation in Dakawa. However, with maximum and minimum precipitation of 283.1 and 0.5 mm respectively, the mean precipitation of 71.84

mm for the period starting from 2010 to 2018 was observed along with mean evapotranspiration of 7.50 mm.

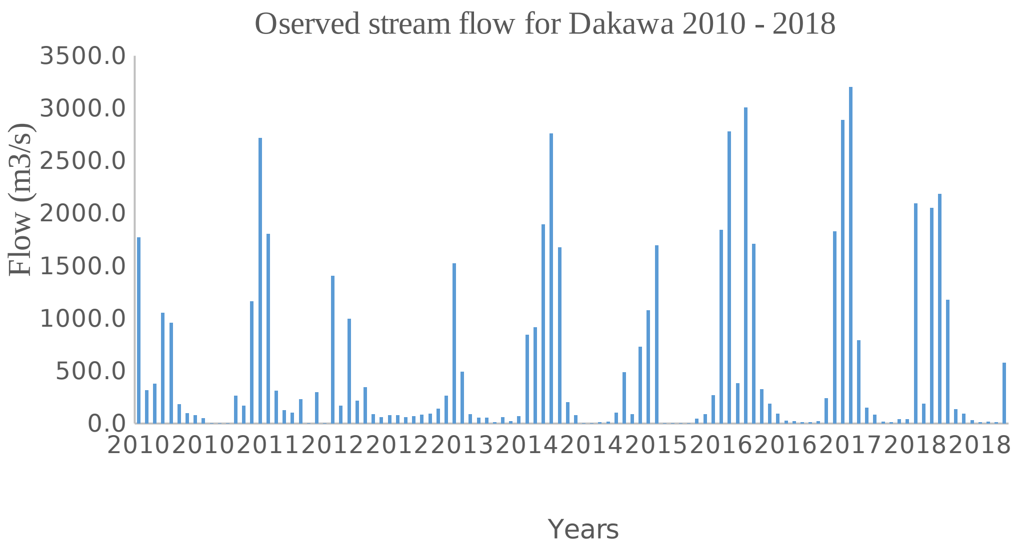

Figure 5: Hydrograph showing monthly flow in Dakawa from 2010- 2018

Basing on the available flow data observed in Dakawa (28,488 km^2), the estimated mean direct flow of 553.32 m^3/s was observed. This mean flow is equivalent to 51.11 millimetre (runoff), of rainfall per month observed in Dakawa. It then implies that, an average of three months interval is needed to generate a mean flow of 553.32 m^3/s, which is equivalent to 17.85 m^3/s average daily flow in Dakawa watershed.

On the other hand, in Mandera (drainage basin), the maximum direct flow observed was 8998.40 m^3/s with the portion of stream flow that is not runoff (base flow), being 0.0 m^3/s, implying that there were no water flowing from the ground to the channels(in the river), during dry the season. Also, the observed mean flow was found to be 866.24 m^3/s (direct flow), which account for 62.27 mm per month. Indeed, the calculated mean flow was found to be 61.04 mm. The mean difference of 1.23 mm per month between the observed stream flow (Q_{obs}) and (Q) simulated stream flow was observed in Mandera. The above mentioned mean difference account for more than hundreds percent (121%), of the annual precipitation. Mandera water catchment was found to have a mean precipitation of 69.02 mm, mean evapotranspiration (ET_0) of 7.98 mm, with maximum and minimum of 12.5 and 3.47 mm respectively.

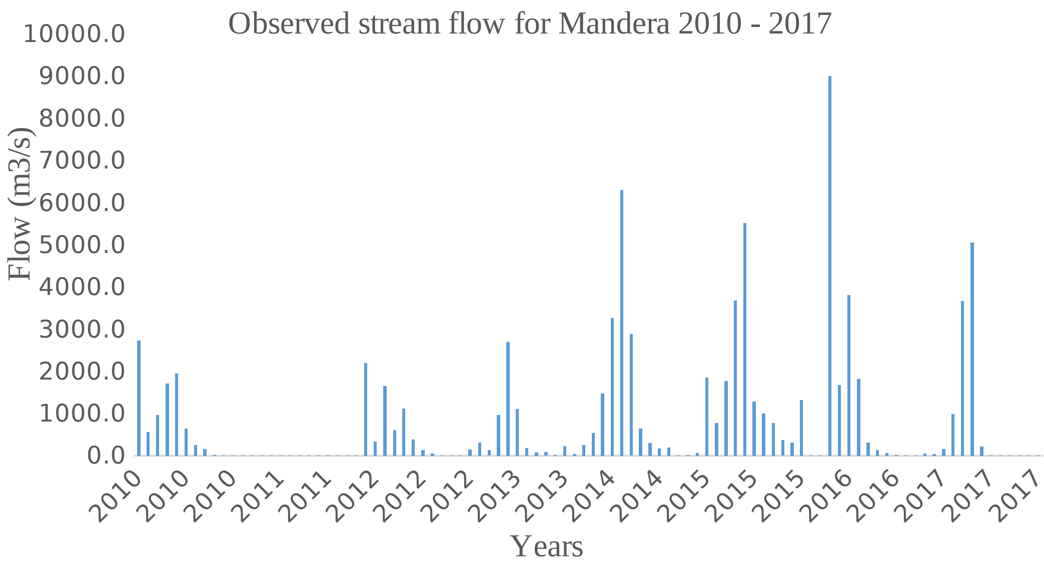

Figure 6: Hydrograph showing monthly flow in Mandera from 2010- 2017

Likewise, based to the available observed flow data in Mandera (at 36 450 km^2 area), the estimated mean direct flow of 866.24 m^3/s was observed. This is equivalent to 62.27 millimetre (runoff), of rainfall per month observed in Mandera. It then implies that, an average of 84 months interval is needed to generate a mean flow of 866.24 m3/s in Mandera which is equivalent to 27.94 m^3/s average daily flow.

These results differ with (Tobey, 2008), that average daily flows for Dakawa and Mandera gaging stations were found to be 25.8 m3/s and 60.6 m3/s respectively.

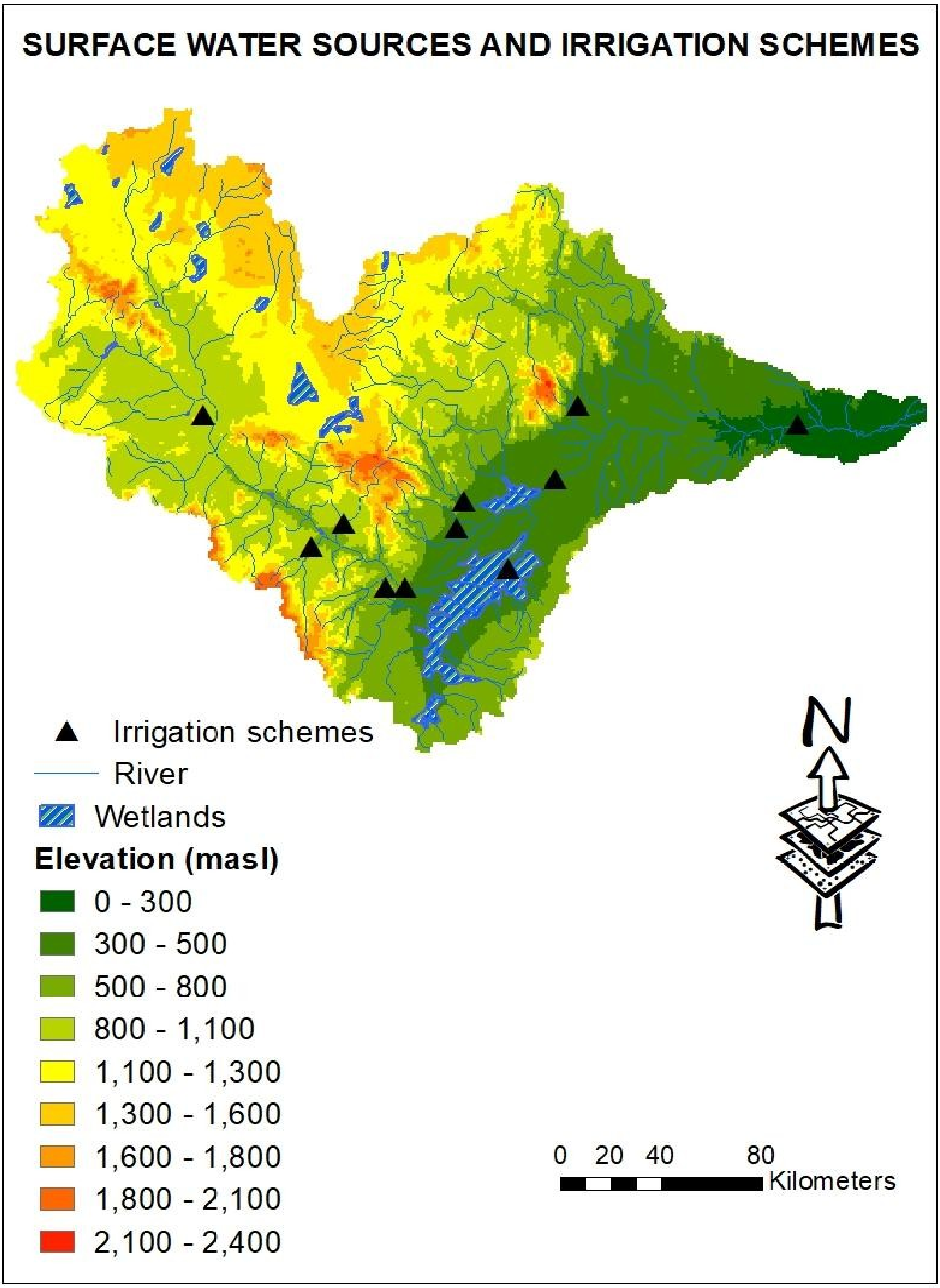

Figure 7: Existing surface water resources and irrigation schemes in Wami sub-basin

4.2 Potential Land Available and Suitable for Irrigation Using GIS-Based Multi Criteria Decision Analysis (MCDA).

4.2.1 Land use land cover map of Wami sub-basin

Basing on the created land use land cover map of the study area (Wami sub-basin), Figure 7, and forest was found have an area of 97129.9 km^2 accounting for 84.067% of the entire sub-basin. This was found to be the largest land use type in the Wami sub-basin in accordance to the available data. Likewise, sparse vegetation was found to be the least land use type in the Wami sub-basin with an area of 6.332 km^2 accounting for 0.005 % of the entire sub-basin as observed in Table 6.

Table 6: Distribution of areas for different land use/land cover types

No.	Land use type	Area (km^2)	Area (%)
1	Forest	97129.900	84.067
2	Woodland	10723.600	9.282
3	Grassland	7512.9200	6.503
4	Cultivated land	13310.300	11.521
5	Dense vegetation	10.543	0.009
6	Sparse vegetation	6.332	0.005
7	Bare land	12.084	0.010
8	Built up area	103.719	0.090
9	Wetlands	13.533	0.012

Furthermore, based on the available data, the analysis shows that on average dense vegetation, sparse vegetation, bare land and wetlands were found to have distribution of area ranging from 6 to 13 km^2, which account for 0.01% as presented in (Figure 8).

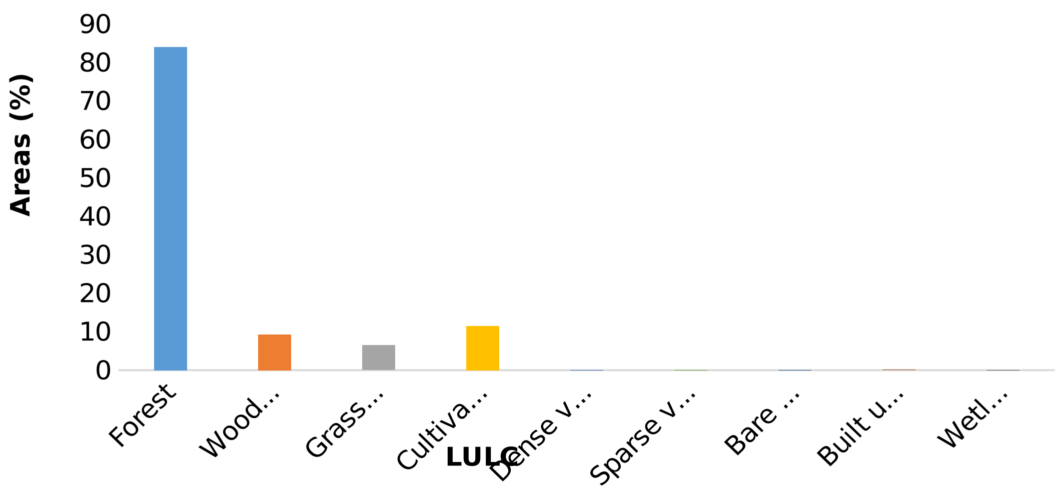

Figure 8: Distribution of areas for different land use/land cover types

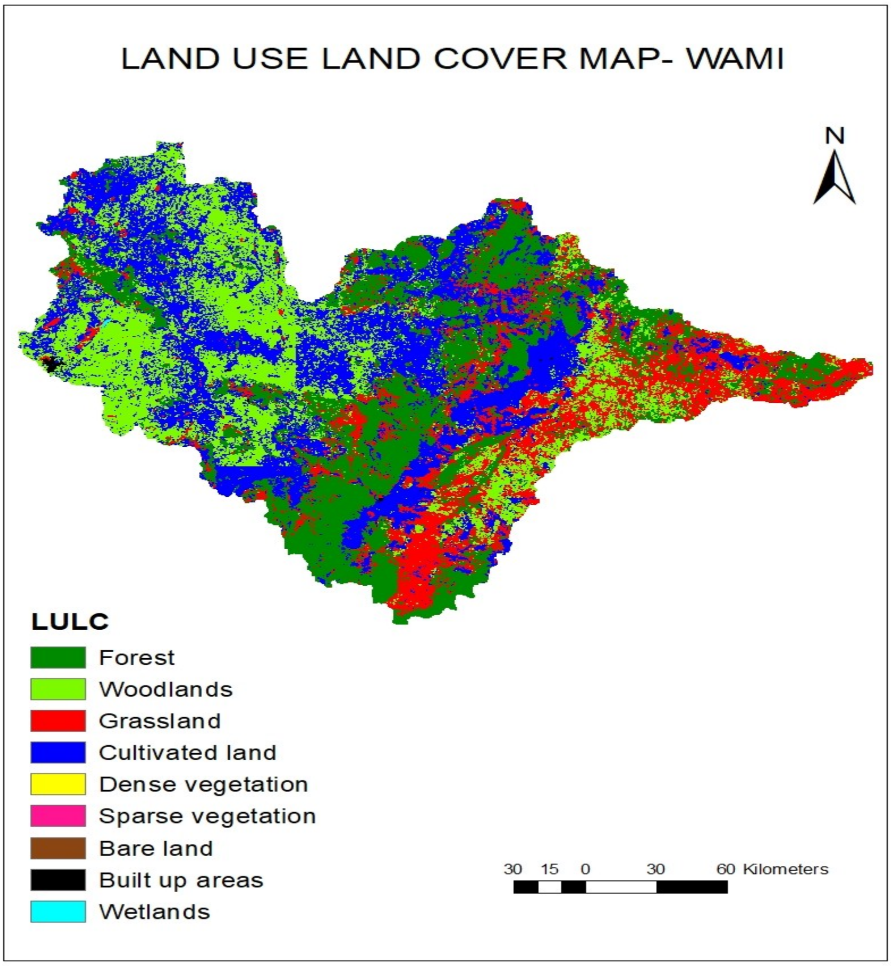

Figure 9: Land use land cover map of the study area

4.2.2 Criterion Weights Using AHP-process

Table 7 shows weights to each criterion based on the Most Influencing Factor (MIF) to the suitability analysis. Slope was given the highest score due to its influence to the surface irrigation.

Table 7: Map showing criteria weights- Analytical Hierarchy Process (AHP)

CRITERIA		WEIGHTS (%)
- Perennial rivers		14
- Slope		35
- Land use Land cover		20
- Road		10
*Soil		
-PH	5%	21
-Depth	6%	
-Texture	5%	
-Drainage	5%	

4.2.3 Standardization and suitability classification

4.2.3.1 Slope classification

The irrigation suitability analysis indicates that 37 227.57 km^2 accounting for 92.32% of the slope (Table 8), of the study area is highly suitable for the surface irrigation systems, 2 623.84 km^2 accounting for 6.51% of slope in the sub-basin is moderately suitable, 439.64 km^2 accounting for 0.01% of slope is marginally suitable and 31.80 km^2 accounting for 1.16 % of slope in the study area was found to be unsuitable for surface irrigation. As such, slope tend to define an area in terms of the erosion hazard and workability as suggested by Mandal *et al.* (2018).

Table 8: Criteria for slope classification in AHP

Class ranges (%)	Area(km^2)	Area (%)	Weight	Description
0 – 11.276	37227.57	92.32	4	Highly suitable (S1)
11.276 – 22.552	2623.84	6.51	3	Moderately suitable (S2)
22.552 – 33.827	439.64	0.01	2	Marginally suitable (S3)
33.827 – 45.103	31.80	1.16	1	Not suitable (N)

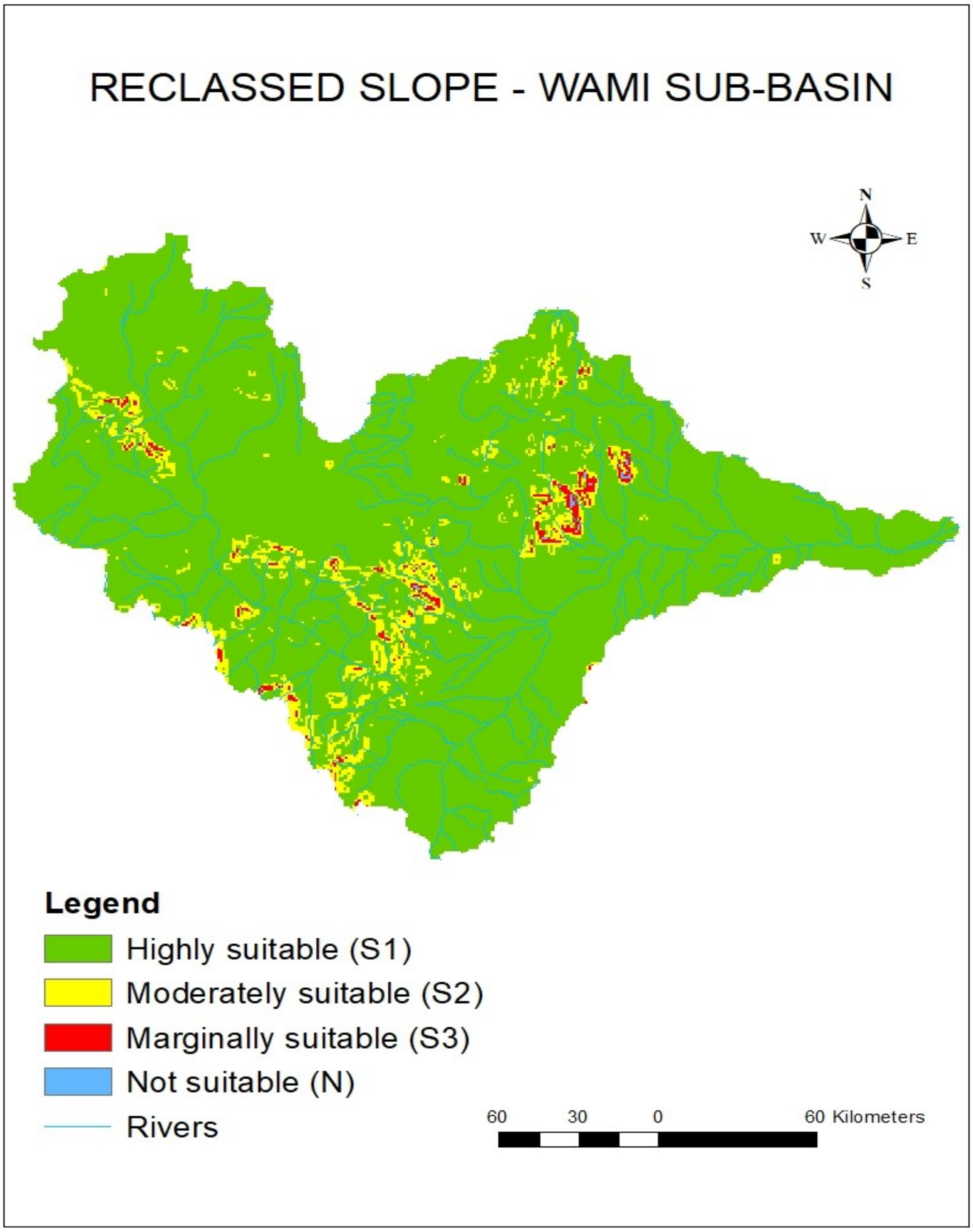

Figure 10: Suitability map for irrigation in the study area based on slope

4.2.3.2 Soil depth classification

The surface irrigation suitability analysis based on soil depth (Table 9), characteristics indicates that 10334.98 km^2 accounting for 24.958% of soil depth is highly suitable (*very deep*), for surface irrigation, 10359.02 km^2 accounting for 25.015% of soil depth was found to be moderately suitable for surface irrigation, 10358.22 km^2 accounting for

25.014 % of soil depth was found to be marginally suitable for surface irrigation and 10357.36 km^2 accounting for 25.012% of soil depth was found unsuitable for the surface irrigation.

Table 9: Soil depth characteristics

Class range (cm)	Area(Km^2)	Area (%)	Weight	Description
60 – 100 *(Very deep)*	10334.98	24.958	4	Highly suitable
30 – 60 *(Deep)*	10359.02	25.015	3	Moderately suitable
15 – 30 (*Moderately deep)*	10358.22	25.014	2	Marginally suitable
0 – 15 *(Shallow)*	10357.36	25.012	1	Not suitable

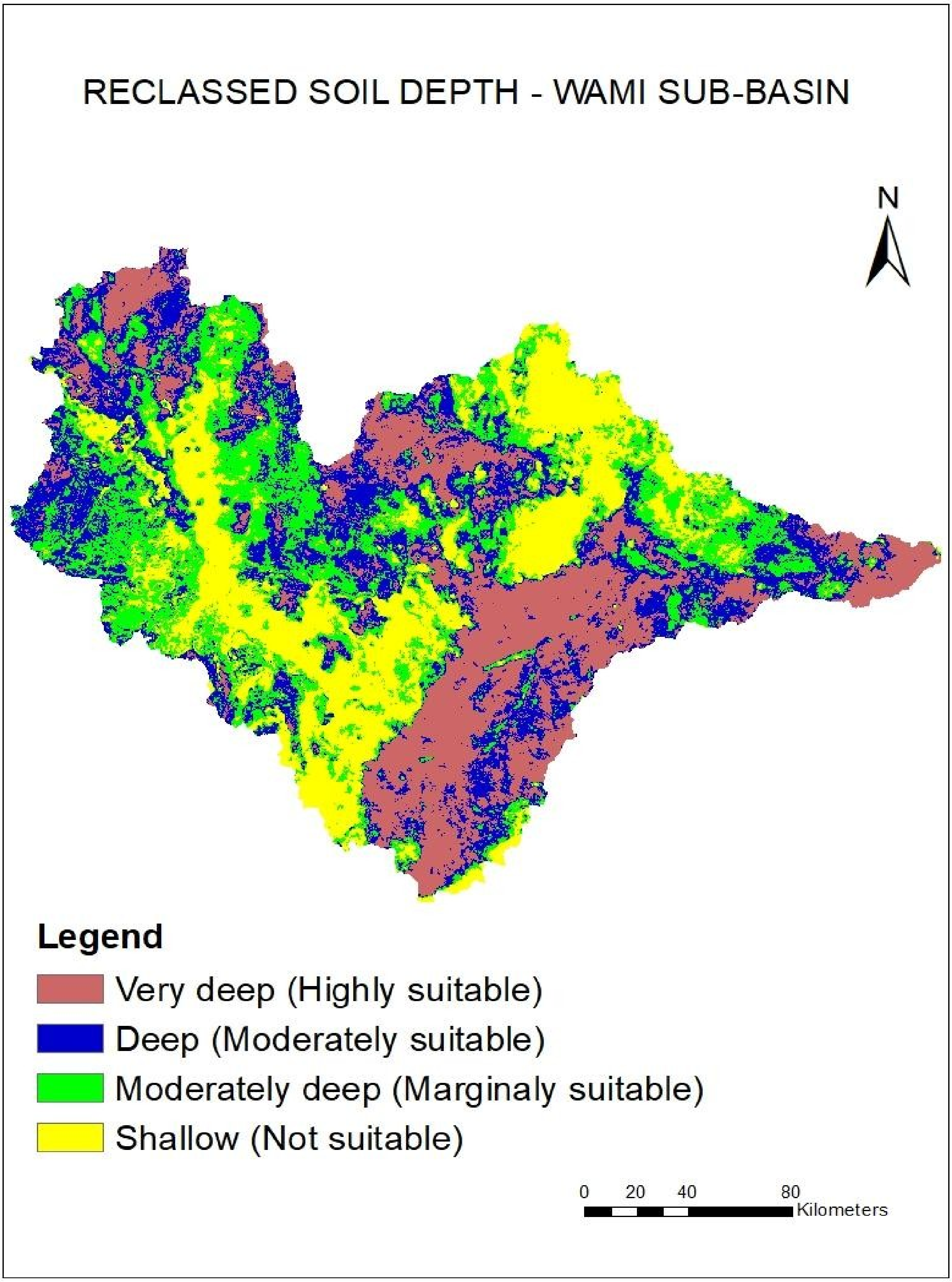

Figure 11: Suitability map for irrigation in the study area based on soil depth

4.2.3.3 Soil drainage classification

About 504.81 km^2 (1.22 %), of soil drainage in the Wami sub-basin is composed of the soils that are well drained soil (Table 10), Likewise, 33761km^2 accounting for 81.55 % of the soil in sub-basin was found to be moderately drained, this type of soil allows slowly removal of water during some periods of the year. Also, 6684.63 km^2 accounting for 16.15 % of the soil in the study area was found to be imperfectly drained, that allows sufficiently slowly removal of water from the soil. In addition, 449.75 km^2 accounting for 1.086 % of the soil in the Wami sub-basin was found to be poorly drained, This type of the soils allows very slowly removal of water leaving the soils wet for long period of time as reported by Bernal *et al.* (2015).

Table 10: Soil drainage characteristics

Class range (m)	Area (Km^2)	Area (%)	Weight	Description
5.5 - 7	504.81	1.22	4	Well drained
4 – 5.5	33761	81.55	3	Moderately drained
2.5 – 4	6684.63	16.15	2	Imperfectly drained
1 – 2.5	449.75	1.086	1	Poorly drained

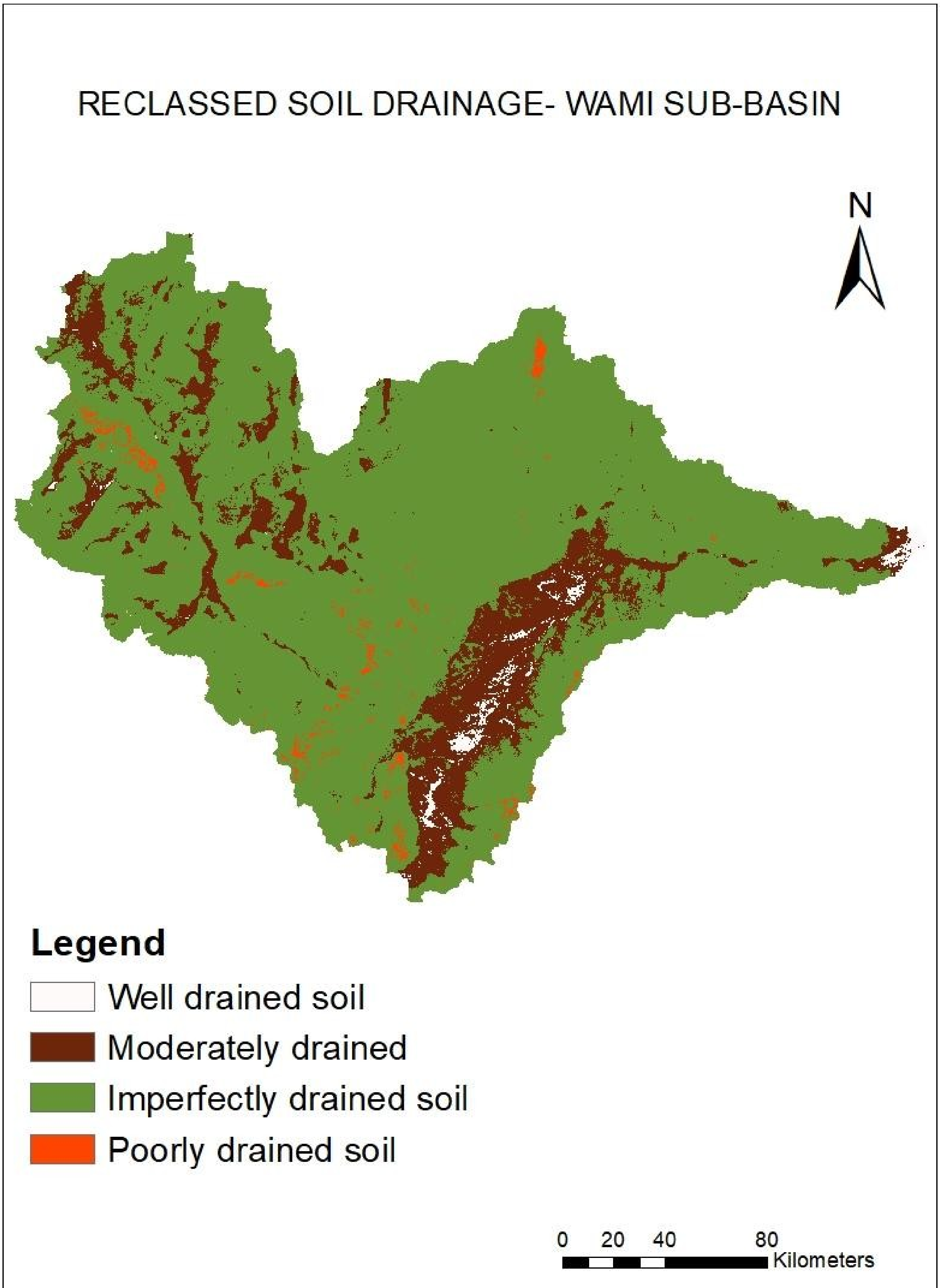

Figure 12: Suitability map for irrigation in the Study area based on soil drainage

4.2.3.4 Soil texture classification

In general, about 2.675 km^2 accounting for 0.006 % of the soils texture in the Wami sub-basin was found to have a well textural values (sandy loam), for surface irrigation, 17 404.32 km^2 accounting for 42.039 % of the soils textures was found to be moderately well, this comprises of the sand clay loam type of textural soil, 1007.07km^2 accounting for 2.433 % of the soil texture was found to be marginally well. On the other hand, this study found that 22985.895 km^2 accounting for 55.52 % of the soil texture in the study area was found to be imperfectly soil as observed in Table 11.

Table 11: Soil texture characteristics

Class names	Area (km^2)	Area (%)	Weight	Description
Sandy loam	2.675	0.006	4	Well
Sand clay loam	17404.323	42.039	3	Moderately well
Clay loam	1007.071	2.433	2	Marginally well
Sand clay	22985.895	55.52	1	Imperfectly

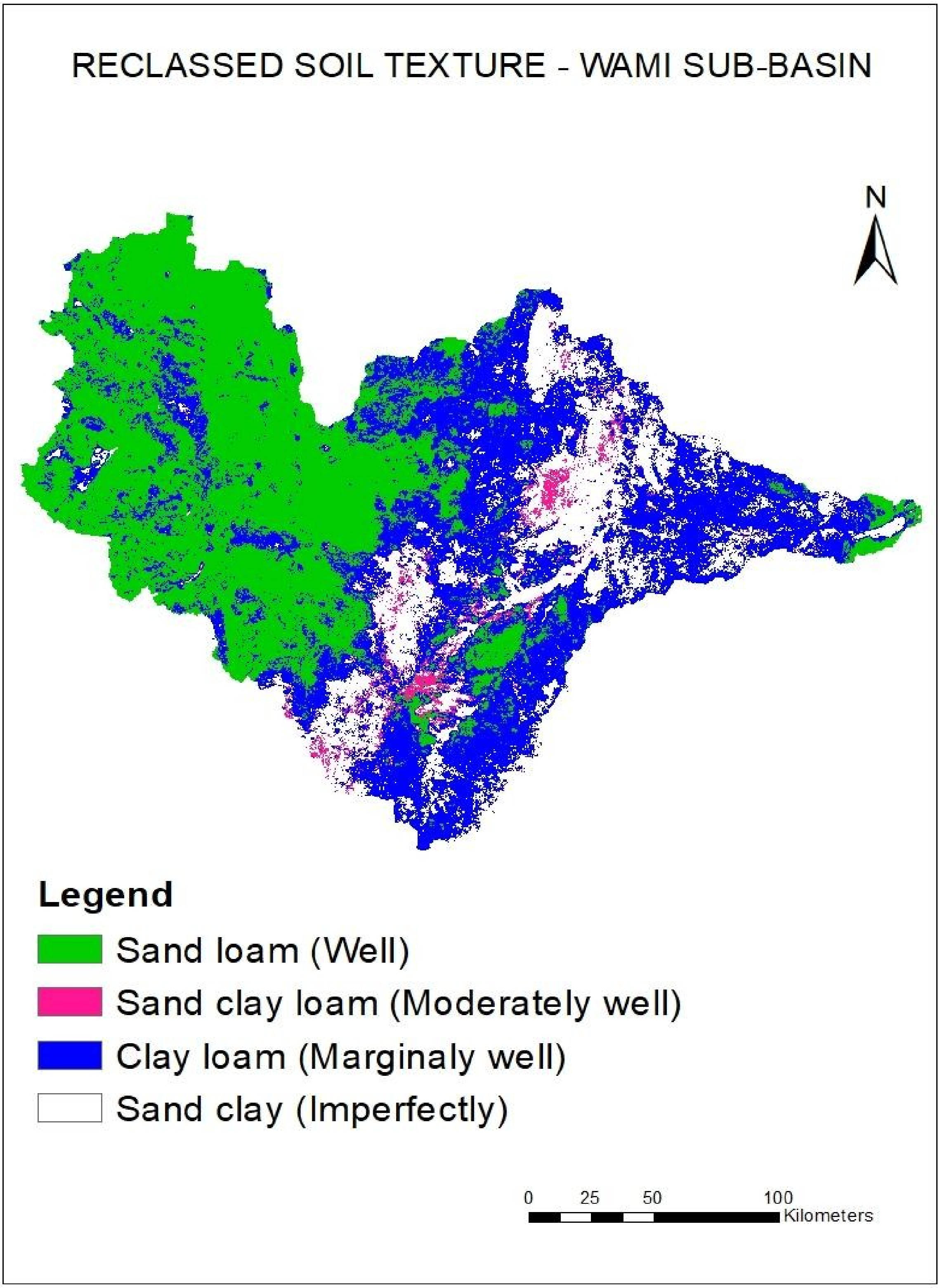

Figure 13: Suitability map for irrigation in the Wami sub-basin based on soil texture

4.2.3.5 Soil pH classification

Approximately 1.759 % of the soils (Table 12), which account for 727.750 km^2 in the Wami sub-basin was found to have highly suitable pH value ranging from 4.4 to 5.6. This is optimum range of soil acidic which favour plants growth. As such, a research by NRCS (1998), found that these soils are highly corrosive to steel and concrete. On the other hand, this study found that, about 37178.44 km^2 (89.870 %), of the soils within the study area is moderately suitable with pH value ranging from 5.6 to 6.8. The soils pH value within this range is reported to be favourable for microbial activities that contributes to the availability of nitrogen, sulphur and phosphorous in the soils as reported by NRCS (1998). However, 3461.875 km^2 nearly 8.368 % of the soils in the Wami sub-basin is found to be marginally suitable with soil pH values ranging from 6.8 to 8.0, and 0.813 km^2 equivalent to 0.002 % of the soil in the study area was found to be unsuitable for the surface irrigation in the Wami sub-basin within Morogoro region.

Table 12: Soil pH Characteristics

Class ranges (%)	Areas (km^2)	Area (%)	Weight	Description	
4.4 – 5.6	727.750	1.759	4	Highly suitable	(*S1*)
5.6 – 6.8	37178.44	89.870	3	Moderately suitable	(*S2*)
6.8 – 8.0	3461.875	8.368	2	Marginally suitable	(*S3*)
< 4.5; > 9.0	0.813	0.002	1	Not suitable	(*N*)

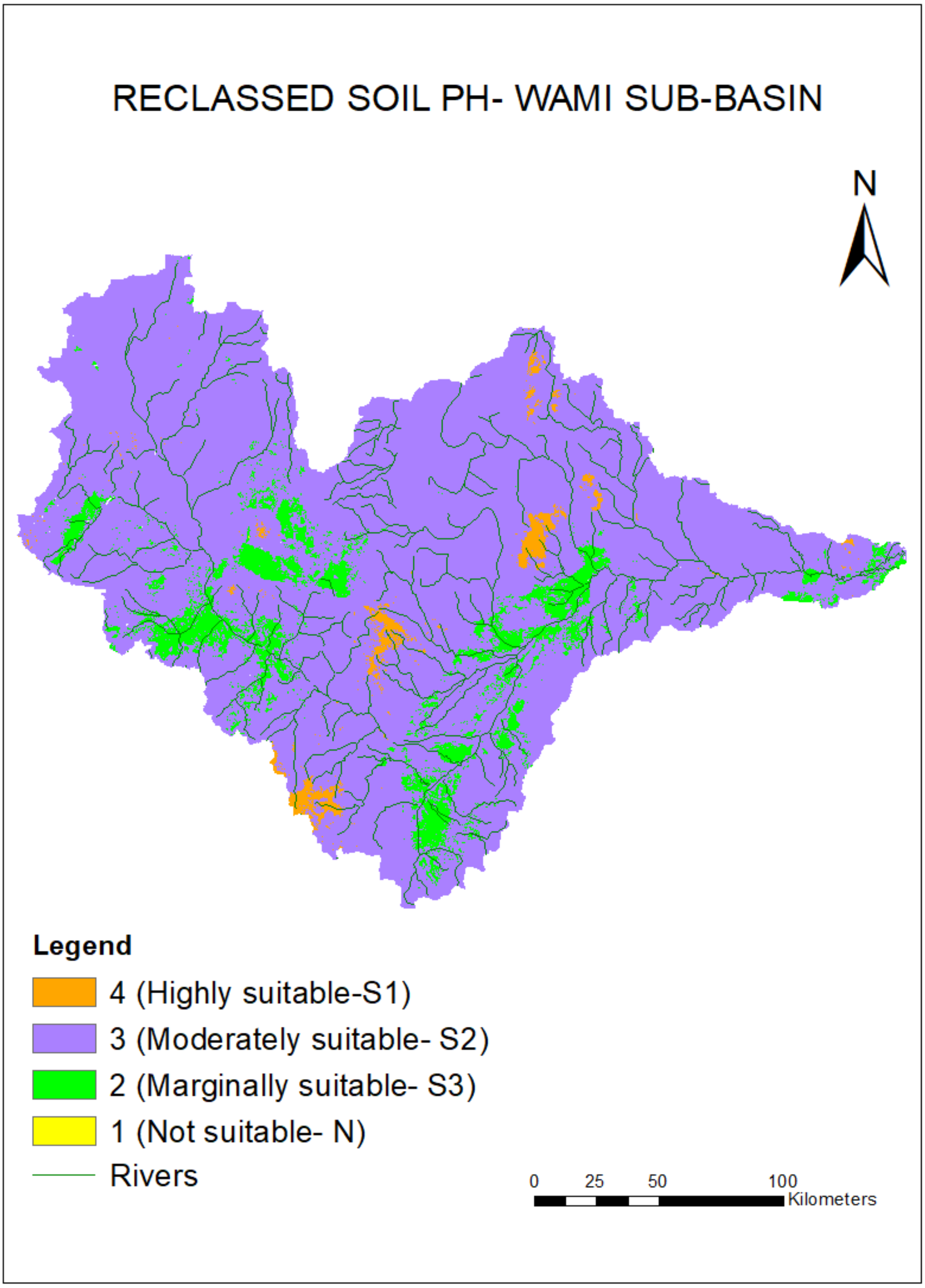

Figure 14: Map showing land suitability of the study area based on soil pH.

4.2.3.6 Euclidean Road Distance Suitability

The calculated Euclidean road distance in the study area (Table 13), indicates that about 3418.37 km^2 accounting for 3.597 % of the road distance was found to be highly suitable distance to the surface irrigation, 8 910.41 km^2 equivalent to 9.376 % of the road distance moderately suitable, 16 434.94 km^2 accounting for 17.294 % of the road distance was found to be marginally suitable for surface irrigation and 66 271.06 km^2 equivalent to 69.734 % of the road distance was found to be unsuitable for surface irrigation.

Table 13: Euclidean Road distance characteristics

Class	Area(km^2)	Area (%)	Weight	Description
S1	3 418.37	3.59699	4	Highly suitable
S2	8 910.41	9.3760	3	Moderately suitable
S3	16 434.94	17.2937	2	Marginally suitable
N	66 271.06	69.734	1	Not suitable

4.2.3.7 Euclidean River Distance Suitability

The Euclidean river distance of the study area (Table 14),indicates that, about 2874.65 km^2 accounting for 3.178 % of the river distance in Wami sub-basin is highly suitable for surface irrigation, this suggest the fact that irrigated areas should located as close as possible to the river, with consideration of a buffer zone for water protection. Also, 7882.86 km^2 equivalent to 8.715 % of Euclidean river distance moderately suitable for surface irrigation, 14546.4 km^2 accounting for 16.081 % of the river distance was found to be marginally suitable for surface irrigation and 65147.9 km^2 equal to 72.025 % of the river distance was found to be unsuitable for the surface irrigation in the Wami sub—basin.

Table 14: Euclidean River distance characteristics

Class	Area(km^2)	Area (%)	Weight	Description
S1	2874.65	3.178	4	Highly suitable
S2	7882.86	8.715	3	Moderately suitable
S3	14546.4	16.081	2	Marginally suitable
N	65147.9	72.025	1	Not suitable

4.2.3.8 Potential land suitable for surface irrigation

The results of this study shows that out of 27 025.75 km^2 of irrigable land assessed in the Wami sub-basin (Table 15), about 7 939.87 km^2 accounting for 29.38% of irrigable land was found to be highly suitable land for surface irrigation, whereas, a total of 18 244.49 km^2 equivalent to 67.51% of land was found to be moderately suitable for surface irrigation. Likewise, 841.39 km^2 of the land in the Wami sub-basin accounting for 3.11% of land was found to be marginally suitable for surface irrigation as observed in Figure 15.

Table 15: Showing potential areas for surface irrigation in Wami sub-basin

Class	Area (km^2)	Area (%)	Suitability
S1	7939.87	29.38	Highly suitable
S2	18 244.49	67.51	Moderately suitable
S3	841.39	3.11	Marginally suitable

Likewise, out of 11 918.77 km^2 of irrigable land in Morogoro (within Wami sub-basin), about 1 170.76 km^2 was found to be highly suitable for surface irrigation. This accounted for 9.82 % of the total area (Table 16). Moreover, about 10 086.09 km^2 accounting for

84.62 % of irrigable land in the sub-basin was found to be moderately suitable for surface irrigation.

In addition to that, nearly 661.92 km^2 accounting 5.55 % of irrigable land in the Wami sub-basin was found to be marginally suitable for surface irrigation as observed in Figure 16.

Table 16: Showing potential land for surface irrigation in Morogoro region

Class	Area (km^2)	Area (%)	Suitability
S1	1170.76	9.82	Highly suitable
S2	10086.09	84.62	Moderately suitable
S3	661.92	5.55	Marginally suitable

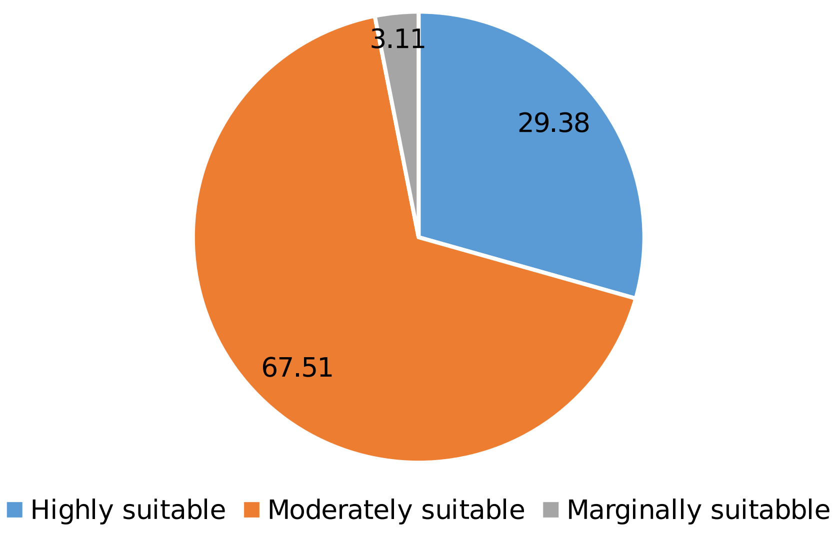

Figure 15: Potential land for irrigation in percentages (%) - Wami

The observed result of 29.38% of irrigable land in Wami agree with (FAO, 1976), that 20-30% of suitable land is highly suitable-S1 for irrigation application. However, the observed difference about (Ranges of land suitability classes), between the results of this study and the other studies such as (Muema, 2016; Mandal *et al.*, 2017; Ostovari *et al.*, 2019; Teshome and Halefom, 2020), might be due to the assumptions made in choosing the types and number of criteria to be analysed, allocation of AHP weights to each criterion and the weighted overlay method of analysis in ArcGIS software.

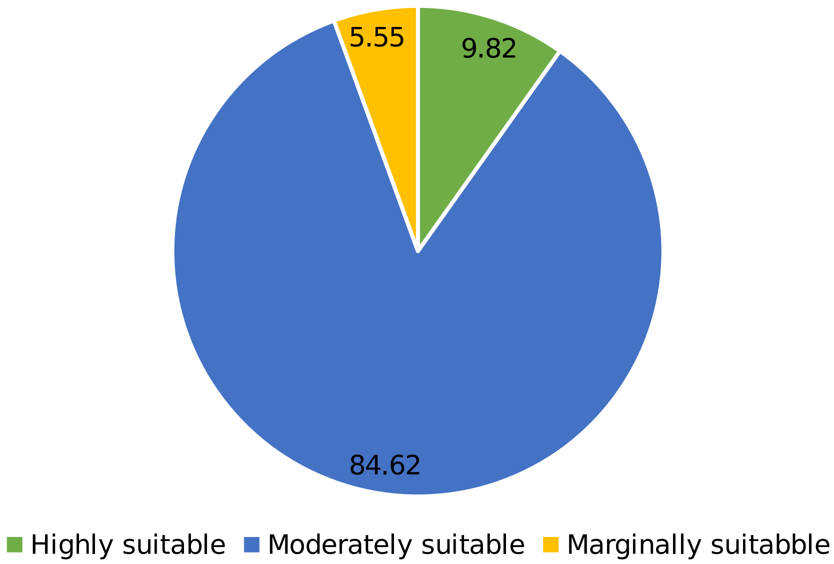

Figure 16: Potential land for irrigation in percentages (%) - Morogoro

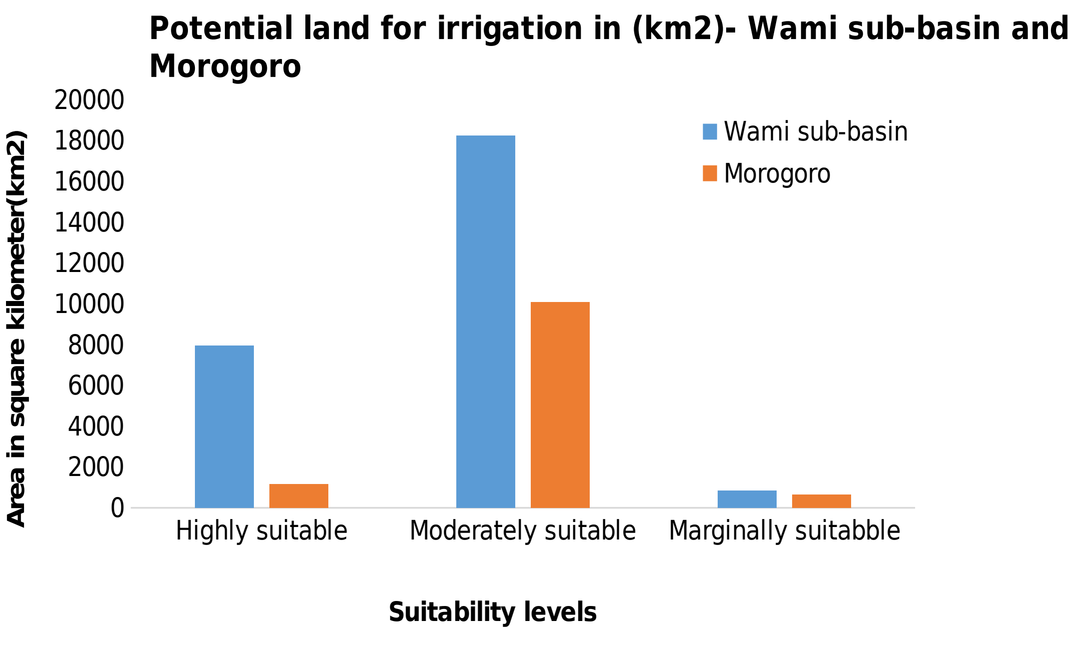

Figure 17: Potential land for irrigation in square kilometres (km^2)

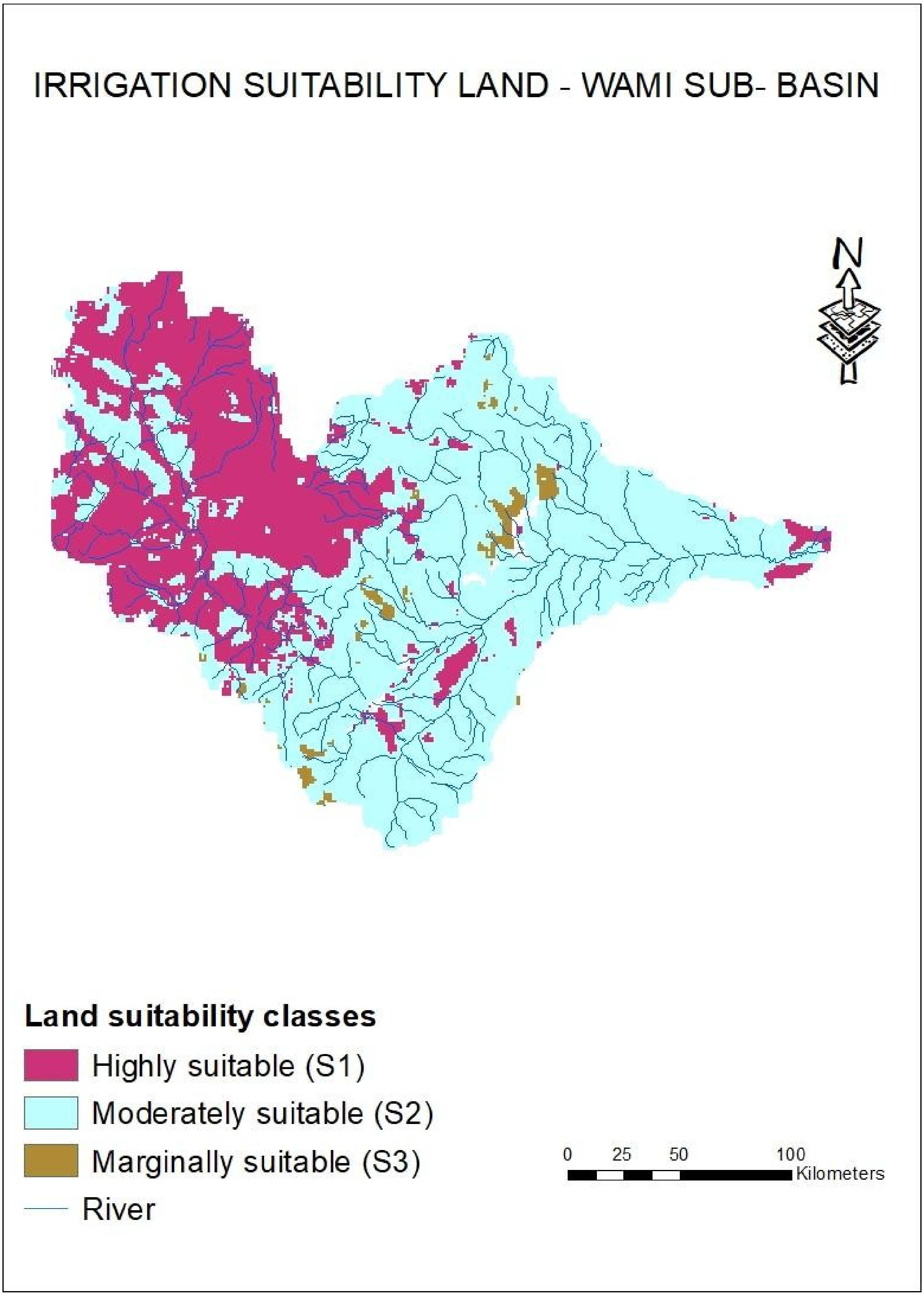

Figure 18: Showing potential land suitable for surface irrigation in Wami

On the other hand, the identified surface water bodies in the study area (Wami sub-basin), in Morogoro was found to occupy a total area of 1526 Square Kilometre as observed in (Figure, 19B).

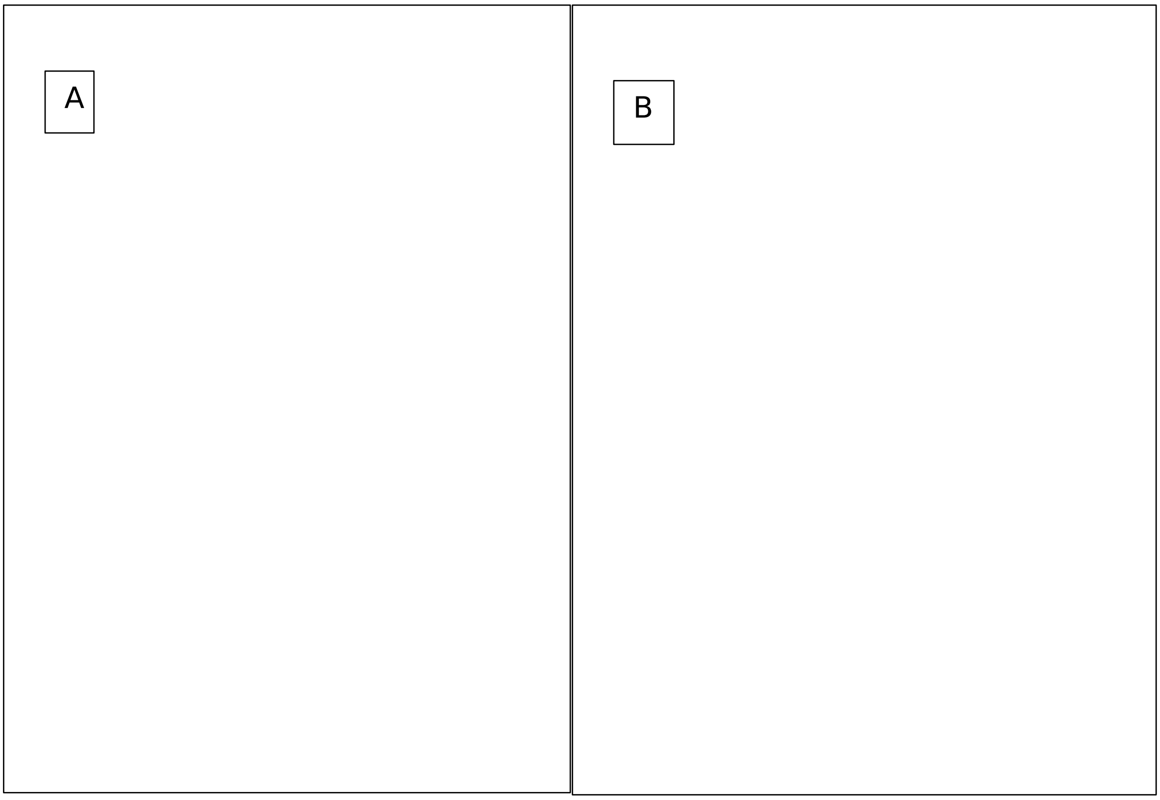

Figure 19: Suitable areas for irrigation overlay with water sources in the study area

4.3 The Extent of Small-scale Irrigation Using Remote Sensing Indices Derived from Landsat- 8 OLI.

4.3.1 Remote sensing data and pre-processing

Results shows that out of 166 Ground truthing data, 31 points were for small-scale irrigated areas and 135 for other land covers. Likewise, out of 96 images of landsat-8 OLI satellite data, only 16 satellite images representing band 4 and 5 were used in NDVI calculations after undergoing atmospheric radiometric correction using QGIS 2.18 software, in order to attain surface reflectance data (Table 17).

Table 17: Landsat-8 OLI bands characteristics

Band No.	Description	Wavelength (λ)
4	Red	0.630-0.680 µm
5	Near infrared	0.845- 0.885 µm

4.3.2 Remote sensing model generation

The Normalized Difference Vegetation Index (NDVI), for surface greenness detection was created using band 4 (0.630-0.680 µm), and band 5 (0.845-0.885 µm) of the landsat-8 OLI obtained from the USGS (Table 18).

Table 18: Multiband indexes used for water feature detection

Index	Equation	Water value	Reference
NDVI	NDVI= (NIR-RED)/(NIR+RED)	Negative	Achary *et al.* (2018)

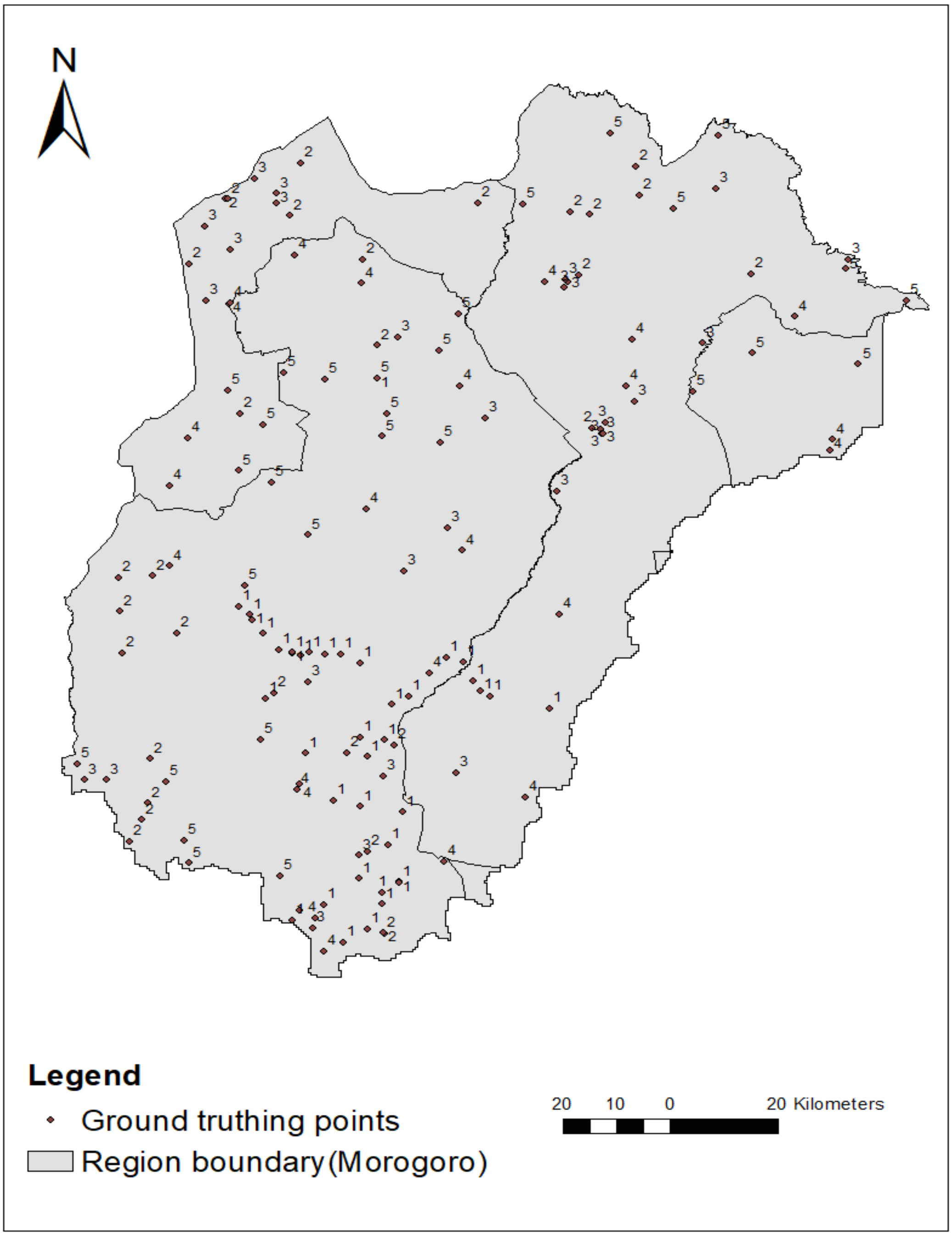

Figure 20: Ground truthing points collected in the study area with code 1, 2, 3, 4 and 5 representing the NDVI classification i.e. water, bare land, sparse vegetation, moderate vegetation and dense vegetation, respectively.

4.3.3 Analyzed NDVI Image

Results based on the control chart and the ground truthing points gathered randomly in the study area during the dry season indicates that, the computed mean value of the classified NDVI was found to be 2.769231. This calculated mean value of classified NDVI, tend to correspond with the sparse vegetation (by approximation), which correspond to number 3(coded value), as observed in (Figure 24 and 25). Likewise, based on the randomly coded NDVI and the ground points, the integer number 1 represents lower control limit(LCL), whereas 5 represents upper control limit(UCL) of the NDVI classification process.

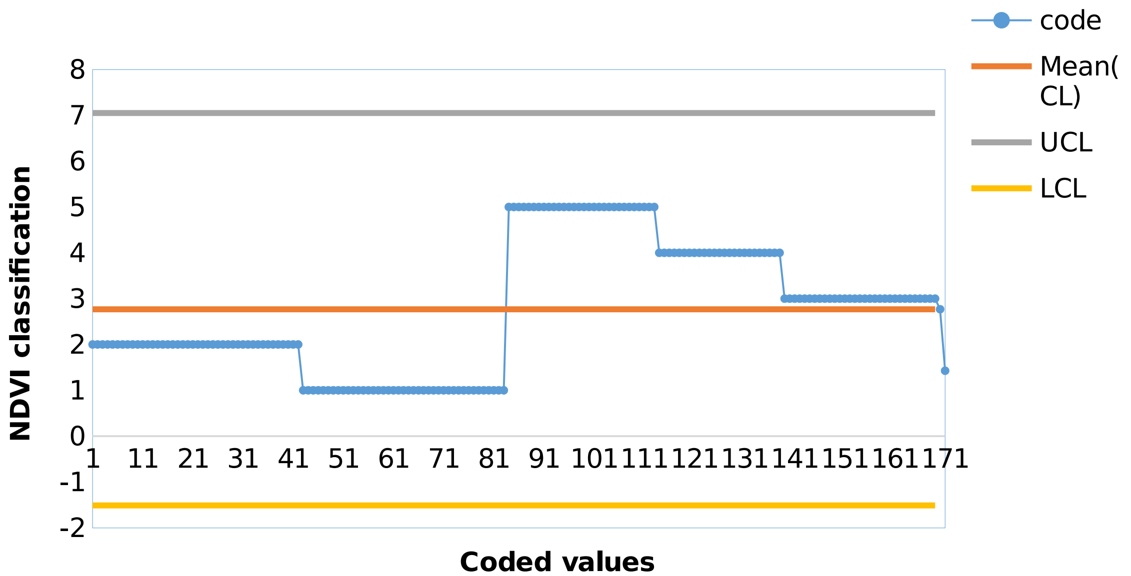

Figure 21: Control chart for NDVI classification process

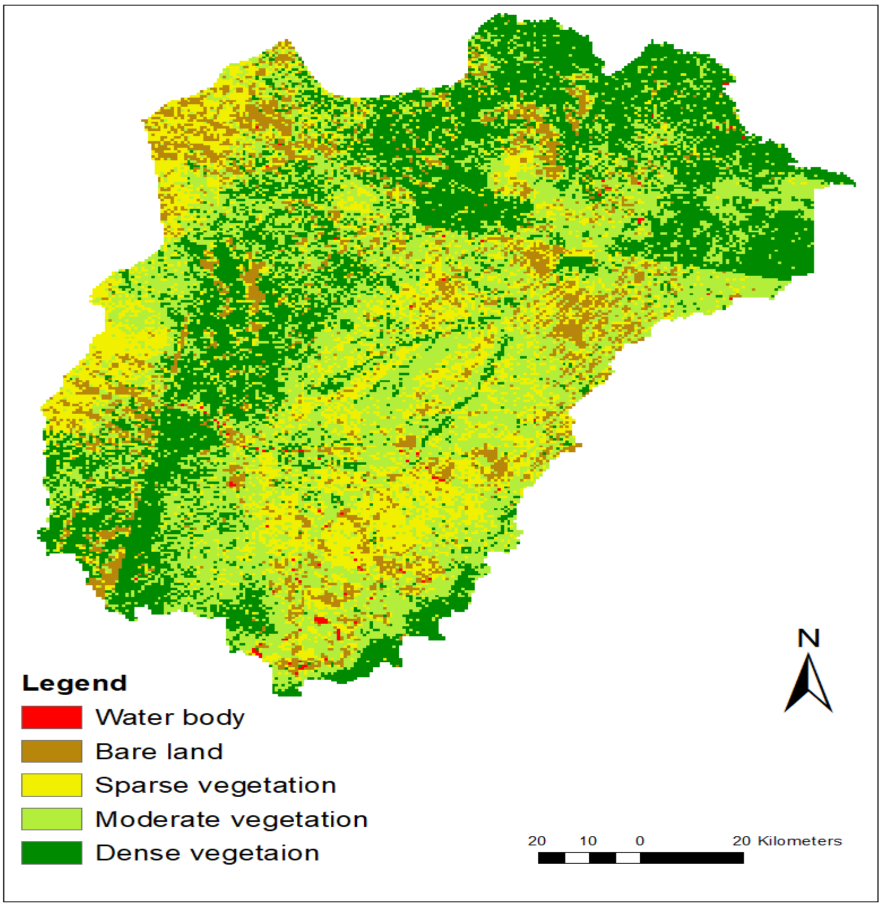

Figure 22: Map showing NDVI classification for Morogoro in Wami sub-basin

4.3.4 Accuracy assessment

Results of the accuracy assessment shows that; there is a high correlation between the observed data on the ground and the classified images. This is in accordance to the strength of agreement for the calculated value of kappa coefficient which found to be 0.8929 accounting for 89.29% (Table 19). The obtained value of kappa coefficient lies between 0.81 and 1, implying that strength of agreement is almost perfect as reported by

Sim and Wright (2005). Moreover, the overall classification of accuracy was found to be 91.57%. This is the total number of correctly classified pixels (diagonal elements), divide by the total number of test pixels as observed in error matrix table.

Table 19: Accuracy assessment for NDVI classification

Class	Producers' accuracy (%)	Users' accuracy (%)
Water	100	100
Bare land	74.07	100
Sparse vegetation	100	77.42
Moderate vegetation	100	80
Dense vegetation	100	93.33
Overall classification accuracy = 91.57 %		
Overall Kappa coefficient = 0.8929		

Kappa coefficient obtained in Table 20 was calculated using the formula given by; Kappa coefficient= (total accuracy – random accuracy)/ (1- random accuracy). The total accuracy denoted by P (a) was 0.915663, and random accuracy denoted by P(r) was found to be 0.212077.

4.3.5 Surface water resources within 1.5 Km buffer zone

Study area map (Morogoro- within the sub-basin), in a vector format presenting water bodies that assumed to be utilized for surface irrigation (Figure 23).

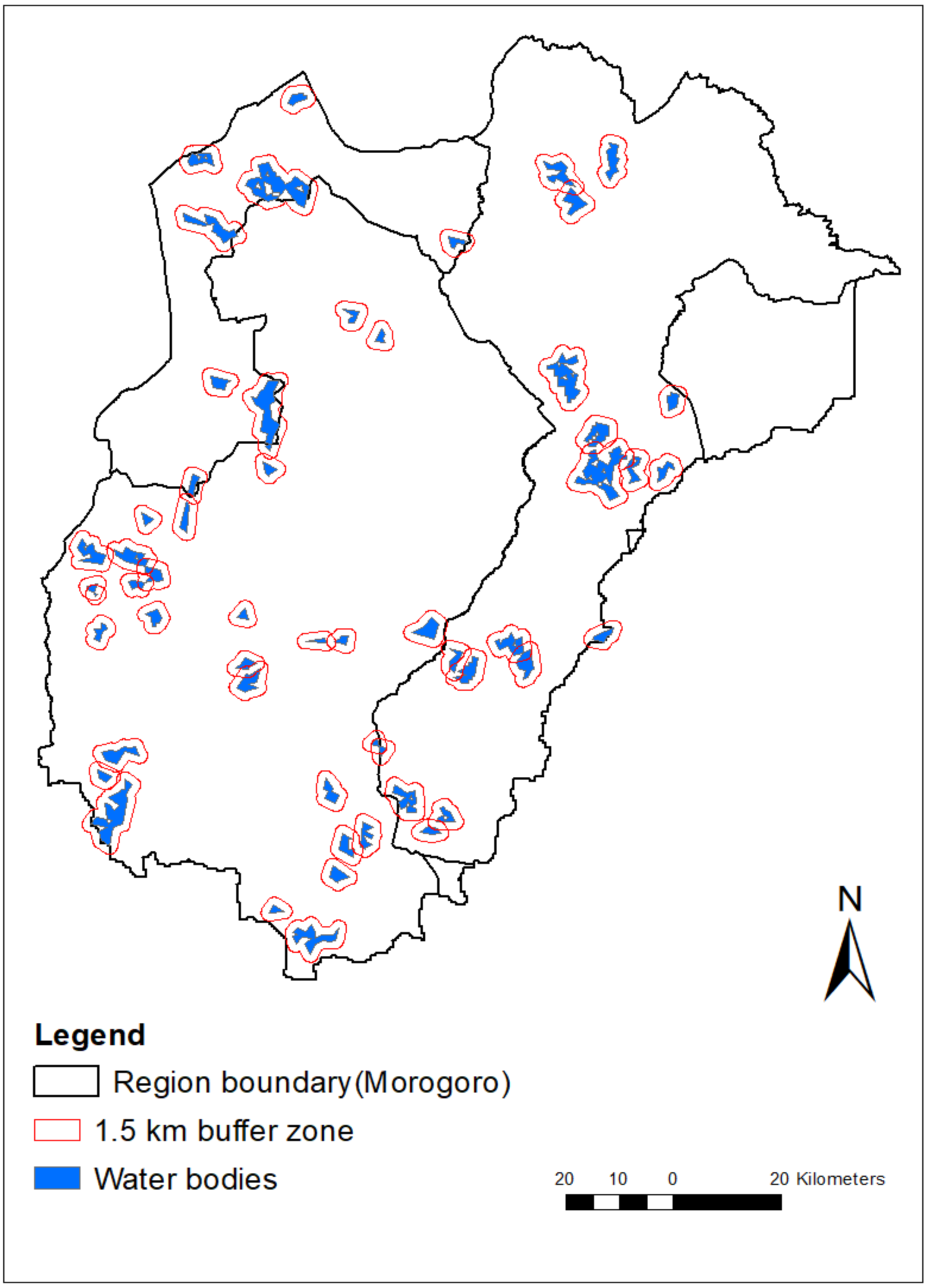

Figure 23: Surface water for irrigation within 1.5 km buffer zone in Morogoro

4.3.6 The Extent of Small-Scale Irrigation

Based on the assumption that, 1.5 km buffer zone (a zone for protection water resources), it was discovered that 1 958.87 km^2, (equivalent to 391.774 ha), is under small scale irrigation in Wami sub-basin (Figure 24). This observation is similar to what was reported by Hatibu *et al.* (2002), in relevance of Kenya irrigation with experience to eastern and southern Africa showing that for Tanzania in particular, small-scale irrigation is indicated by less than 400 ha. Likewise, NDVI is assumed to be sufficiently good indicator of irrigation presence as advocated by Pervez *et al*. (2014), thus NDVI classes in this study indicated that irrigation was assumed to be observed in sparse vegetation areas (within the 1.5 km buffer zone), as it possess strong positive correlation with available moisture for vegetation (Pervez *et al*., 2014).

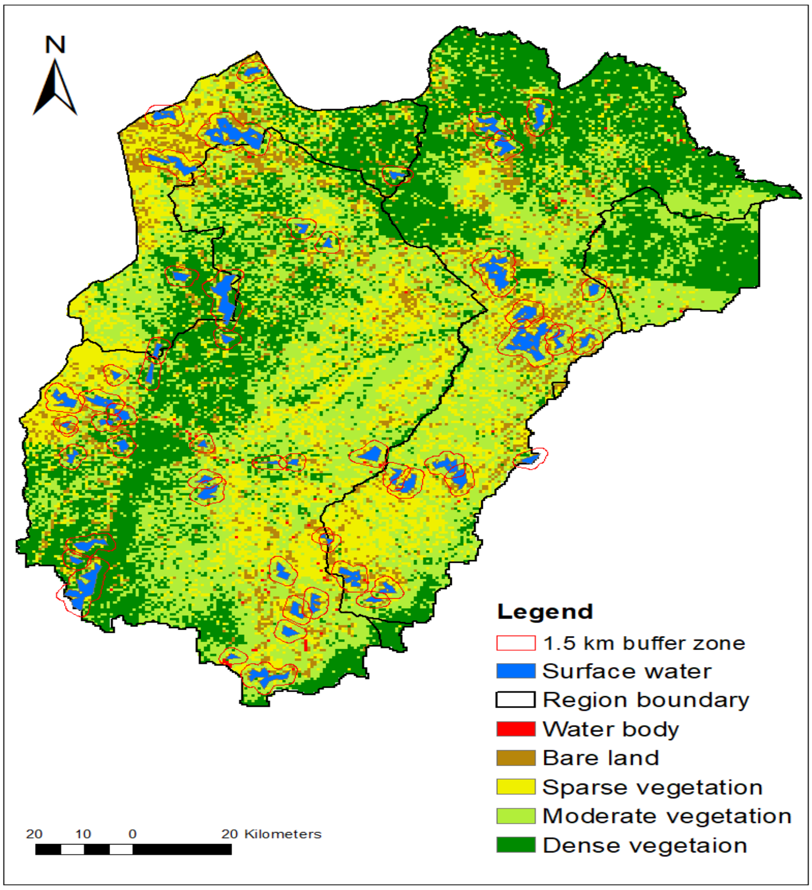

Figure 24: Map showing small scale irrigation areas within 1.5 km buffer zone

The total area of land available to smallholder was found to be 1958.87km^2. This is in accordance to the closest distance to the road and rivers assumption, which led to the creation of 1.5 km buffer zone (assumption). However, small-scale farmers in the Wami sub-basin own farms of sizes ranging from 0.25 acre to 3.5 acre. Farming practices are performed by both men and women, they utilize water from Wami River sub-basin for surface irrigation (Figure 25). They irrigate twice in a month. Cultivation is done throughout the year so as to maintain their cost of living. Small-scale farmers cultivate vegetables like spinach, African eggplants, tembele, pepper, green pepper and some food crops comprising of rice and maize.

Figure 25: Irrigated agriculture using Wami River sub-basin water- Dakawa

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study assessed the potential land and surface water resources available and suitable for irrigated agriculture in the Wami sub-basin within Morogoro in particular. Thus, land suitability for surface irrigation indicates that 841.39 km^2 accounting for 3.11% of land is highly suitable for surface irrigation, 18 244.49 km^2 accounting for 67.51% of land is moderately suitable for surface irrigation, and 7 939.87 km^2 accounting for 29.38 % of land is marginally suitable for surface irrigation. In addition, 92.32 % of slope in the Wami sub-basin, was found to be highly suitable for the surface irrigation as well, 6.51% of slope is moderately suitable, whereas 0.01% is marginally suitable and 1.16% of slope was found to be unsuitable for surface irrigation.

In terms of surface water availability, an average of 92.0 % of the annual precipitation is assumed to be available for surface irrigation in Dakawa and more than hundreds percent (121%), is observed in Mandera watershed. As such, the presence of river networks and wetlands within Morogoro districts is also assumed to contribute to the available surface water resource in the Wami sub-basin. However, in terms of the soil depth, 24.96% accounting for 10 334.98 km^2 was found to be highly suitable (very deep soil), whereas 0.006% of the soil accounting for 2.68km^2 was found to be well (sandy loam) in terms of texture. Indeed, 1.759% of the soil accounting for 727.750 km2 was found to be highly suitable in terms of the soil pH.

Moreover, results for extent of small-scale irrigation in Wami sub-basin (within Morogoro), indicates that, the total area under small-scale irrigation in the study area is

1 958.87 km^2. Thus, the observed area was calculated within 1.5 km buffer zone (a zone for protection water resources). Therefore, the results obtained in this part of study reveal the fact that GIS can as well be used as a tool in exploration of water resources.

5.2 Recommendations

i. Farmers in the Wami sub-basin needs to consider other means of irrigation so as to enhance sustainability and investment in irrigated agriculture. This is due to the unevenly distribution of seasonal rainfall across the sub-basin and other environmental problems such as salinity, and waterlogging.

ii. The potential land suitability assessment should create knowledge based on different irrigation suitability factors such as soil types, slope and land utilization type that will provide a clear understanding of irrigation potential to farmers.

iii. National Irrigation Commission (for Tanzania), and other governing board such as Wami Ruvu Basin Water Office (WRBWO), and Institute of Resources Assessment (IRA),at the University of Dar es Salaam should put an emphasis on the proper utilization of GIS- Based Multi Criteria Decision Analysis (MCDA), in identifying suitable land for irrigation, and water resource exploitation so as to enhance surface irrigation for unskilled and poor farmers not only in the Wami sub-basin but also countrywide.

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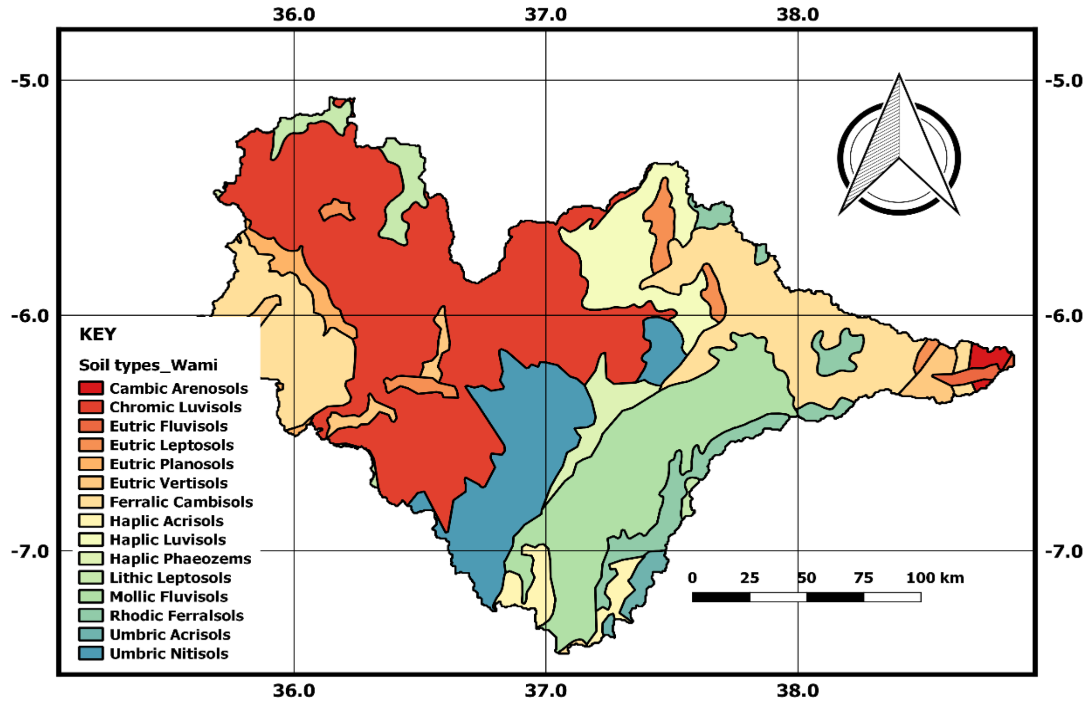
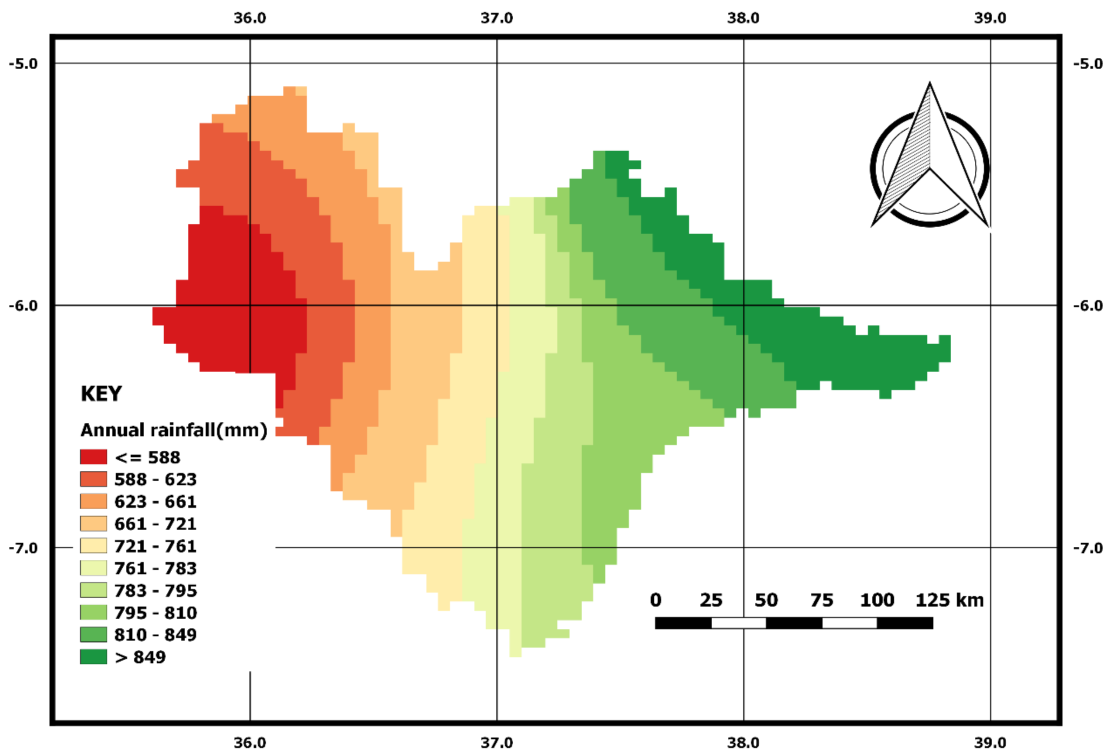
APPENDICES

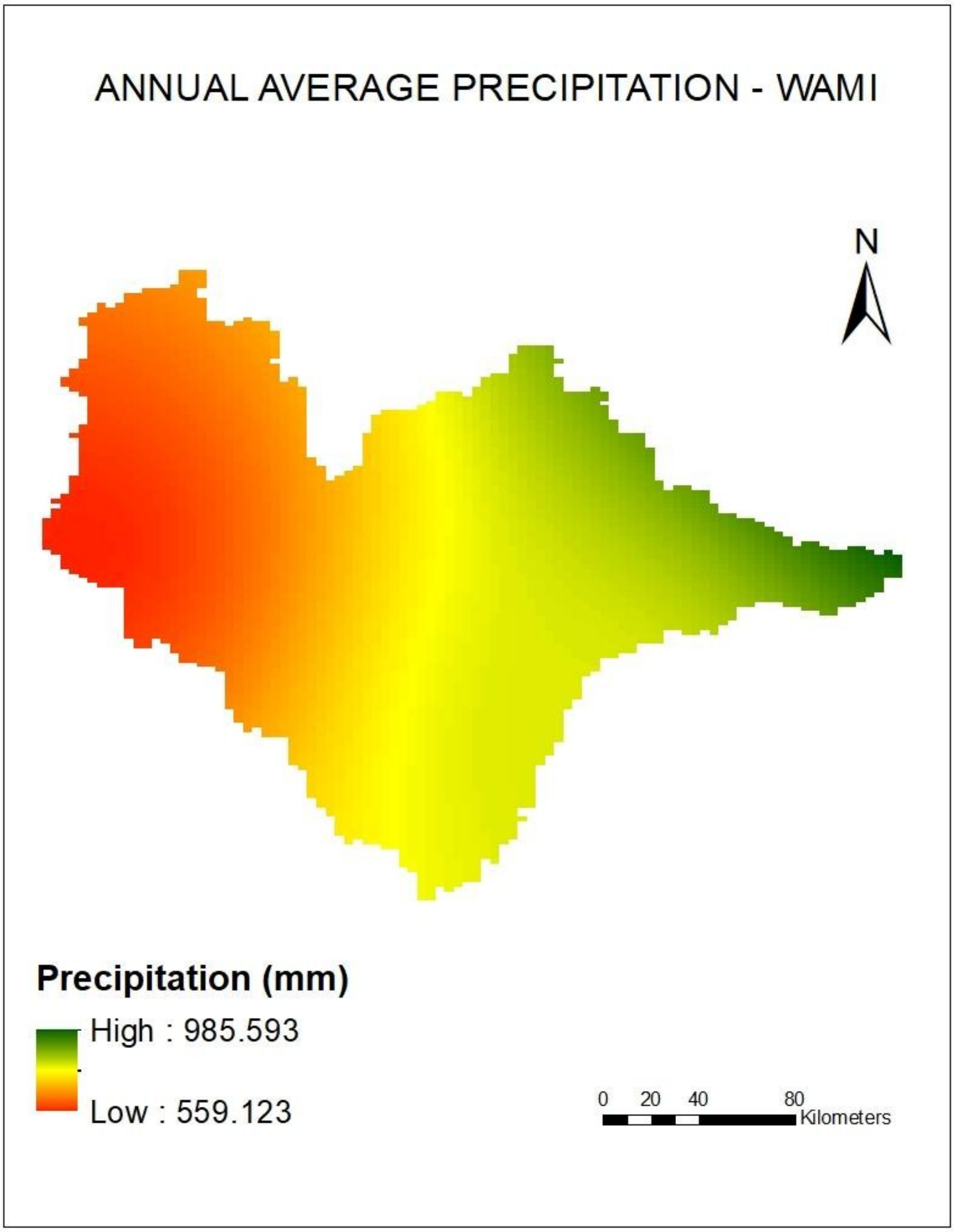
Appendix 1: Map showing soils of the study area in the Wami sub-basin



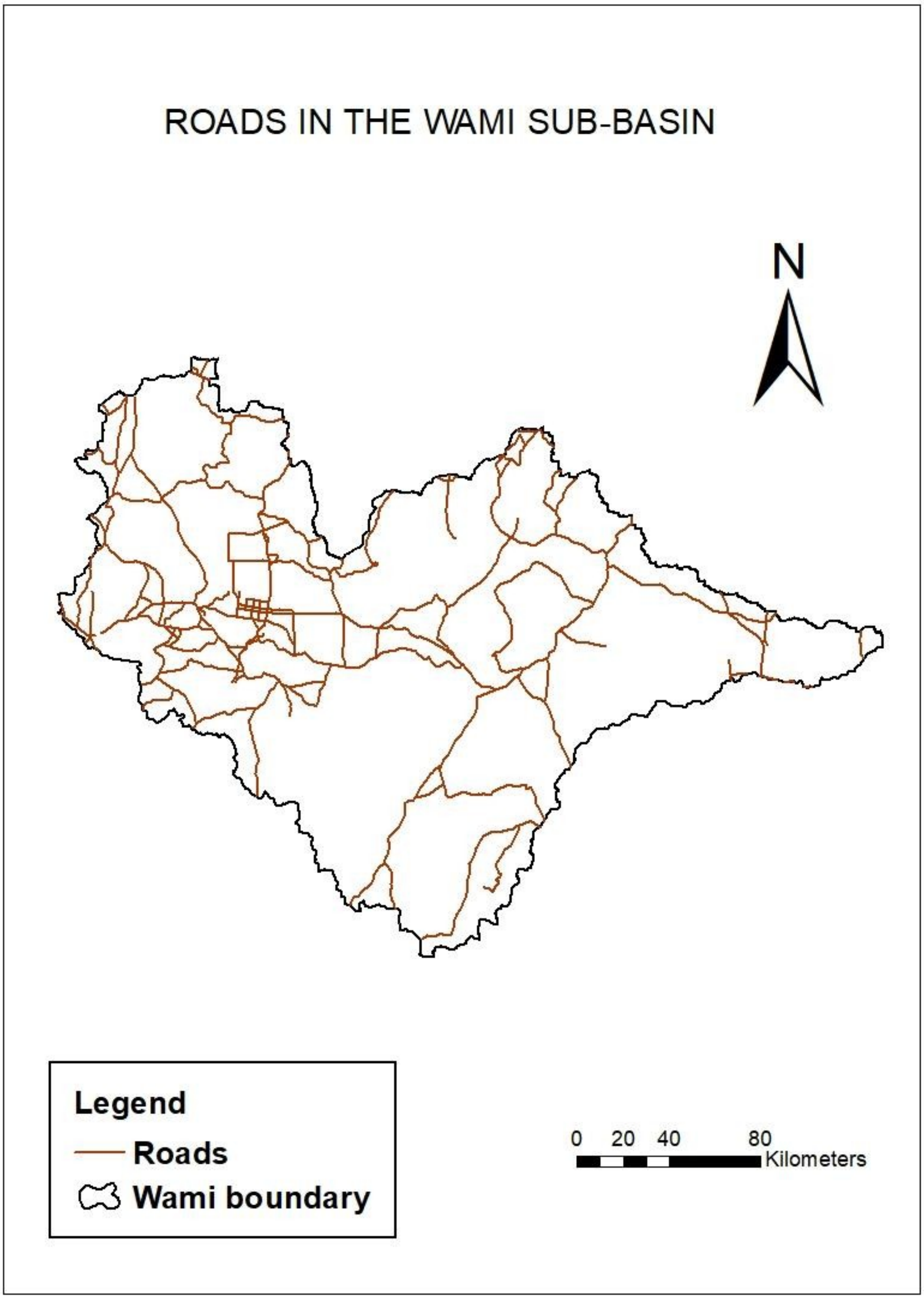
Appendix 2: Map showing rainfall distribution in the Wami sub-basin



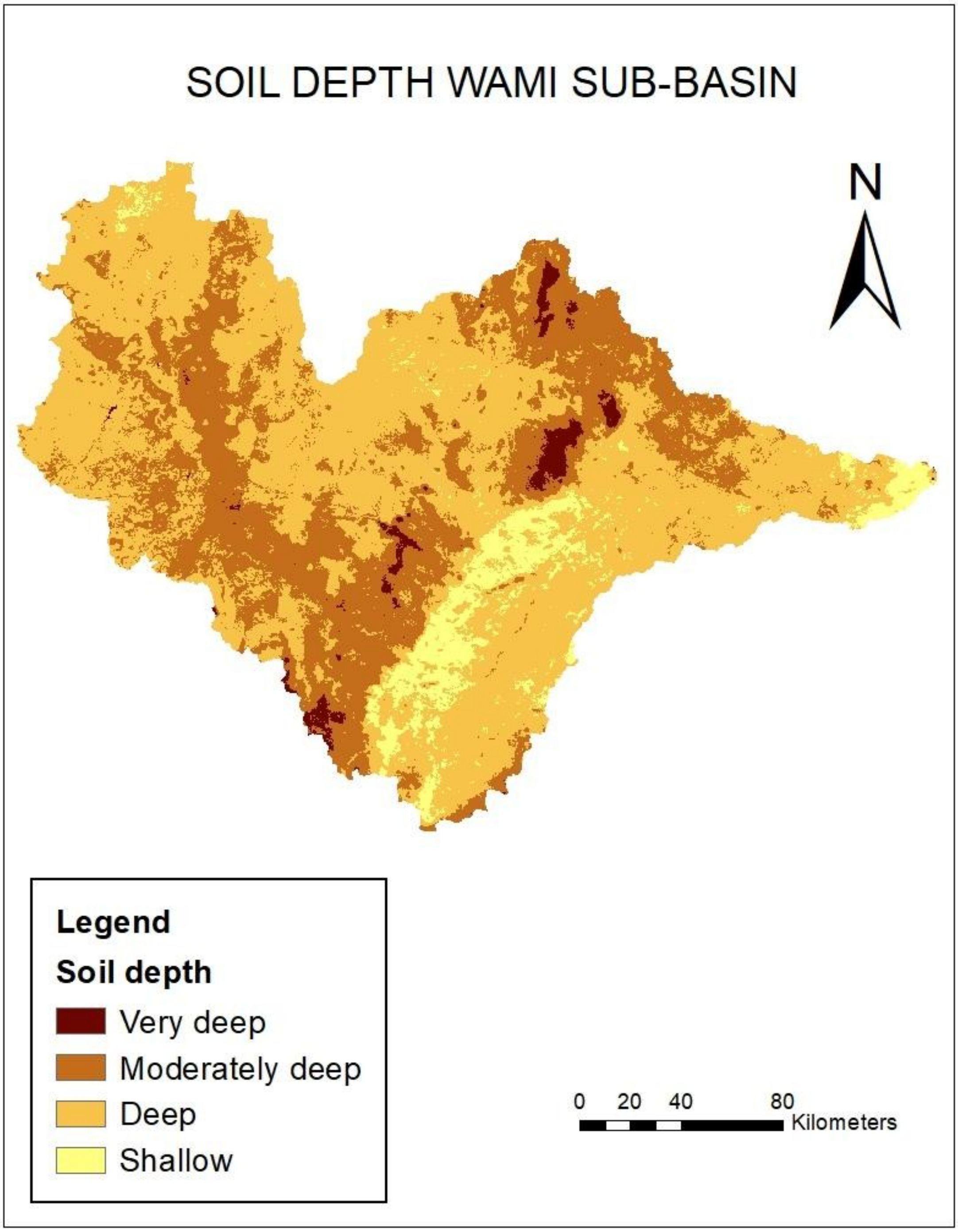
Appendix 3: Map showing annual average rainfall in the Wami sub-basin



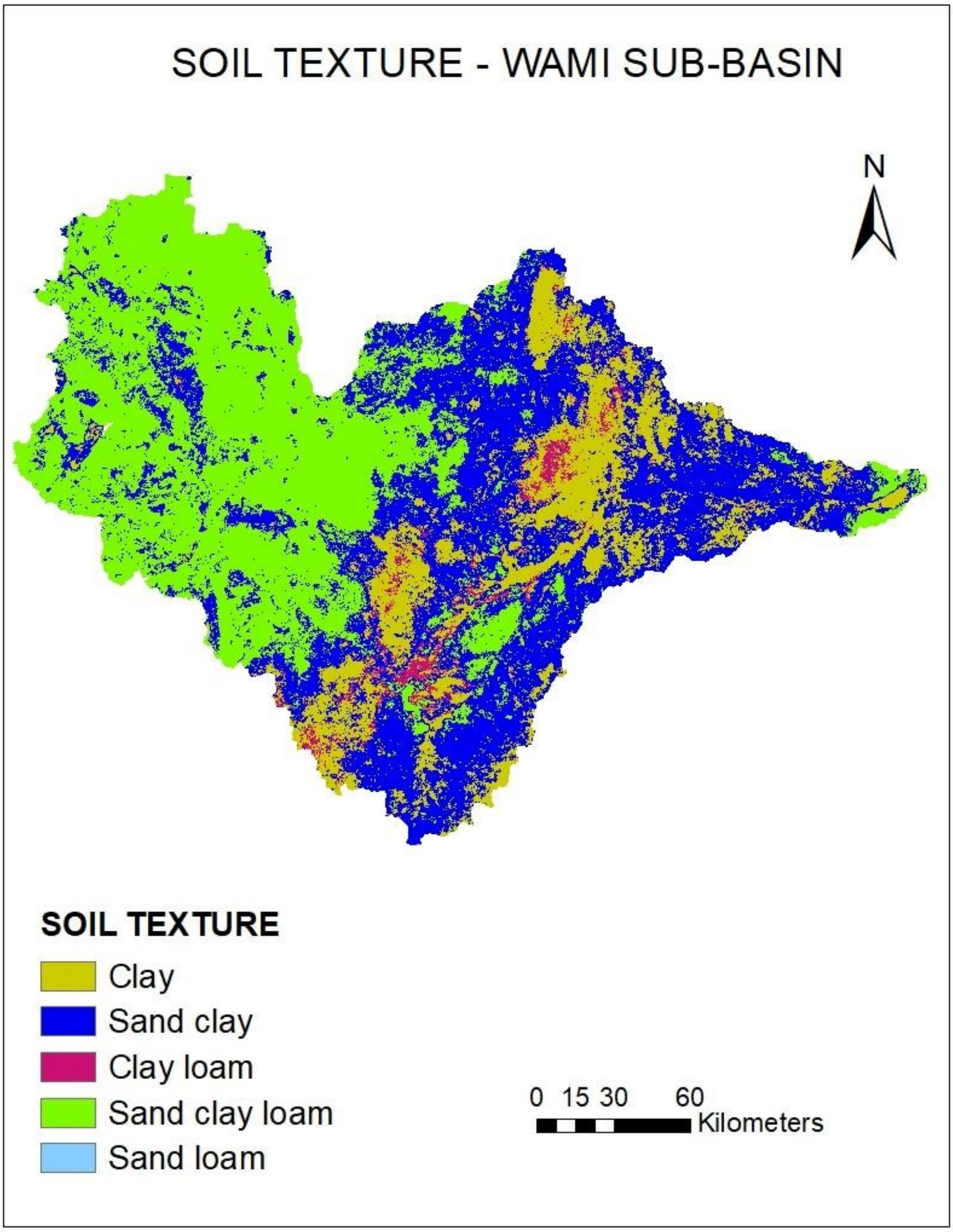
Appendix 4: Map showing road networks of the study area (Wami Sub-basin)



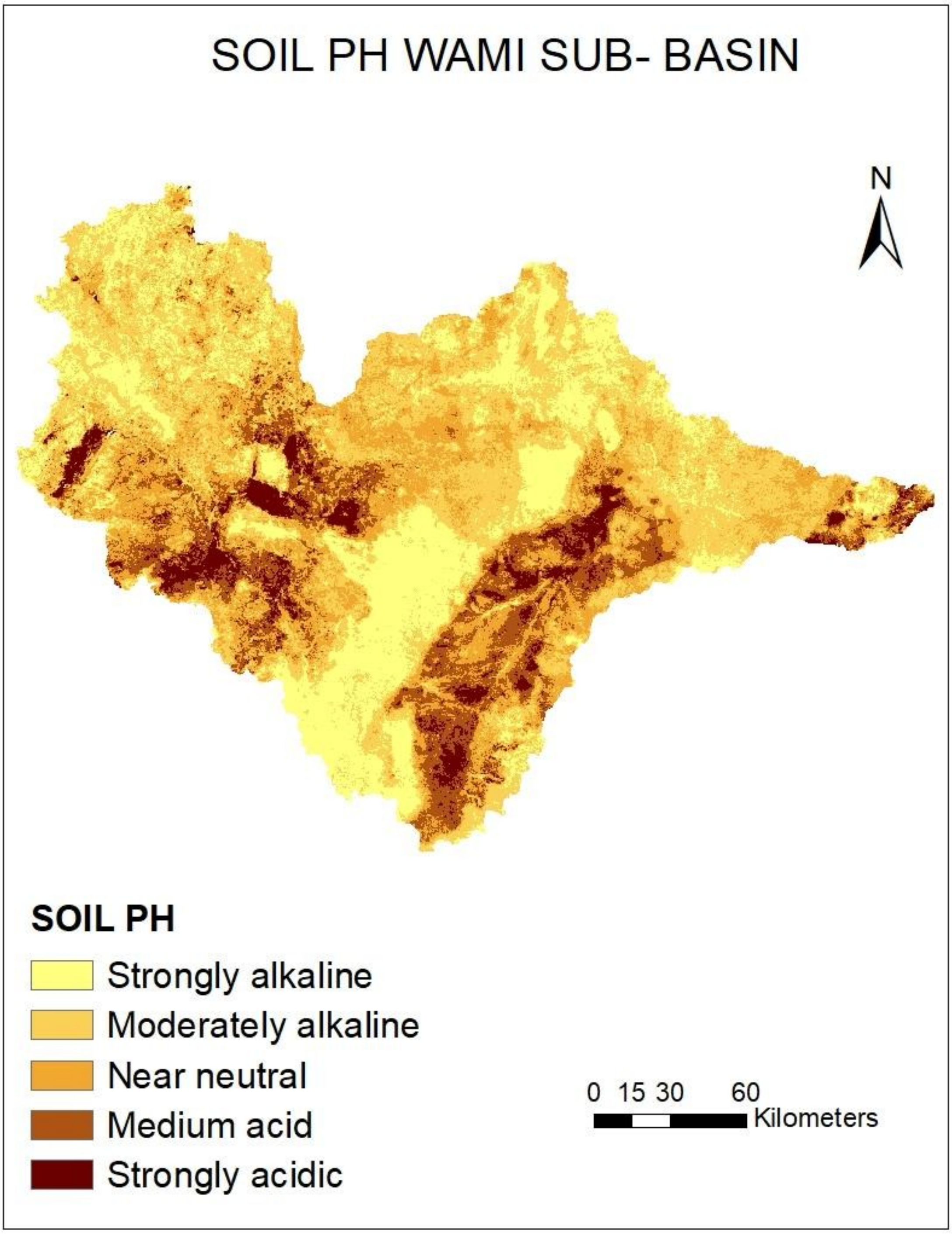
Appendix 5: Map showing soil depth of the study area (Wami Sub-basin)



Appendix 6: Map showing soil texture of the study area (Wami Sub-basin).



Appendix 7: Map showing soil PH of the study area (Wami Sub-basin).



Appendix 8: Showing Table Comprising of Raw Data and Output for Evapotranspiration Calculation

Mintmp	Maxtmp	sunshin	dwpoint	AER	Date	Rs	suh	Rns	C	V	L	Rnl	Rn	RAD	ET0
20.90	32.00	7.00	23.70	3.10	1	7	1.67	5.39	0.02	0.10	39.40	0.09	5.48	0.56	3.66
21.90	33.60	3.10	24.70	4.31	2	3.1	4.19	2.39	0.20	0.09	40.09	0.76	3.15	0.20	4.51
21.40	31.50	9.50	23.60	4.35	3	9.5	0.06	7.31	0.10	0.10	39.40	0.38	6.93	0.19	4.54
20.90	30.40	10.20	23.40	3.39	4	10.2	0.39	7.85	0.13	0.10	38.98	0.51	7.34	0.18	3.56
21.00	33.00	10.60	23.20	5.75	5	10.6	0.64	8.16	0.15	0.10	39.69	0.61	7.56	0.23	5.98
20.80	31.30	10.60	25.70	0.54	6	10.6	0.64	8.16	0.15	0.09	39.19	0.49	7.67	0.29	0.83
20.90	30.30	9.80	25.20	0.62	7	9.79	0.12	7.55	0.11	0.09	38.95	0.38	7.17	0.21	0.83
22.30	33.60	10.40	24.80	5.00	8	10.4	0.51	8.01	0.14	0.09	40.20	0.51	7.50	0.26	5.26
20.80	29.30	6.10	25.20	0.22	9	6.1	2.26	4.70	0.06	0.09	38.67	0.22	4.92	0.21	0.01
20.70	31.70	10.40	24.40	2.81	10	10.4	0.50	8.01	0.14	0.10	39.27	0.51	7.50	0.19	3.00
20.60	31.30	6.50	25.00	1.50	11	6.5	2.01	5.01	0.05	0.09	39.14	0.16	5.17	0.12	1.63
21.40	32.20	9.00	23.50	5.08	12	9	0.40	6.93	0.07	0.10	39.58	0.28	6.65	0.17	5.26
21.30	31.40	9.30	24.70	2.58	13	9.29	0.21	7.16	0.08	0.09	39.35	0.31	6.85	0.19	2.77
21.70	33.00	8.40	23.40	5.99	14	8.39	0.79	6.47	0.04	0.10	39.88	0.17	6.30	0.21	6.20
21.00	31.60	6.20	24.60	2.31	15	6.1	2.20	4.77	0.06	0.09	39.32	0.22	5.00	0.32	2.63
21.10	31.30	4.80	24.10	2.45	16	4.8	3.10	3.70	0.13	0.10	39.27	0.48	4.18	0.40	2.85
22.20	34.20	10.30	23.30	6.61	17	10.3	0.42	7.93	0.13	0.10	40.33	0.54	7.39	0.51	5.13
21.70	30.70	1.20	24.30	1.91	18	1.2	5.40	0.92	0.29	0.10	39.27	1.11	2.03	0.26	2.16
22.30	33.40	10.20	25.00	4.06	19	10.2	0.35	7.85	0.13	0.09	40.14	0.46	7.40	0.47	4.54

21.40	33.20	7.30	23.30	4.84	20	7.30	1.51	5.62	0.01	0.10	39.85	0.04	5.66	0.51	5.35
21.70	30.40	2.10	23.50	3.71	21	2.1	4.83	1.62	0.25	0.10	39.19	1.01	2.62	0.10	3.81
22.40	32.00	4.60	23.80	5.11	22	4.6	3.23	3.54	0.14	0.10	39.80	0.54	4.08	0.15	5.27
21.40	31.90	8.80	24.80	2.94	23	8.80	0.55	6.78	0.06	0.09	39.51	0.22	6.56	0.17	3.11
22.60	33.00	9.90	24.90	4.59	24	9.89	0.14	7.62	0.11	0.09	40.12	0.41	7.22	0.26	4.84
21.60	32.90	8.30	24.70	3.77	25	8.29	0.88	6.39	0.04	0.09	39.82	0.13	6.26	0.31	4.07
22.70	34.00	8.00	24.40	6.13	26	8	1.07	6.16	0.02	0.10	40.41	0.08	6.08	0.25	6.38
21.90	31.50	9.50	24.60	3.13	27	9.5	0.12	7.31	0.09	0.09	39.53	0.34	6.98	0.30	3.42
22.40	33.10	7.30	23.60	6.41	28	7.30	1.52	5.62	0.01	0.10	40.09	0.04	5.67	0.18	6.60
22.50	33.80	6.60	25.20	4.55	29	6.6	1.96	5.08	0.04	0.09	40.30	0.16	5.24	0.25	4.80
22.40	31.40	9.50	25.60	1.92	30	9.5	0.12	7.31	0.09	0.09	39.64	0.31	7.00	0.37	2.29
21.60	32.10	9.30	23.80	4.47	31	9.29	0.25	7.16	0.08	0.10	39.61	0.32	6.84	0.29	4.76
21.40	32.30	7.20	25.00	2.62	32	7.19	1.58	5.54	0.02	0.09	39.61	0.06	5.60	0.33	2.95
22.00	33.70	9.80	26.40	2.15	33	9.79	0.06	7.55	0.10	0.08	40.14	0.34	7.21	0.45	2.61
21.70	33.40	6.40	24.60	4.08	34	6.4	2.09	4.93	0.05	0.09	39.98	0.20	5.13	0.34	4.43
20.70	31.00	5.50	25.30	0.86	35	5.5	2.66	4.23	0.09	0.09	39.08	0.33	4.56	0.13	0.99
20.80	30.90	8.30	24.10	2.71	36	8.29	0.89	6.39	0.03	0.10	39.08	0.13	6.26	0.14	2.85
20.80	33.70	8.90	24.70	3.93	37	8.89	0.51	6.85	0.06	0.09	39.82	0.23	6.62	0.25	4.18
21.10	32.10	2.50	24.70	2.76	38	2.5	4.55	1.93	0.23	0.09	39.48	0.86	2.78	0.14	2.90
22.20	33.10	6.40	23.80	5.92	39	6.4	2.09	4.93	0.05	0.10	40.04	0.21	5.14	0.18	6.09

21.30	32.80	8.60	23.80	5.09	40	8.60	0.70	6.62	0.05	0.10	39.72	0.19	6.43	0.16	5.25
21.60	32.60	9.50	23.80	5.15	41	9.5	0.13	7.31	0.09	0.10	39.74	0.36	6.96	0.19	5.34
20.30	33.60	6.80	23.90	4.61	42	6.80	1.83	5.24	0.03	0.10	39.66	0.14	5.37	0.19	4.80
21.70	32.70	9.90	24.30	4.60	43	9.89	0.12	7.62	0.11	0.10	39.80	0.42	7.21	0.19	4.79
21.20	31.70	10.80	25.10	2.09	44	10.8	0.686	8.32	0.15	0.09	39.40	0.53	7.78	0.26	2.35
20.80	32.00	10.90	24.90	2.26	45	10.9	0.749	8.39	0.16	0.09	39.37	0.56	7.83	0.31	2.57
20.60	31.70	10.80	24.20	2.82	46	10.8	0.686	8.32	0.15	0.10	39.24	0.57	7.75	0.34	3.16
21.60	31.10	10.80	25.20	1.81	47	10.8	0.687	8.32	0.15	0.09	39.35	0.53	7.79	0.23	2.04
21.80	33.90	10.90	24.80	4.85	48	10.9	0.751	8.39	0.16	0.09	40.14	0.58	7.82	0.27	5.11
22.30	32.00	8.50	25.80	2.17	49	8.5	0.756	6.55	0.04	0.09	39.77	0.15	6.40	0.21	2.38
22.20	33.80	9.00	25.80	3.29	50	9	0.440	6.93	0.07	0.09	40.22	0.23	6.70	0.39	3.68
21.30	33.90	7.30	24.60	4.00	51	7.30	1.506	5.62	0.01	0.09	40.01	0.04	5.66	0.43	4.43
21.20	33.40	7.20	24.70	3.30	52	7.20	1.566	5.54	0.02	0.09	39.85	0.06	5.60	0.49	3.79
22.00	31.70	6.90	23.60	3.70	53	6.9	1.752	5.31	0.03	0.10	39.61	0.12	5.43	0.55	4.25
21.90	33.90	6.10	25.70	3.04	54	6.1	2.252	4.70	0.07	0.09	40.17	0.23	4.93	0.38	3.42
21.60	30.90	3.30	23.50	3.37	55	3.3	4.008	2.54	0.20	0.10	39.30	0.79	3.33	0.27	3.64
22.30	33.10	10.60	25.00	4.20	56	10.6	0.581	8.16	0.14	0.09	40.06	0.52	7.64	0.31	4.51
22.60	34.40	8.70	26.50	3.09	57	8.70	0.609	6.70	0.06	0.08	40.49	0.18	6.52	0.38	3.46
21.70	33.20	7.00	23.90	5.09	58	7	1.673	5.39	0.02	0.10	39.93	0.10	5.49	0.29	5.38
21.40	30.70	7.40	23.30	3.68	59	7.4	1.418	5.70	0.01	0.10	39.19	0.02	5.72	0.33	4.01

21.40	31.60	10.80	25.80	0.00	60	10.8	0.723	8.32	0.15	0.09	39.43	0.51	7.80	2.43	2.43
22.40	32.50	10.90	25.30	0.00	61	10.9	0.791	8.39	0.16	0.09	39.93	0.56	7.83	2.47	2.47
21.50	32.60	8.50	25.90	0.00	62	8.5	0.713	6.55	0.05	0.08	39.72	0.16	6.39	2.00	2.00
20.70	32.10	9.00	26.20	0.28	63	9	0.393	6.93	0.07	0.08	39.37	0.23	6.70	0.46	0.74
20.90	33.40	7.30	26.40	1.09	64	7.30	1.458	5.62	0.01	0.08	39.77	0.03	5.65	0.36	1.45
21.60	33.40	7.20	25.80	2.23	65	7.20	1.516	5.54	0.01	0.08	39.96	0.04	5.59	0.48	2.72
20.20	31.50	6.90	25.40	0.55	66	6.9	1.699	5.31	0.03	0.09	39.09	0.09	5.40	0.48	1.03
20.30	32.60	6.10	23.30	4.44	67	6.1	2.198	4.70	0.06	0.10	39.40	0.26	4.96	0.23	4.67
20.70	31.40	3.30	26.00	0.07	68	3.3	3.959	2.54	0.20	0.08	39.19	0.64	3.18	0.25	0.32
21.60	32.40	10.60	25.00	2.89	69	10.6	0.654	8.16	0.15	0.10	39.69	0.54	7.63	0.42	3.31
21.70	32.40	8.70	26.30	1.09	70	8.70	0.538	6.70	0.06	0.08	39.72	0.19	6.51	0.40	1.50
20.90	31.40	7.00	25.30	1.10	71	7	1.605	5.39	0.02	0.09	39.24	0.07	5.46	0.43	1.53
20.40	29.90	7.40	24.90	0.36	72	7.4	1.345	5.70	0.00	0.09	38.72	0.00	5.70	0.24	0.60
21.00	33.00	7.10	23.90	4.40	73	7.1	1.528	5.47	0.01	0.10	39.69	0.06	5.52	0.29	4.69
21.30	31.90	6.30	25.30	2.00	74	6.30	2.028	4.85	0.05	0.09	39.48	0.18	5.03	0.19	2.19
20.70	31.20	0.00	25.90	0.08	75	0	6.019	0.00	0.35	0.08	39.14	1.15	1.15	0.03	0.11
20.50	31.00	8.60	23.90	2.77	76	8.60	0.552	6.62	0.06	0.10	39.03	0.23	6.40	0.19	2.96
20.50	30.80	7.00	25.40	0.38	77	7	1.560	5.39	0.02	0.09	38.98	0.06	5.44	0.19	0.57
21.80	31.00	8.20	25.80	0.89	78	8.20	0.788	6.31	0.04	0.09	39.37	0.14	6.17	0.31	1.20
21.80	31.50	9.30	25.90	1.13	79	9.30	0.077	7.16	0.09	0.08	39.51	0.31	6.85	0.32	1.46

22.50	31.70	6.80	26.00	1.74	80	6.8	1.662	5.24	0.03	0.08	39.74	0.08	5.32	0.21	1.95
21.80	31.20	8.30	25.80	1.07	81	8.30	0.695	6.39	0.05	0.09	39.43	0.16	6.23	0.26	1.33
21.40	31.00	2.20	25.30	1.39	82	2.2	4.589	1.69	0.24	0.09	39.27	0.85	2.54	0.09	1.48
21.40	31.30	10.30	26.40	0.08	83	10.3	0.609	7.93	0.14	0.08	39.34	0.46	7.47	0.25	0.17
21.80	30.60	10.60	25.40	1.22	84	10.6	0.814	8.16	0.16	0.08	39.26	0.55	7.60	0.30	1.52
22.10	33.80	10.60	25.30	4.12	85	10.6	0.828	8.16	0.16	0.09	40.20	0.58	7.59	0.34	4.45
21.70	31.20	8.90	26.00	0.65	86	8.90	0.253	6.85	0.08	0.08	39.40	0.27	6.59	0.38	1.03
22.10	32.20	10.00	24.90	2.98	87	10	0.469	7.70	0.14	0.09	39.77	0.49	7.21	0.56	3.54
21.80	31.20	8.90	24.80	2.34	88	8.90	0.228	6.85	0.08	0.09	39.43	0.30	6.55	0.42	2.75
21.60	32.00	9.60	25.20	2.25	89	9.60	0.238	7.39	0.12	0.09	39.58	0.42	6.98	0.43	2.68
21.50	31.60	10.20	25.10	1.61	90	10.2	0.642	7.85	0.15	0.09	39.45	0.53	7.33	0.83	2.44
21.40	32.20	9.90	24.80	2.23	91	9.90	0.462	7.62	0.14	0.09	39.58	0.49	7.13	0.80	3.03
23.00	32.70	10.10	25.10	3.49	92	10.1	0.607	7.78	0.15	0.09	40.14	0.53	7.25	0.67	4.16
21.40	31.80	9.70	24.80	2.09	93	9.79	0.362	7.47	0.13	0.09	39.48	0.46	7.01	0.72	2.81
20.70	29.50	8.70	23.90	1.34	94	8.70	0.276	6.70	0.08	0.10	38.69	0.30	6.40	0.62	1.96
20.30	29.90	10.40	24.00	1.25	95	10.4	0.852	8.01	0.16	0.10	38.69	0.62	7.38	0.70	1.94
20.60	30.80	10.20	24.50	1.41	96	10.2	0.737	7.85	0.16	0.09	39.01	0.57	7.28	0.68	2.09
20.20	29.50	8.30	23.90	0.92	97	8.30	0.494	6.39	0.06	0.10	38.56	0.24	6.15	0.76	1.68
20.20	29.20	9.80	24.50	0.19	98	9.80	0.508	7.55	0.14	0.09	38.49	0.50	7.04	0.89	1.08
20.20	30.10	9.60	24.40	0.89	99	9.60	0.393	7.39	0.13	0.10	38.72	0.48	6.91	0.61	1.49

21.00	30.90	4.70	24.10	2.27	100	4.70	2.831	3.62	0.11	0.10	39.14	0.44	4.06	0.34	2.60
21.30	30.50	5.20	24.20	1.94	101	5.20	2.489	4.00	0.10	0.10	39.11	0.34	4.34	0.43	2.37
20.50	29.10	1.40	24.90	0.12	102	1.4	5.004	1.08	0.28	0.09	38.54	0.99	2.06	0.19	0.07
20.80	29.70	7.50	25.00	0.24	103	7.5	0.936	5.78	0.03	0.09	38.77	0.10	5.67	0.74	0.98
20.40	30.10	7.00	25.00	0.27	104	7	1.255	5.39	0.01	0.09	38.77	0.02	5.37	0.59	0.86
21.00	29.30	6.90	25.00	0.17	105	6.9	1.308	5.31	0.00	0.09	38.72	0.00	5.31	0.56	0.72
20.70	29.90	1.60	24.90	0.43	106	1.6	4.849	1.23	0.27	0.09	38.80	0.95	2.19	0.25	0.67
19.50	29.00	2.70	25.20	0.96	107	2.7	4.103	2.08	0.21	0.09	38.26	0.72	2.80	0.33	0.63
20.30	29.90	8.50	25.00	0.12	108	8.5	0.187	6.55	0.09	0.09	38.69	0.30	6.24	0.58	0.70
20.30	30.00	9.40	24.80	0.40	109	9.40	0.439	7.24	0.13	0.09	38.72	0.48	6.76	0.64	1.05
21.10	28.60	9.30	24.70	0.16	110	9.30	0.390	7.16	0.13	0.09	38.56	0.47	6.70	0.70	0.86
21.90	30.20	3.80	24.30	2.12	111	3.8	3.327	2.93	0.15	0.10	39.19	0.58	3.50	0.31	2.42
20.50	29.50	2.70	23.50	1.66	112	2.7	4.066	2.08	0.21	0.10	38.64	0.83	2.90	0.28	1.94
20.60	30.90	6.50	24.10	1.97	113	6.5	1.465	5.01	0.01	0.10	39.03	0.04	5.04	0.44	2.41
21.00	29.60	6.10	24.40	0.84	114	6.1	1.724	4.70	0.03	0.10	38.80	0.12	4.81	0.65	1.49
21.10	28.40	3.20	24.40	0.38	115	3.2	3.700	2.46	0.18	0.10	38.51	0.67	3.13	0.33	0.71
21.10	30.80	7.30	24.30	1.82	116	7.30	0.872	5.62	0.03	0.10	39.14	0.13	5.50	0.59	2.40
21.00	29.80	10.10	23.70	1.68	117	10.1	1.075	7.78	0.18	0.10	38.85	0.71	7.07	0.86	2.54
21.50	30.50	10.50	23.80	2.36	118	10.5	1.373	8.09	0.21	0.10	39.16	0.80	7.29	0.80	3.16
21.20	29.30	8.20	23.00	2.33	119	8.20	0.200	6.31	0.09	0.11	38.77	0.35	5.97	0.65	2.98

21.00	30.80	9.30	23.30	2.84	120	9.30	0.582	7.16	0.15	0.10	39.11	0.58	6.58	0.68	3.52
20.80	28.50	6.30	23.20	1.56	121	6.30	1.489	4.85	0.01	0.10	38.46	0.06	4.91	0.48	2.04
21.10	29.70	9.60	23.10	2.50	122	9.60	0.831	7.39	0.16	0.11	38.85	0.67	6.73	0.67	3.17
21.50	30.50	2.90	22.80	3.20	123	2.9	3.843	2.23	0.19	0.11	39.16	0.81	3.05	0.36	3.56
20.80	29.80	8.40	23.60	0.00	124	8.40	0.028	6.47	0.10	0.10	38.80	0.40	6.07	1.86	1.86
18.50	28.10	6.30	23.40	0.07	125	6.30	1.433	4.85	0.01	0.10	37.77	0.04	4.89	0.75	0.68
18.90	28.40	6.80	24.40	0.52	126	6.80	1.066	5.24	0.02	0.10	37.95	0.07	5.17	0.88	0.35
19.80	29.40	8.20	24.50	0.11	127	8.20	0.060	6.31	0.10	0.09	38.44	0.35	5.97	0.55	0.67
18.40	28.50	9.30	23.80	0.38	128	9.30	0.738	7.16	0.16	0.10	37.84	0.59	6.57	0.60	0.22
18.20	28.80	1.40	23.50	0.00	129	1.4	4.863	1.08	0.27	0.10	37.87	1.05	2.13	0.17	0.17
19.60	28.30	4.60	24.00	0.05	130	4.6	2.576	3.54	0.10	0.10	38.10	0.37	3.91	0.42	0.37
19.20	29.10	5.70	23.80	0.38	131	5.70	1.779	4.39	0.04	0.10	38.20	0.14	4.53	0.44	0.82
18.50	29.70	3.40	23.80	0.30	132	3.4	3.415	2.61	0.16	0.10	38.18	0.62	3.24	0.37	0.67
19.30	28.30	4.60	24.10	0.32	133	4.6	2.545	3.54	0.10	0.10	38.02	0.36	3.90	0.40	0.08
18.70	29.20	0.00	24.40	0.48	134	0	5.848	0.00	0.35	0.10	38.10	1.27	1.27	0.13	0.34
19.80	28.60	5.10	24.10	0.11	135	5.1	2.163	3.93	0.07	0.10	38.23	0.25	4.18	0.37	0.49
19.10	28.70	3.60	25.00	1.23	136	3.6	3.238	2.77	0.15	0.09	38.08	0.52	3.29	0.31	0.91
19.60	28.80	6.30	24.60	0.33	137	6.30	1.271	4.85	0.00	0.09	38.23	0.01	4.84	0.72	0.40
18.60	27.60	0.40	24.60	1.18	138	0.4	5.549	0.31	0.31	0.09	37.67	1.16	1.47	0.22	0.96
18.90	27.70	1.60	24.50	1.05	139	1.6	4.672	1.23	0.26	0.09	37.77	0.93	2.16	0.29	0.77

19.00	27.50	0.60	21.90	1.23	140	0.6	5.398	0.46	0.32	0.11	37.74	1.35	1.81	0.21	1.44
19.20	27.80	2.30	22.70	0.89	141	2.3	4.150	1.77	0.22	0.11	37.87	0.90	2.67	0.22	1.11
18.60	29.80	3.90	23.20	1.18	142	3.9	2.971	3.00	0.13	0.10	38.23	0.51	3.52	0.27	1.44
19.40	28.90	3.00	22.80	1.32	143	3	3.625	2.31	0.18	0.11	38.20	0.73	3.04	0.34	1.66
19.00	29.60	0.70	24.00	0.32	144	0.7	5.313	0.54	0.31	0.10	38.28	1.17	1.70	0.17	0.49
19.80	28.70	3.20	23.80	0.47	145	3.2	3.465	2.46	0.17	0.10	38.26	0.64	3.10	0.32	0.80
18.60	29.00	0.60	24.10	0.30	146	0.6	5.382	0.46	0.32	0.10	38.02	1.17	1.63	0.19	0.11
20.50	29.40	1.10	23.50	1.25	147	1.1	5.009	0.85	0.29	0.10	38.62	1.13	1.98	0.28	1.54
17.80	29.00	2.30	24.60	1.22	148	2.3	4.115	1.77	0.22	0.09	37.82	0.77	2.54	0.28	0.95
19.40	28.90	4.70	24.80	0.71	149	4.70	2.325	3.62	0.08	0.09	38.20	0.28	3.90	0.39	0.33
20.20	28.60	5.70	23.70	0.61	150	5.70	1.572	4.39	0.02	0.10	38.33	0.08	4.47	0.61	1.23
20.40	29.20	1.70	21.10	3.01	151	1.7	4.549	1.31	0.25	0.12	38.54	1.15	2.46	0.35	3.36
18.40	28.70	3.70	23.00	0.51	152	3.7	3.051	2.85	0.14	0.11	37.90	0.54	3.39	0.41	0.92
19.10	29.00	7.40	22.40	1.51	153	7.4	0.275	5.70	0.08	0.11	38.15	0.33	5.37	0.66	2.16
20.30	29.60	6.40	23.40	1.42	154	6.4	1.015	4.93	0.02	0.10	38.62	0.09	4.84	0.63	2.06
19.20	28.80	4.30	23.50	0.41	155	4.30	2.584	3.31	0.10	0.10	38.13	0.39	3.70	0.54	0.95
15.20	27.40	0.00	23.70	2.48	156	0	5.812	0.00	0.35	0.10	36.76	1.29	1.29	0.12	2.36
16.90	28.40	2.60	22.90	0.27	157	2.6	3.854	2.00	0.20	0.11	37.44	0.79	2.79	0.24	0.02
16.90	28.70	6.20	23.50	0.73	158	6.20	1.136	4.77	0.01	0.10	37.51	0.05	4.73	0.44	0.29
15.90	27.20	4.70	23.30	1.74	159	4.70	2.262	3.62	0.08	0.10	36.88	0.29	3.91	0.37	1.37

15.20	28.20	3.50	23.90	2.40	160	3.5	3.164	2.70	0.15	0.10	36.96	0.53	3.23	0.26	2.14
15.30	27.80	2.90	22.00	0.40	161	2.9	3.615	2.23	0.18	0.11	36.88	0.75	2.98	0.33	0.07
15.30	28.50	5.20	24.20	2.15	162	5.20	1.871	4.00	0.05	0.10	37.06	0.16	4.17	0.47	1.68
18.50	28.70	6.20	24.40	0.79	163	6.20	1.109	4.77	0.01	0.10	37.92	0.05	4.72	0.55	0.24
16.40	27.20	2.10	23.50	1.83	164	2.1	4.214	1.62	0.23	0.10	37.01	0.85	2.47	0.21	1.62
16.30	28.70	5.20	23.50	1.06	165	5.20	1.860	4.00	0.04	0.10	37.36	0.17	4.17	0.37	0.69
15.90	27.80	10.30	23.60	1.83	166	10.3	2.015	7.93	0.26	0.10	37.03	0.96	6.97	0.62	1.21
16.60	27.30	8.20	23.30	1.46	167	8.20	0.425	6.31	0.13	0.10	37.08	0.51	5.81	0.47	0.98
16.20	27.30	7.90	22.60	0.83	168	7.9	0.200	6.08	0.12	0.11	36.98	0.46	5.62	0.55	0.28
14.30	27.70	10.10	22.50	1.57	169	10.1	1.875	7.78	0.25	0.11	36.61	0.98	6.80	0.53	1.04
14.30	27.10	5.70	22.90	2.19	170	5.	1.469	4.39	0.01	0.11	36.46	0.05	4.44	0.39	1.79
16.50	27.20	4.10	22.30	0.49	171	4.1	2.685	3.16	0.11	0.11	37.03	0.44	3.60	0.26	0.24
18.10	27.20	7.90	21.80	0.87	172	7.9	0.207	6.08	0.12	0.11	37.44	0.49	5.59	0.49	1.36
17.20	28.80	7.70	21.60	1.47	173	7.70	0.055	5.93	0.10	0.12	37.62	0.45	5.48	0.46	1.93
17.30	28.20	6.80	23.20	0.48	174	6.80	0.630	5.24	0.05	0.10	37.49	2.00	5.04	0.44	0.04
17.40	27.90	10.30	23.80	1.23	175	10.3	2.033	7.93	0.26	0.10	37.44	0.96	6.97	0.63	0.59
17.00	27.80	4.40	21.60	0.74	176	4.4	2.457	3.39	0.09	0.12	37.31	0.39	3.78	0.40	1.14
15.70	27.80	5.20	21.80	0.05	177	5.20	1.850	4.00	0.04	0.11	36.98	0.18	4.19	0.39	0.34
17.80	28.80	7.20	23.90	0.63	178	7.20	0.331	5.54	0.07	0.10	37.77	0.28	5.27	0.51	0.12
16.20	28.10	7.80	21.70	0.43	179	7.80	0.123	6.01	0.11	0.11	37.19	0.47	5.54	0.54	0.97

18.00	28.80	9.80	21.80	1.34	180	9.80	1.639	7.55	0.23	0.11	37.82	0.98	6.57	0.86	2.20
17.40	27.70	9.50	21.80	0.74	181	9.5	1.406	7.32	0.21	0.11	37.39	0.89	6.43	0.61	1.35
16.70	28.20	8.20	21.80	0.73	182	8.20	0.415	6.31	0.13	0.11	37.34	0.56	5.75	0.39	1.18
15.70	27.20	9.60	21.90	0.46	183	9.60	1.471	7.39	0.21	0.11	36.83	0.89	6.50	0.53	0.07
18.30	29.20	8.20	22.00	1.87	184	8.20	0.404	6.31	0.13	0.11	38.00	0.56	5.75	0.50	2.37
17.90	29.00	2.00	21.90	1.62	185	2	4.295	1.54	0.23	0.11	37.84	0.10	2.54	0.23	1.85
16.50	28.00	7.40	21.90	0.00	186	7.4	0.214	5.70	0.08	0.11	37.24	0.35	5.35	1.57	1.57
14.00	26.70	8.90	22.40	2.16	187	8.90	0.913	6.85	0.17	0.11	36.29	0.68	6.17	0.44	1.71
16.40	27.90	9.30	22.60	0.51	188	9.30	1.207	7.16	0.19	0.11	37.19	0.78	6.38	0.44	0.06
15.90	28.40	2.70	21.80	0.41	189	2.7	3.778	2.08	0.19	0.11	37.19	0.81	2.89	0.17	0.57
16.10	26.90	4.80	21.20	0.34	190	4.80	2.200	3.70	0.07	0.12	36.86	0.31	4.00	0.22	0.56
15.80	27.80	8.10	20.80	1.04	191	8.10	0.276	6.24	0.12	0.12	37.01	0.54	5.70	0.43	1.46
14.20	27.40	8.30	21.90	1.03	192	8.29	0.417	6.39	0.13	0.11	36.51	0.55	5.85	0.56	0.47
15.70	28.20	7.70	20.50	1.10	193	7.70	0.043	5.93	0.10	0.12	37.08	0.44	5.49	0.73	1.83
16.60	28.80	10.70	20.00	2.42	194	10.7	2.194	8.24	0.27	0.13	37.46	1.27	6.97	0.74	3.16
15.30	27.20	10.40	21.20	0.05	195	10.4	1.956	8.01	0.25	0.12	36.73	1.09	6.92	0.52	0.57
14.70	27.50	7.20	20.80	0.31	196	7.20	0.447	5.54	0.07	0.12	36.66	0.29	5.26	0.37	0.68
15.50	27.50	10.20	22.90	1.49	197	10.2	1.778	7.85	0.24	0.11	36.86	0.93	6.93	0.55	0.95
15.10	26.60	9.50	23.00	2.24	198	9.5	1.243	7.32	0.20	0.11	36.53	0.75	6.56	0.53	1.72
14.60	26.60	6.60	22.70	2.27	199	6.6	0.925	5.08	0.03	0.11	36.41	0.11	4.97	0.35	1.92

15.20	27.50	2.90	22.40	1.09	200	2.9	3.678	2.23	0.18	0.11	36.78	0.74	2.97	0.24	0.85
14.90	27.90	1.40	22.40	1.07	201	1.4	4.794	1.08	0.27	0.11	36.81	1.09	2.17	0.16	0.90
15.50	26.70	1.70	21.90	0.89	202	1.7	4.576	1.31	0.25	0.11	36.66	1.05	2.36	0.15	0.74
20.20	27.70	7.80	21.50	2.45	203	7.80	0.084	6.01	0.09	0.12	38.10	0.41	5.59	0.56	3.01
16.10	28.00	7.70	21.80	0.26	204	7.70	0.171	5.93	0.09	0.11	37.14	0.37	5.56	0.44	0.71
16.50	26.50	4.80	22.00	0.51	205	4.80	2.313	3.70	0.08	0.11	36.86	0.32	4.0	0.34	0.17
15.50	28.00	8.50	22.10	0.35	206	8.5	0.388	6.55	0.13	0.11	36.98	0.54	6.01	0.54	0.19
15.70	26.60	10.00	21.60	0.49	207	10	1.469	7.70	0.21	0.12	36.68	0.90	6.80	0.43	0.07
16.90	28.30	2.10	20.40	2.33	208	2.1	4.311	1.62	0.23	0.12	37.41	1.07	2.69	0.20	2.53
16.70	27.90	2.90	19.40	2.83	209	2.9	3.735	2.23	0.19	0.13	37.26	0.91	3.14	0.26	3.09
15.50	28.40	7.50	21.80	0.16	210	7.5	0.401	5.78	0.08	0.11	37.08	0.29	5.48	0.39	0.55
16.30	28.10	2.80	21.80	0.43	211	2.8	3.821	2.16	0.19	0.11	37.21	0.82	2.98	0.22	0.65
16.20	27.50	7.20	21.90	0.05	212	7.20	0.647	5.54	0.05	0.11	37.03	0.21	5.33	0.38	0.33
16.80	27.90	6.10	22.90	0.61	213	6.1	1.455	4.70	0.01	0.11	37.29	0.05	4.74	0.36	0.24
15.90	27.20	7.50	22.80	1.39	214	7.5	0.460	5.78	0.07	0.11	36.88	0.26	5.52	0.39	1.01
15.90	28.30	9.20	21.80	0.34	215	9.20	0.745	7.08	0.16	0.11	37.16	0.66	6.42	0.39	0.73
16.30	28.60	10.10	21.80	0.59	216	10.1	1.372	7.78	0.21	0.11	37.34	0.87	6.91	0.76	1.35
15.90	27.60	10.70	21.20	0.00	217	10.7	1.780	8.24	0.24	0.12	36.98	1.03	7.21	2.10	2.10
15.80	28.20	10.80	21.10	0.92	218	10.8	1.831	8.32	0.24	0.12	37.11	1.06	7.26	0.59	1.51
15.70	28.40	10.60	21.60	0.51	219	10.6	1.667	8.16	0.23	0.12	37.14	0.97	7.19	0.44	0.95

16.30	28.10	6.50	21.20	1.17	220	6.5	1.261	5.01	0.00	0.12	37.21	0.02	4.99	0.26	1.43
15.60	27.00	8.00	21.90	0.68	221	8	0.214	6.16	0.08	0.11	36.76	0.35	5.81	0.33	0.35
14.10	28.60	8.10	21.40	0.05	222	8.10	0.160	6.24	0.09	0.17	36.78	0.38	5.86	0.40	0.34
15.40	28.50	8.50	22.60	0.77	223	8.5	0.105	6.55	0.11	0.11	37.08	0.43	6.11	0.34	0.43
17.20	28.80	3.20	22.40	0.71	224	3.2	3.634	2.46	0.18	0.11	37.62	0.73	3.20	0.20	0.91
17.50	28.90	3.00	22.10	1.28	225	3	3.783	2.31	0.19	0.11	37.72	0.80	3.11	0.20	1.49
16.10	27.40	3.20	22.60	1.00	226	3.2	3.651	2.46	0.18	0.11	36.98	0.72	3.18	0.18	0.81
16.00	27.50	4.80	22.50	0.91	227	4.80	2.544	3.70	0.09	0.11	36.98	0.38	4.08	0.20	0.72
16.00	28.50	10.10	22.20	0.06	228	10.1	1.129	7.78	0.19	0.11	37.24	0.77	7.01	0.39	0.45
15.40	28.00	10.40	22.20	0.57	229	10.4	1.317	8.01	0.20	0.11	36.96	0.82	7.19	0.44	0.13
16.60	28.70	9.90	22.80	0.18	230	9.90	0.951	7.62	0.17	0.11	37.44	0.69	6.93	0.45	0.28
15.80	28.10	9.80	23.60	2.09	231	9.80	0.862	7.55	0.17	0.10	37.08	0.62	6.93	0.32	1.77
16.60	28.70	8.10	22.90	0.31	232	8.10	0.328	6.24	0.08	0.11	37.44	0.30	5.94	0.29	0.03
15.70	27.90	7.70	21.40	0.46	233	7.70	0.619	5.93	0.05	0.12	37.01	0.23	5.70	0.30	0.77
16.50	28.90	5.40	22.40	0.36	234	5.4	2.210	4.16	0.07	0.11	37.46	0.28	4.44	0.24	0.61
17.10	29.30	7.20	22.20	1.23	235	7.20	0.992	5.54	0.03	0.11	37.72	0.10	5.44	0.29	1.52
17.50	26.90	10.00	22.50	0.37	236	10	0.903	7.70	0.17	0.11	37.21	0.68	7.02	0.35	0.02
17.00	28.40	10.40	22.40	0.36	237	10.4	1.156	8.01	0.19	0.11	37.46	0.77	7.24	0.40	0.76
15.80	28.30	6.50	21.60	0.49	238	6.5	1.510	5.01	0.02	0.12	37.14	0.06	5.07	0.35	0.84
17.00	28.20	9.70	21.90	0.83	239	9.70	0.643	7.47	0.15	0.11	37.41	0.63	6.84	0.38	1.21

16.60	28.00	10.40	21.80	0.57	240	10.4	1.098	8.01	0.18	0.11	37.26	0.78	7.23	0.46	1.03
16.50	29.20	8.10	21.20	1.38	241	8.10	0.471	6.24	0.06	0.12	37.54	0.28	5.95	0.74	2.12
17.10	28.90	7.30	21.60	1.60	242	7.30	1.025	5.62	0.02	0.12	37.62	0.10	5.52	0.36	1.96
17.50	28.40	9.10	21.30	2.02	243	9.10	0.169	7.01	0.11	0.12	37.59	0.50	6.51	0.30	2.32
17.70	28.80	10.20	21.80	1.72	244	10.2	0.889	7.85	0.17	0.11	37.74	0.72	7.14	0.43	2.14
16.60	28.70	8.00	22.70	0.06	245	8	0.598	6.16	0.06	0.11	37.44	0.22	5.94	0.36	0.30
17.30	28.70	3.10	22.10	1.10	246	3.1	3.879	2.39	0.19	0.11	37.62	0.81	3.20	0.17	1.27
16.90	29.00	5.30	22.10	1.07	247	5.30	2.423	4.08	0.08	0.11	37.59	0.35	4.43	0.20	1.27
16.40	28.40	7.60	21.40	1.22	248	7.6	0.906	5.85	0.03	0.12	37.31	0.14	5.72	0.25	1.47
16.60	29.70	0.00	21.20	2.32	249	0	5.955	0.00	0.35	0.12	37.69	1.55	1.55	0.08	2.40
17.40	29.70	8.10	22.80	0.94	250	8.10	0.602	6.24	0.06	0.11	37.90	0.22	6.02	0.33	1.27
16.90	30.30	9.70	22.60	1.26	251	9.70	0.441	7.47	0.13	0.11	37.92	0.55	6.92	0.36	1.62
16.00	30.30	6.90	21.70	1.72	252	6.9	1.419	5.31	0.01	0.11	37.69	0.03	5.34	0.31	2.03
16.60	30.30	6.20	22.10	1.70	253	6.20	1.891	4.77	0.04	0.11	37.84	0.18	4.95	0.23	1.94
16.50	29.80	7.30	22.10	1.34	254	7.30	1.179	5.62	0.01	0.11	37.69	0.05	5.57	0.24	1.58
17.70	30.50	7.40	22.10	2.45	255	7.4	1.125	5.70	0.02	0.11	38.18	0.07	5.63	0.34	2.78
17.60	29.70	3.60	22.10	1.79	256	3.6	3.622	2.77	0.17	0.11	37.95	0.73	3.50	0.25	2.03
16.90	29.90	8.20	22.10	1.55	257	8.20	0.626	6.31	0.05	0.11	37.82	0.22	6.09	0.37	1.92
16.60	29.00	8.40	22.60	0.25	258	8.40	0.507	6.47	0.06	0.11	37.51	0.25	6.22	0.32	0.57
16.50	30.00	9.80	22.20	1.40	259	9.80	0.392	7.55	0.13	0.11	37.74	0.54	7.00	0.23	1.63

16.60	29.90	8.40	22.10	1.45	260	8.40	0.531	6.47	0.06	0.11	37.74	0.25	6.22	0.29	1.74
16.20	29.40	9.30	22.00	0.99	261	9.30	0.042	7.16	0.10	0.11	37.51	0.44	6.73	0.32	1.31
16.60	30.10	5.90	23.70	0.47	262	5.9	2.173	4.54	0.06	0.10	37.79	0.24	4.78	0.21	0.26
17.00	29.90	0.30	23.70	0.33	263	0.3	5.805	0.23	0.34	0.10	37.84	1.27	1.50	0.08	0.25
17.20	29.30	0.40	22.10	1.44	264	0.4	5.744	0.31	0.33	0.11	37.74	1.39	1.70	0.08	1.52
17.50	30.80	0.60	22.90	1.60	265	0.6	5.618	0.46	0.32	0.11	38.20	1.30	1.76	0.10	1.69
18.30	30.50	0.20	22.80	2.07	266	0.2	5.880	0.15	0.34	0.11	38.33	1.39	1.55	0.08	2.15
17.60	29.40	6.90	22.60	1.17	267	6.9	1.569	5.31	0.02	0.11	37.87	0.07	5.39	0.23	1.40
17.20	29.80	7.50	22.60	1.14	268	7.5	1.192	5.78	0.01	0.11	37.87	0.04	5.73	0.29	1.43
17.10	30.10	6.10	22.60	1.24	269	6.1	2.100	4.70	0.06	0.11	37.92	0.23	4.93	0.27	1.52
18.20	29.90	8.50	22.60	1.93	270	8.5	0.567	6.55	0.06	0.11	38.15	0.24	6.31	0.26	2.19
18.00	30.30	5.80	23.20	1.27	271	5.80	2.306	4.47	0.07	0.10	38.20	0.29	4.75	0.21	1.48
17.70	30.80	9.40	22.60	2.10	272	9.40	0.007	7.24	0.10	0.11	38.26	0.41	6.83	0.37	2.47
22.40	30.50	10.30	23.30	4.31	273	10.3	0.560	7.93	0.14	0.10	39.40	0.58	7.36	0.40	4.71
17.90	29.40	8.70	23.20	0.59	274	8.70	0.472	6.70	0.07	0.10	37.95	0.26	6.44	0.31	0.89
17.80	30.80	9.50	22.50	2.24	275	9.5	0.032	7.32	0.10	0.11	38.28	0.43	6.89	0.41	2.65
17.10	30.40	10.10	22.10	2.04	276	10.1	0.407	7.78	0.13	0.11	38.00	0.55	7.22	0.40	2.43
17.20	30.70	10.10	23.60	0.45	277	10.1	0.399	7.78	0.13	0.10	38.10	0.50	7.28	0.40	0.85
17.60	30.50	7.30	23.10	1.27	278	7.30	1.393	5.62	0.00	0.11	38.15	0.02	5.64	0.25	1.52
17.40	30.10	9.20	22.80	0.00	279	9.19	0.188	7.08	0.09	0.11	38.0	0.35	6.74	2.02	2.03

18.50	31.40	7.60	23.20	2.51	280	7.6	1.213	5.85	0.01	0.10	38.62	0.04	5.81	0.19	2.69
19.30	29.80	6.10	23.60	1.25	281	6.1	2.174	4.70	0.06	0.10	38.41	0.24	4.94	0.26	1.52
18.20	31.30	6.00	23.00	2.28	282	6	2.242	4.62	0.07	0.11	38.51	0.27	4.89	0.27	2.54
17.90	31.70	10.20	21.70	3.24	283	10.2	0.424	7.85	0.13	0.11	38.54	0.58	7.27	0.70	3.95
17.80	31.30	7.60	23.00	1.55	284	7.6	1.234	5.85	0.01	0.11	38.41	0.03	5.82	0.64	2.20
18.90	32.00	10.00	23.20	2.95	285	10	0.286	7.70	0.12	0.10	38.88	0.49	7.21	0.42	3.37
19.10	31.50	10.30	23.10	3.10	286	10.3	0.472	7.93	0.14	0.11	38.80	0.55	7.38	0.28	3.38
18.70	32.20	10.50	22.90	3.15	287	10.5	0.594	8.09	0.14	0.11	38.88	0.59	7.49	0.53	3.68
18.20	30.30	0.40	21.80	2.47	288	0.4	5.823	0.31	0.33	0.11	38.26	1.44	1.75	0.18	2.65
17.80	30.60	0.30	21.50	2.89	289	0.3	5.890	0.23	0.34	0.12	38.23	1.49	1.72	0.15	3.04
18.70	31.90	0.40	23.00	2.87	290	0.4	5.829	0.31	0.33	0.11	38.80	1.35	1.66	0.11	2.99
17.80	31.60	6.80	23.60	1.33	291	6.80	1.770	5.24	0.03	0.10	38.49	0.12	5.36	0.41	1.73
17.60	30.70	6.40	23.60	0.63	292	6.4	2.027	4.93	0.05	0.10	38.20	0.19	5.12	0.43	1.06
18.50	31.60	3.30	23.80	1.55	293	3.3	3.997	2.54	0.20	0.10	38.67	0.75	3.29	0.24	1.79
18.80	30.70	0.00	23.50	1.53	294	0	6.095	0.00	0.35	0.10	38.51	1.37	1.37	0.10	1.63
18.10	30.00	0.40	23.60	0.57	295	0.4	5.844	0.31	0.33	0.10	38.15	1.28	1.59	0.09	0.67
19.90	30.60	0.30	24.30	1.13	296	0.3	5.910	0.23	0.34	0.10	38.77	1.25	1.48	0.13	1.26
17.80	31.50	2.80	24.30	0.40	297	2.8	4.325	2.16	0.22	0.10	38.46	0.81	2.96	0.27	0.67
22.30	33.40	3.90	24.60	4.00	298	3.9	3.629	3.00	0.17	0.09	40.14	0.63	3.63	0.35	4.35
18.60	32.30	9.00	25.00	0.53	299	9	0.392	6.93	0.07	0.09	38.88	0.25	6.68	0.62	1.15

18.50	31.70	7.10	24.90	0.29	300	7.1	1.601	5.47	0.02	0.09	38.69	0.06	5.53	0.25	0.53
19.30	31.40	8.10	24.60	1.02	301	8.10	0.967	6.24	0.03	0.09	38.82	0.11	6.13	0.35	1.37
19.10	31.50	0.00	24.40	1.01	302	0	6.117	0.00	0.35	0.10	38.80	1.29	1.29	0.13	1.14
19.60	31.80	3.10	23.60	2.56	303	3.1	4.149	2.39	0.21	0.10	39.01	0.81	3.20	0.25	2.82
18.80	32.00	5.60	23.60	2.30	304	5.6	2.560	4.31	0.09	0.10	38.85	0.35	4.66	0.31	2.61
19.30	31.30	5.20	23.80	1.76	305	5.20	2.816	4.00	0.11	0.10	38.80	0.41	4.42	0.38	2.14
18.70	31.70	10.60	24.00	1.61	306	10.6	0.620	8.16	0.15	0.10	38.75	0.55	7.61	0.43	2.04
19.60	31.90	9.60	24.30	2.06	307	9.60	0.017	7.39	0.10	0.10	39.03	0.37	7.02	0.33	2.39
19.10	32.00	6.00	24.00	2.22	308	6	2.310	4.62	0.07	0.10	38.93	0.27	4.89	0.20	2.42
19.00	33.30	6.90	24.70	2.10	309	6.9	1.737	5.31	0.03	0.09	39.24	0.10	5.41	0.25	2.37
18.80	31.50	9.50	24.30	1.08	310	9.5	0.080	7.32	0.09	0.10	38.72	0.35	6.97	0.50	1.57
19.60	33.30	8.50	24.00	3.27	311	8.5	0.718	6.55	0.05	0.10	39.40	0.18	6.36	0.42	3.68
20.40	30.50	10.10	23.60	2.53	312	10.1	0.304	7.78	0.12	0.10	38.88	0.48	7.30	0.37	2.90
20.10	33.50	10.50	24.00	4.14	313	10.5	0.560	8.09	0.14	0.10	39.58	0.55	7.54	0.31	4.45
20.10	30.80	10.40	24.90	0.74	314	10.4	0.497	8.01	0.14	0.09	38.88	0.49	7.52	0.48	1.22
19.70	32.50	10.60	25.20	1.37	315	10.6	0.626	8.16	0.15	0.09	39.22	0.51	7.65	0.29	1.65
20.50	31.40	10.80	26.40	0.54	316	10.8	0.755	8.32	0.16	0.08	39.14	0.49	7.83	0.78	0.24
20.40	32.40	9.50	24.10	3.07	317	9.5	0.075	7.32	0.10	0.10	39.37	0.36	6.95	0.45	3.53
20.60	32.00	8.50	24.20	2.44	318	8.5	0.714	6.55	0.05	0.10	39.32	0.18	6.36	0.62	3.06
19.60	31.80	9.60	24.00	1.86	319	9.60	0.009	7.39	0.10	0.10	39.01	0.38	7.01	0.74	2.60

20.00	30.70	6.20	25.00	0.38	320	6.20	2.186	4.77	0.06	0.09	38.82	0.21	4.99	0.55	0.93
20.10	32.90	10.00	23.90	2.96	321	10	0.250	7.70	0.12	0.10	39.43	0.46	7.24	0.73	3.69
18.70	31.10	0.80	23.80	1.37	322	0.8	5.651	0.62	0.31	0.10	38.59	1.20	1.82	0.13	1.50
19.50	32.00	8.00	23.90	2.05	323	8	1.031	6.16	0.03	0.10	39.03	0.10	6.06	0.62	2.67
19.30	30.90	4.50	24.10	1.39	324	4.5	3.277	3.47	0.14	0.10	38.69	0.52	3.99	0.18	1.58
19.30	32.30	3.10	23.10	3.98	325	3.1	4.177	2.39	0.20	0.11	39.06	0.84	3.22	0.09	4.07
19.40	32.20	4.60	24.80	1.55	326	4.6	3.214	3.54	0.13	0.09	39.06	0.48	4.03	0.11	1.66
21.10	30.80	9.70	24.40	2.23	327	9.70	0.066	7.47	0.11	0.10	39.14	0.39	7.08	0.32	2.55
19.60	32.40	9.60	24.90	1.70	328	9.60	0.003	7.39	0.10	0.09	39.16	0.36	7.03	0.21	1.91
20.00	32.90	7.30	25.20	1.82	329	7.30	1.476	5.62	0.01	0.09	39.40	0.03	5.65	0.29	2.11
21.40	33.00	10.30	24.20	3.42	330	10.3	0.457	7.93	0.13	0.10	39.80	0.51	7.42	0.79	4.21
20.50	33.70	10.90	25.20	1.76	331	10.9	0.845	8.39	0.16	0.09	39.74	0.57	7.82	1.16	2.93
20.60	31.80	10.50	24.70	1.86	332	10.5	0.589	8.09	0.14	0.09	39.27	0.52	7.56	0.65	2.50
20.90	33.70	8.90	25.70	2.46	333	8.90	0.441	6.85	0.07	0.09	39.85	0.23	6.62	0.30	2.76
21.00	32.60	5.20	25.80	1.31	334	5.20	2.828	4.00	0.11	0.09	39.58	0.36	4.36	0.36	1.67
21.00	33.00	7.20	25.70	1.60	335	7.20	1.537	5.54	0.01	0.09	39.69	0.04	5.58	0.55	2.14
21.30	30.80	7.10	25.40	0.81	336	7.1	1.601	5.47	0.02	0.09	39.19	0.06	5.52	0.48	1.29
20.90	31.10	0.80	25.80	0.28	337	0.8	5.670	0.62	0.31	0.09	39.16	1.04	1.65	0.10	0.38
21.70	32.30	7.70	25.50	2.06	338	7.70	1.212	5.93	0.01	0.09	39.69	0.04	5.89	0.42	2.48
21.10	32.80	7.60	25.20	2.54	339	7.6	1.276	5.85	0.01	0.09	39.66	0.03	5.83	0.32	2.86

20.60	33.80	7.30	25.30	3.07	340	7.30	1.469	5.62	0.01	0.09	39.80	0.02	5.65	0.16	3.23
20.30	32.20	7.90	24.80	0.00	341	7.9	1.081	6.08	0.02	0.09	39.30	0.08	6.01	1.86	1.86
21.00	30.40	8.30	23.90	2.44	342	8.30	0.822	6.39	0.04	0.10	39.01	0.16	6.24	0.35	2.79
21.20	31.10	6.70	24.20	2.47	343	6.70	1.857	5.16	0.04	0.10	39.24	0.13	5.29	0.41	2.88
21.70	32.70	5.80	24.70	2.98	344	5.80	2.439	4.47	0.08	0.09	39.80	0.29	4.75	0.48	3.45
21.00	31.70	4.30	23.80	3.04	345	4.30	3.410	3.31	0.15	0.10	39.35	0.58	3.89	0.35	3.39
21.30	32.80	9.30	24.80	2.80	346	9.30	0.173	7.16	0.09	0.09	39.72	0.32	6.84	0.62	3.42
21.50	30.80	6.40	24.10	2.30	347	6.4	2.051	4.93	0.05	0.10	39.24	0.19	5.12	0.53	2.83
22.10	33.80	2.40	24.70	3.66	348	2.4	4.641	1.85	0.24	0.09	40.10	0.89	2.73	0.32	3.98
21.10	31.50	3.30	24.30	2.44	349	3.3	4.059	2.54	0.20	0.10	39.32	0.74	3.28	0.28	2.73
21.50	31.90	0.80	24.80	2.36	350	0.8	5.678	0.62	0.31	0.09	39.53	1.14	1.76	0.15	2.51
20.40	31.50	2.10	25.70	0.38	351	2.1	4.836	1.62	0.25	0.09	39.14	0.84	2.46	0.10	0.48
21.10	31.60	10.40	24.10	3.30	352	10.4	0.540	8.01	0.14	0.10	39.35	0.53	7.48	0.30	3.61
19.30	30.40	7.70	24.90	0.07	353	7.70	1.210	5.93	0.01	0.09	38.56	0.04	5.89	0.20	0.13
21.20	33.90	6.30	25.50	2.90	354	6.30	2.117	4.85	0.05	0.09	39.98	0.19	5.04	0.34	3.24
20.50	32.00	8.10	24.20	2.76	355	8.10	0.951	6.24	0.03	0.10	39.30	0.12	6.12	0.39	3.15
21.40	33.80	0.00	24.20	4.46	356	0	6.197	0.00	0.35	0.10	40.01	1.35	1.35	0.11	4.57
22.30	33.60	1.60	24.60	4.62	357	1.6	5.161	1.23	0.28	0.09	40.20	1.04	2.27	0.16	4.78
21.40	29.90	4.70	24.40	1.35	358	4.70	3.154	3.62	0.13	0.10	38.98	0.48	4.10	0.45	1.80
22.30	34.30	10.60	24.70	4.86	359	10.6	0.664	8.16	0.15	0.09	40.38	0.56	7.61	0.60	5.46

20.50	31.60	7.80	24.10	2.55	360	7.80	1.149	6.01	0.02	0.10	39.19	0.06	5.94	0.41	2.96
21.60	30.90	9.10	24.80	1.85	361	9.10	0.309	7.01	0.08	0.09	39.30	0.28	6.73	0.54	2.39
22.60	33.30	10.10	24.20	4.89	362	10.1	0.336	7.78	0.12	0.10	40.20	0.48	7.29	0.60	5.49
21.80	32.50	8.40	22.80	5.92	363	8.40	0.764	6.47	0.04	0.11	39.77	0.19	6.28	0.36	6.28
22.40	34.40	3.70	24.30	5.04	364	3.7	3.803	2.85	0.18	0.10	40.44	0.68	3.53	0.35	5.39
22.10	31.80	7.90	24.20	3.95	365	7.9	1.090	6.08	0.02	0.10	39.66	0.08	6.00	0.31	4.26
22.70	34.50	6.50	24.70	5.02	366	6.5	1.995	5.01	0.05	0.09	40.54	0.17	5.18	0.48	5.49

Appendix 9: Water Balance Model for Surface Water Assessment in Dakawa catchment within Wami sub-basin

Year	Months	Days	Q_{obs} (m3/s)	Q_{obs} (mm)	P(mm)	ET0 (mm)	Q= P-ET0 (mm)	Q_{obs}-Q (mm)	(Q_{obs}-Q)/P (mm)	$Q_{dir}=\sum(Q_{obs}-Q_{base})$ (mm)
2010	1	31	1771.9	166.59	99.78	6.76	93.02	73.57	0.74	1771.9
2010	2	28	314.1	26.67	99.86	8.69	91.18	-64.50	-0.65	314.1
2010	3	31	376.4	35.39	86.36	6.82	79.54	-44.15	-0.51	376.4
2010	4	30	1050.0	95.53	135.52	5.79	129.73	-34.20	-0.25	1050.0
2010	5	31	956.5	89.93	94.82	9.06	85.76	4.16	0.04	956.5
2010	6	30	180.6	16.43	4.75	7.46	-2.71	19.14	4.03	180.6
2010	7	31	97.4	9.16	3.63	5.94	-2.31	11.47	3.16	97.4
2010	8	31	76.9	7.23	5.23	10.37	-5.15	12.38	2.37	76.9
2010	9	30	49.6	4.51	11.27	5.28	5.99	-1.48	-0.13	49.6
2010	10	31	0.0	0.00	17.16	7.69	9.47	-9.47	-0.55	0.0
2010	11	30	0.0	0.00	39.79	7.11	32.68	-32.68	-0.82	0.0
2010	12	31	0.0	0.00	97.18	9.46	87.72	-87.72	-0.90	0.0
2011	1	31	263.2	24.75	79.87	9.23	70.64	-45.90	-0.57	263.2
2011	2	28	166.1	14.11	61.54	9.78	51.76	-37.66	-0.61	166.1
2011	3	31	1162.8	109.32	172.37	7.12	165.25	-55.93	-0.32	1162.8
2011	4	30	2718.3	247.33	168.07	5.81	162.25	85.07	0.51	2718.3
2011	5	31	1804.0	169.61	56.40	10.13	46.27	123.34	2.19	1804.0
2011	6	30	312.9	28.47	3.72	4.81	-1.09	29.56	7.95	312.9

2011	7	31	126.9	11.93	5.40	8.74	-3.34	15.27	2.83	126.9
2011	8	31	99.4	9.35	7.61	7.59	0.03	9.32	1.22	99.4
2011	9	30	229.0	20.84	23.30	5.84	17.46	3.37	0.14	229.0
2011	10	31	0.0	0.00	42.10	8.01	34.09	-34.09	-0.81	0.0
2011	11	30	294.5	26.80	57.57	8.63	48.94	-22.15	-0.38	294.5
2011	12	31	0.0	0.00	266.54	10.17	256.37	-256.37	-0.96	0.0
2012	1	31	1403.7	131.97	91.36	8.66	82.70	49.27	0.54	1403.7
2012	2	29	169.4	14.90	66.42	10.67	55.75	-40.85	-0.62	169.4
2012	3	31	994.8	93.53	140.36	9.15	131.21	-37.68	-0.27	994.8
2012	4	30	216.1	19.66	106.28	10.17	96.12	-76.46	-0.72	216.1
2012	5	31	341.9	32.14	93.24	11.00	82.24	-50.09	-0.54	341.9
2012	6	30	88.4	8.04	7.25	8.60	-1.35	9.39	1.30	88.4
2012	7	31	57.9	5.44	3.88	8.45	-4.57	10.02	2.58	57.9
2012	8	31	76.8	7.22	1.52	8.23	-6.70	13.92	9.14	76.8
2012	9	30	75.5	6.87	2.28	9.19	-6.91	13.78	6.06	75.5
2012	10	31	57.4	5.40	13.42	7.91	5.51	-0.12	-0.01	57.4
2012	11	30	65.4	5.95	48.75	6.23	42.53	-36.58	-0.75	65.4
2012	12	31	83.2	7.82	85.04	6.73	78.31	-70.48	-0.83	83.2
2013	1	31	91.3	8.58	120.82	10.45	110.37	-101.79	-0.84	91.3
2013	2	28	141.1	11.98	28.51	7.14	21.36	-9.38	-0.33	141.1

2013	3	31	261.8	24.61	129.53	8.83	120.70	-96.08	-0.74	261.8
2013	4	30	1524.3	138.69	141.74	8.62	133.12	5.57	0.04	1524.3
2013	5	31	491.7	46.23	44.37	10.05	34.32	11.91	0.27	491.7
2013	6	30	88.5	8.05	1.54	9.63	-8.09	16.14	10.49	88.5
2013	7	31	52.4	4.93	1.74	10.36	-8.62	13.55	7.80	52.4
2013	8	31	51.9	4.88	6.55	9.36	-2.81	7.69	1.17	51.9
2013	9	30	13.5	1.23	19.25	10.00	9.25	-8.02	-0.42	13.5
2013	10	31	55.4	5.21	61.98	8.92	53.06	-47.85	-0.77	55.4
2013	11	30	19.5	1.77	51.77	9.55	42.22	-40.44	-0.78	19.5
2013	12	31	67.8	6.37	38.97	11.01	27.96	-21.58	-0.55	67.8
2014	1	31	841.8	79.14	37.15	8.60	28.56	50.59	1.36	841.8
2014	2	28	914.4	77.65	118.55	9.29	109.26	-31.60	-0.27	914.4
2014	3	31	1894.1	178.08	230.50	8.42	222.09	-44.01	-0.19	1894.1
2014	4	30	2761.9	251.29	152.34	7.35	144.99	106.30	0.70	2761.9
2014	5	31	1673.7	157.36	141.07	7.44	133.63	23.72	0.17	1673.7
2014	6	30	202.8	18.45	10.57	9.05	1.53	16.93	1.60	202.8
2014	7	31	77.8	7.31	7.83	5.65	2.18	5.14	0.66	77.8
2014	8	31	0.0	0.00	9.50	10.41	-0.91	0.91	0.10	0.0
2014	9	30	0.0	0.00	15.00	10.89	4.11	-4.11	-0.27	0.0
2014	10	31	12.1	1.14	47.30	8.90	38.40	-37.26	-0.79	12.1

2014	11	30	15.4	1.40	103.43	8.61	94.82	-93.41	-0.90	15.4
2014	12	31	102.3	9.62	171.61	6.72	164.89	-155.27	-0.90	102.3
2015	1	31	486.5	45.74	68.08	6.86	61.22	-15.48	-0.23	486.5
2015	2	28	85.2	7.24	29.03	7.11	21.91	-14.68	-0.51	85.2
2015	3	31	731.4	68.77	110.80	6.11	104.69	-35.92	-0.32	731.4
2015	4	30	1076.5	97.95	196.37	6.99	189.38	-91.43	-0.47	1076.5
2015	5	31	1693.9	159.26	75.41	8.07	67.34	91.91	1.22	1693.9
2015	6	30	0.0	0.00	4.17	5.63	-1.47	1.47	0.35	0.0
2015	7	31	0.0	0.00	9.10	5.76	3.33	-3.33	-0.37	0.0
2015	8	31	0.0	0.00	12.73	5.23	7.50	-7.50	-0.59	0.0
2015	9	30	0.0	0.00	7.14	7.76	-0.63	0.63	0.09	0.0
2015	10	31	44.5	4.18	16.68	7.92	8.75	-4.57	-0.27	44.5
2015	11	30	86.5	7.87	153.57	7.02	146.55	-138.68	-0.90	86.5
2015	12	31	268.9	25.28	112.63	6.84	105.79	-80.51	-0.71	268.9
2016	1	31	1841.1	173.10	265.85	9.85	256.00	-82.90	-0.31	1841.1
2016	2	29	2780.6	244.56	78.13	9.20	68.93	175.63	2.25	2780.6
2016	3	31	383.0	36.01	112.12	9.12	103.00	-66.99	-0.60	383.0
2016	4	30	3005.5	273.46	283.10	8.08	275.02	-1.56	-0.01	3005.5
2016	5	31	1709.6	160.73	55.53	7.78	47.74	112.99	2.03	1709.6
2016	6	30	326.8	29.73	11.21	8.28	2.93	26.80	2.39	326.8

2016	7	31	185.3	17.42	8.52	9.04	-0.52	17.94	2.10	185.3
2016	8	31	93.4	8.78	8.80	9.05	-0.25	9.03	1.03	93.4
2016	9	30	24.3	2.21	6.99	8.76	-1.77	3.98	0.57	24.3
2016	10	31	18.0	1.69	17.56	8.38	9.19	-7.50	-0.43	18.0
2016	11	30	12.0	1.09	23.86	9.42	14.44	-13.35	-0.56	12.0
2016	12	31	10.9	1.02	26.98	7.08	19.90	-18.87	-0.70	10.9
2017	1	31	17.9	1.68	43.48	9.67	33.81	-32.13	-0.74	17.9
2017	2	28	239.7	20.36	84.17	6.03	78.14	-57.78	-0.69	239.7
2017	3	31	1824.6	171.55	141.96	6.34	135.62	35.93	0.25	1824.6
2017	4	30	2885.6	262.55	270.14	5.74	264.39	-1.84	-0.01	2885.6
2017	5	31	3200.4	300.90	205.51	6.63	198.88	102.02	0.50	3200.4
2017	6	30	793.8	72.22	11.93	6.30	5.62	66.60	5.58	793.8
2017	7	31	150.6	14.16	0.46	5.31	-4.85	19.01	41.11	150.6
2017	8	31	80.0	7.52	7.05	7.22	-0.17	7.69	1.09	80.0
2017	9	30	16.3	1.48	11.54	5.23	6.31	-4.82	-0.42	16.3
2017	10	31	12.0	1.13	41.86	4.20	37.66	-36.53	-0.87	12.0
2017	11	30	40.3	3.67	74.44	3.47	70.97	-67.30	-0.90	40.3
2017	12	31	41.4	3.89	37.72	5.05	32.67	-28.78	-0.76	41.4
2018	1	31	2091.0	196.59	238.74	4.32	234.42	-37.83	-0.16	2091.0
2018	2	28	188.6	16.02	30.99	3.37	27.62	-11.60	-0.37	188.6

2018	3	31	2048.5	192.60	242.46	3.28	239.18	-46.59	-0.19	2048.5
2018	4	30	2181.0	198.44	242.82	4.34	238.47	-40.03	-0.16	2181.0
2018	5	31	1174.4	110.42	146.00	4.77	141.24	-30.82	-0.21	1174.4
2018	6	30	134.3	12.22	8.06	2.90	5.16	7.06	0.88	134.3
2018	7	31	92.0	8.65	9.80	3.58	6.21	2.44	0.25	92.0
2018	8	31	32.1	3.02	2.07	4.72	-2.65	5.66	2.73	32.1
2018	9	30	13.4	1.22	11.73	4.86	6.87	-5.65	-0.48	13.4
2018	10	31	14.4	1.35	33.31	4.34	28.97	-27.62	-0.83	14.4
2018	11	30	9.2	0.84	32.93	2.85	30.09	-29.25	-0.89	9.2
2018	12	31	576.9	54.24	143.99	4.02	139.96	-85.72	-0.60	576.9
Mean			553.3	51.11	71.84	7.50	64.34	-13.23	0.92	553.32
SD			821.5	75.76	73.85	2.06	73.99	56.58	4.43	821.52
Sum			59758.8	5519.69	7758.80	810.42	6948.39	-1428.70	99.33	59758.80
Max			3200.4	300.9	283.1	11.0	275.0	175.6	41.1	3200.4
Min			0.0	0.0	0.5	2.8	-8.6	-256.4	-1.0	0.0

Appendix 10: Water Balance Model for Surface Water Assessment in Mandera catchment within Wami sub-basin

Year	Months	Days	Q_{obs} (m^3/s)	Q_{obs} (mm)	P (mm)	ET0 (mm)	Q= P-ET0 (mm)	Q_{obs}-Q (mm)	(Q_{obs}-Q)/P (mm)	$Q_{dir}=\sum(Q_{obs}-Q_{base})$
2010	1	31	2734.40	200.93	99.78	6.76	93.02	107.90	1.08	2734.40
2010	2	28	563.30	37.39	99.86	8.69	91.18	-53.79	-0.54	563.30
2010	3	31	968.60	71.17	86.36	6.82	79.54	-8.36	-0.10	968.60
2010	4	30	1703.80	121.16	135.52	5.79	129.73	-8.57	-0.06	1703.80
2010	5	31	1946.40	143.02	94.82	9.06	85.76	57.26	0.60	1946.40
2010	6	30	639.70	45.49	4.75	7.46	-2.71	48.20	10.14	639.70
2010	7	31	251.80	18.50	3.63	5.94	-2.31	20.81	5.73	251.80
2010	8	31	152.50	11.21	5.23	10.37	-5.15	16.35	3.13	152.50
2010	9	30	20.50	1.46	11.27	5.28	5.99	-4.54	-0.40	20.50
2010	10	31	0.00	0.00	17.16	7.69	9.47	-9.47	-0.55	0.00
2010	11	30	0.00	0.00	39.79	7.11	32.68	-32.68	-0.82	0.00
2010	12	31	0.00	0.00	97.18	9.46	87.72	-87.72	-0.90	0.00
2011	1	31	0.00	0.00	79.87	9.23	70.64	-70.64	-0.88	0.00
2011	2	28	0.00	0.00	61.54	9.78	51.76	-51.76	-0.84	0.00
2011	3	31	0.00	0.00	172.37	7.12	165.25	-165.25	-0.96	0.00
2011	4	30	0.00	0.00	168.07	5.81	162.25	-162.25	-0.97	0.00
2011	5	31	0.00	0.00	56.40	10.13	46.27	-46.27	-0.82	0.00
2011	6	30	0.00	0.00	3.72	4.81	-1.09	1.09	0.29	0.00
2011	7	31	0.00	0.00	5.40	8.74	-3.34	3.34	0.62	0.00

2011	8	31	0.00	0.00	7.61	7.59	0.03	-0.03	0.00	0.00
2011	9	30	0.00	0.00	23.27	5.84	17.43	-17.43	-0.75	0.00
2011	10	31	0.00	0.00	42.14	8.01	34.13	-34.13	-0.81	0.00
2011	11	30	0.00	0.00	57.57	8.63	48.95	-48.95	-0.85	0.00
2011	12	31	0.00	0.00	266.54	10.17	256.37	-256.37	-0.96	0.00
2012	1	31	2193.10	161.15	91.40	8.66	82.74	78.41	0.86	2193.10
2012	2	29	332.90	22.88	66.42	10.67	55.75	-32.87	-0.49	332.90
2012	3	31	1648.80	121.16	140.36	9.15	131.21	-10.05	-0.07	1648.80
2012	4	30	608.90	43.30	106.28	10.17	96.12	-52.82	-0.50	608.90
2012	5	31	1117.20	82.09	93.24	11.00	82.24	-0.14	0.00	1117.20
2012	6	30	384.10	27.31	7.25	8.60	-1.35	28.67	3.95	384.10
2012	7	31	129.50	9.52	3.88	8.45	-4.57	14.09	3.63	129.50
2012	8	31	53.00	3.89	1.52	8.23	-6.70	10.60	6.95	53.00
2012	9	30	0.00	0.00	2.28	9.19	-6.91	6.91	3.04	0.00
2012	10	31	0.00	0.00	13.42	7.91	5.51	-5.51	-0.41	0.00
2012	11	30	0.00	0.00	48.75	6.23	42.53	-42.53	-0.87	0.00
2012	12	31	151.90	11.16	85.04	6.73	78.31	-67.15	-0.79	151.90
2013	1	31	313.20	23.01	120.82	10.45	110.37	-87.36	-0.72	313.20
2013	2	28	128.70	8.54	28.51	7.14	21.36	-12.82	-0.45	128.70
2013	3	31	966.50	71.02	129.53	8.83	120.70	-49.68	-0.38	966.50
2013	4	30	2699.20	191.94	141.74	8.62	133.12	58.82	0.41	2699.20

2013	5	31	1109.00	81.49	44.37	10.05	34.32	47.17	1.06	1109.00
2013	6	30	186.00	13.23	1.54	9.63	-8.09	21.31	13.86	186.00
2013	7	31	70.80	5.20	1.74	10.36	-8.62	13.82	7.95	70.80
2013	8	31	80.60	5.92	6.75	12.50	-5.75	11.67	1.73	80.60
2013	9	30	12.20	0.87	19.25	10.00	9.25	-8.38	-0.44	12.20
2013	10	31	230.80	16.96	61.98	8.92	53.06	-36.10	-0.58	230.80
2013	11	30	34.40	2.45	51.77	9.55	42.22	-39.77	-0.77	34.40
2013	12	31	256.10	18.82	38.97	11.01	27.96	-9.14	-0.23	256.10
2014	1	31	536.20	39.40	37.15	8.60	28.56	10.84	0.29	536.20
2014	2	28	1473.00	97.76	118.55	9.29	109.26	-11.49	-0.10	1473.00
2014	3	31	3268.90	240.20	230.50	8.42	222.09	18.11	0.08	3268.90
2014	4	30	6303.20	448.23	152.34	7.35	144.99	303.24	1.99	6303.20
2014	5	31	2880.90	211.69	141.07	7.44	133.63	78.06	0.55	2880.90
2014	6	30	640.50	45.55	10.57	9.05	1.53	44.02	4.16	640.50
2014	7	31	294.60	21.65	7.83	5.65	2.18	19.47	2.49	294.60
2014	8	31	170.40	12.52	18.50	10.41	8.09	4.43	0.24	170.40
2014	9	30	195.00	13.87	15.00	10.89	4.11	9.76	0.65	195.00
2014	10	31	0.30	0.02	47.30	8.90	38.40	-38.38	-0.81	0.30
2014	11	30	11.00	0.78	103.43	8.61	94.82	-94.03	-0.91	11.00
2014	12	31	59.60	4.38	171.61	6.72	164.89	-160.51	-0.94	59.60
2015	1	31	1857.60	136.50	68.08	6.86	61.22	75.28	1.11	1857.60
2015	2	28	771.20	51.18	29.03	7.11	21.91	29.27	1.01	771.20

2015	3	31	1773.60	130.33	110.80	6.11	104.69	25.64	0.23	1773.60
2015	4	30	3678.10	261.55	196.37	6.99	189.38	72.17	0.37	3678.10
2015	5	31	5519.60	405.59	75.41	8.07	67.34	338.24	4.49	5519.60
2015	6	30	1278.80	90.94	4.17	5.63	-1.47	92.40	22.18	1278.80
2015	7	31	999.90	73.47	9.10	5.76	3.33	70.14	7.71	999.90
2015	8	31	768.90	56.50	12.73	5.23	7.50	49.00	3.85	768.90
2015	9	30	365.70	26.01	7.14	7.76	-0.63	26.63	3.73	365.70
2015	10	31	311.60	22.90	16.68	7.92	8.75	14.14	0.85	311.60
2015	11	30	1317.50	93.69	153.57	7.02	146.55	-52.86	-0.34	1317.50
2015	12	31	0.00	0.00	112.63	6.84	105.79	-105.79	-0.94	0.00
2016	1	31	0.00	0.00	265.85	9.85	256.00	-256.00	-0.96	0.00
2016	2	29	8998.40	618.56	78.13	9.20	68.93	549.62	7.03	8998.40
2016	3	31	1675.90	123.15	112.12	9.12	103.00	20.14	0.18	1675.90
2016	4	30	3805.60	270.62	283.10	8.08	275.02	-4.40	-0.02	3805.60
2016	5	31	1822.20	133.90	55.53	7.78	47.74	86.15	1.55	1822.20
2016	6	30	313.50	22.29	11.21	8.28	2.93	19.36	1.73	313.50
2016	7	31	129.60	9.52	8.52	9.04	-0.52	10.04	1.18	129.60
2016	8	31	60.50	4.45	9.50	9.05	0.45	4.00	0.42	60.50
2016	9	30	12.30	0.87	6.99	8.76	-1.77	2.65	0.38	12.30
2016	10	31	4.20	0.31	17.56	8.38	9.19	-8.88	-0.51	4.20
2016	11	30	7.00	0.50	23.86	9.42	14.44	-13.94	-0.58	7.00

2016	12	31	48.60	3.57	26.98	7.08	19.90	-16.33	-0.61	48.60
2017	1	31	42.00	3.09	43.48	9.67	33.81	-30.72	-0.71	42.00
2017	2	28	156.30	10.37	84.17	6.03	78.14	-67.77	-0.81	156.30
2017	3	31	982.70	72.21	141.96	6.34	135.62	-63.41	-0.45	982.70
2017	4	30	3665.60	260.66	270.14	5.74	264.39	-3.73	-0.01	3665.60
2017	5	31	5052.60	371.27	205.51	6.63	198.88	172.39	0.84	5052.60
2017	6	30	217.70	15.48	11.93	6.30	5.62	9.86	0.83	217.70
2017	7	31	0.00	0.00	0.46	5.31	-4.85	4.85	10.49	0.00
2017	8	31	0.00	0.00	7.05	7.22	-0.17	0.17	0.02	0.00
2017	9	30	0.00	0.00	11.54	5.23	6.31	-6.31	-0.55	0.00
2017	10	31	0.00	0.00	41.86	4.20	37.66	-37.66	-0.90	0.00
2017	11	30	0.00	0.00	74.44	3.47	70.97	-70.97	-0.95	0.00
2017	12	31	0.00	0.00	37.72	5.05	32.67	-32.67	-0.87	0.00
Mean			866.24	62.27	69.02	7.98	61.04	1.23	1.21	866.24
SD			1531.74	109.03	69.86	1.76	69.90	98.32	3.52	1531.74
Sum			83158.70	5977.79	6625.84	766.21	5859.64	118.15	115.80	83158.70
Max			8998.40	618.56	283.10	12.50	275.02	549.62	22.18	8998.40
Min			0.00	0.00	0.46	3.47	-8.62	-256.37	-0.97	0.00

Appendix 11: Ground Truthing Points of the Study Area

s/n	longitudes	latitudes	code		s/n	longitudes	latitudes	code
1	37.565	6.568	2		84	37.261	-6.290	5
2	37.576	6.492	2		85	37.262	-6.459	5
3	37.516	6.413	2		86	37.174	-6.405	5
4	37.531	-6.436	2		87	37.164	-6.448	5
5	37.517	-6.433	2		88	37.070	-6.342	5
6	37.346	6.459	2		89	37.001	-6.330	5
7	37.011	6.472	2		90	36.906	-6.362	5
8	37.286	6.833	2		91	36.965	-6.425	5
9	37.429	6.864	2		92	36.925	-6.509	5
10	37.574	6.850	2		93	37.040	-6.627	5
11	36.927	-6.405	2		94	36.933	-6.719	5
12	36.779	-6.702	2		95	36.799	-7.079	5
13	36.723	-6.705	2		96	36.959	-7.002	5
14	36.821	-6.807	2		97	36.653	-7.045	5
15	36.982	-6.917	2		98	36.830	-7.187	5
16	36.775	-7.037	2		99	36.990	-7.252	5

17	36.769	-7.118	2		100	36.839	-7.228	5
18	36.760	-7.149	2		101	37.549	-5.893	5
19	36.738	-7.188	2		102	37.730	-5.897	5
20	37.164	-7.359	2		103	37.654	-6.031	5
21	37.138	-7.208	2		104	37.401	-6.023	5
22	37.104	-7.028	2		105	37.943	-6.141	5
23	37.183	-7.014	2		106	37.963	-6.317	5
24	37.163	-7.358	2		107	38.044	-6.201	5
25	36.725	-6.766	2		108	37.785	-6.296	5
26	36.727	-6.843	2		109	37.684	-6.367	5
27	37.013	-6.042	2		110	36.979	-6.531	5
28	36.905	-6.011	2		111	36.840	-6.449	4
29	37.030	-5.945	2		112	36.808	-6.537	4
30	37.481	-6.037	2		113	36.809	-6.684	4
31	37.597	-6.007	2		114	37.138	-6.581	4
32	37.326	-6.020	2		115	37.297	-6.657	4
33	37.134	-6.123	2		116	37.295	-6.355	4
34	36.909	-6.012	2		117	37.132	-6.167	4
35	36.844	-6.130	2		118	37.438	-6.164	4
36	37.156	-6.280	2		119	37.584	-6.270	4

37	37.514	-6.042	2		120	37.573	-6.356	4
38	37.783	-6.152	2		121	37.856	-6.230	4
39	37.494	-6.153	2		122	38.007	6.215	4
40	37.591	-5.953	2		123	37.914	-6.475	4
41	37.126	-6.862	1		124	37.459	-6.775	4
42	37.093	-6.847	1		125	37.241	-6.882	4
43	37.068	-6.846	1		126	37.403	-7.110	4
44	37.444	-6.947	1		127	37.024	-7.084	4
45	37.343	-6.924	1		128	37.266	-7.227	4
46	37.329	-6.916	1		129	37.049	-7.330	4
47	37.316	-6.896	1		130	37.063	-7.391	4
48	37.538	-6.423	1		131	37.020	-6.115	4
49	37.299	-6.861	1		132	36.910	-6.204	4
50	37.271	-6.854	1		133	36.911	-6.202	4
51	37.208	-6.924	1		134	37.019	-7.093	4
52	37.178	-6.939	1		135	37.919	-6.455	4
53	37.042	-6.843	1		136	37.456	-6.548	3
54	37.028	-6.849	1		137	37.274	-6.616	3
55	37.014	-6.843	1		138	37.337	-6.414	3
56	37.013	-6.843	1		139	37.191	-6.266	3

57	36.991	-6.838	1		140	37.469	-6.175	3
58	36.964	-6.808	1		141	37.701	-6.278	3
59	36.947	-6.783	1		142	37.587	-6.384	3
60	36.942	-6.774	1		143	37.200	-6.694	3
61	36.924	-6.759	1		144	37.039	-6.896	3
62	36.968	-6.927	1		145	37.164	-7.070	3
63	37.034	-7.028	1		146	37.286	-7.065	3
64	37.126	-6.999	1		147	37.045	-7.348	3
65	37.166	-7.004	1		148	37.124	-7.215	3
66	37.138	-7.034	1		149	36.700	-7.075	3
67	37.080	-7.115	1		150	36.663	-7.075	3
68	37.197	-7.136	1		151	37.946	-6.125	3
69	37.126	-7.126	1		152	37.724	-5.995	3
70	37.173	-7.196	1		153	37.476	-6.164	3
71	37.191	-7.264	1		154	36.990	-6.018	3
72	37.124	-7.258	1		155	36.954	-5.974	3
73	37.161	-7.283	1		156	36.989	-6.002	3
74	37.162	-7.305	1		157	36.912	-6.104	3
75	37.190	-7.265	1		158	36.871	-6.198	3
76	37.138	-7.350	1		159	36.869	-6.061	3

77	37.064	-7.305	1		160	37.473	-6.160	3
78	37.023	-7.317	1		161	37.534	-6.443	3
79	37.010	-7.334	1		162	37.533	-6.443	3
80	37.096	-7.374	1		163	37.533	-6.444	3
81	37.156	-6.341	1		164	37.538	-6.423	3
82	37.156	-6.341	5		165	37.534	-6.443	3
83	37.293	-6.224	5		166	37.534	-6.443	3

Appendix 12: Control chart for NDVI classification

code	Mean(CL)	UCL	LCL	s/n	lon	lat	code	Mean(CL)	UCL	LCL
2	2.769	7.050	-1.511	85	37.293	-6.224	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	86	37.261	-6.290	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	87	37.262	-6.459	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	88	37.174	-6.405	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	89	37.164	-6.448	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	90	37.070	-6.342	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	91	37.001	-6.330	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	92	36.906	-6.362	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	93	36.965	-6.425	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	94	36.925	-6.509	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	95	37.040	-6.627	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	96	36.933	-6.719	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	97	36.799	-7.079	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	98	36.959	-7.002	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	99	36.102	-6.887	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	100	36.653	-7.045	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	101	36.830	-7.187	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	102	36.990	-7.252	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	103	36.839	-7.228	5	2.769	7.050	-1.511

2	2.769	7.050	-1.511	104	37.549	-5.893	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	105	37.730	-5.897	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	106	37.654	-6.031	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	107	37.401	-6.023	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	108	37.943	-6.141	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	109	37.963	-6.317	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	110	38.044	-6.201	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	111	37.785	-6.296	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	112	37.684	-6.367	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	113	36.979	-6.531	5	2.769	7.050	-1.511
2	2.769	7.050	-1.511	114	36.840	-6.449	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	115	36.808	-6.537	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	116	36.809	-6.684	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	117	37.138	-6.581	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	118	37.297	-6.657	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	119	37.295	-6.355	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	120	37.132	-6.167	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	121	37.438	-6.164	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	122	37.584	-6.270	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	123	37.573	-6.356	4	2.769	7.050	-1.511

2	2.769	7.050	-1.511	124	37.856	-6.230	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	125	38.007	6.215	4	2.769	7.050	-1.511
2	2.769	7.050	-1.511	126	37.914	-6.475	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	127	37.459	-6.775	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	128	37.241	-6.882	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	129	37.403	-7.110	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	130	37.024	-7.084	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	131	37.266	-7.227	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	132	37.049	-7.330	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	133	37.063	-7.391	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	134	37.020	-6.115	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	135	36.910	-6.204	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	136	36.911	-6.202	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	137	37.019	-7.093	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	138	37.919	-6.455	4	2.769	7.050	-1.511
1	2.769	7.050	-1.511	139	37.456	-6.548	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	140	37.274	-6.616	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	141	37.337	-6.414	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	142	37.191	-6.266	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	143	37.469	-6.175	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	144	37.701	-6.278	3	2.769	7.050	-1.511

1	2.769	7.050	-1.511	145	37.587	-6.384	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	146	37.200	-6.694	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	147	37.039	-6.896	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	148	37.164	-7.070	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	149	37.286	-7.065	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	150	37.045	-7.348	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	151	37.124	-7.215	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	152	36.700	-7.075	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	153	36.663	-7.075	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	154	37.946	-6.125	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	155	37.724	-5.995	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	156	37.476	-6.164	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	157	36.990	-6.018	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	158	36.954	-5.974	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	159	36.989	-6.002	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	160	36.912	-6.104	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	161	36.871	-6.198	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	162	36.869	-6.061	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	163	37.473	-6.160	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	164	37.534	-6.443	3	2.769	7.050	-1.511

1	2.769	7.050	-1.511	165	37.533	-6.443	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	166	37.533	-6.444	3	2.769	7.050	-1.511
1	2.769	7.050	-1.511	167	37.538	-6.423	3	2.769	7.050	-1.511
5	2.769	7.050	-1.511	168	37.534	-6.443	3	2.769	7.050	-1.511

Appendix 13: Error Matrix for Accuracy Assessment of NDVI Classification

		References							
		Water	Bare land	Sparse vegetation	Moderate vegetation	Dense vegetation	Total	Commission error's	User's accuracy
Classification	Water	40	0	0	0	0	40	0.00%	100.00%
	Bare land	0	40	0	0	0	40	0.00%	100.00%
	sparse vegetation	0	7	24	0	0	31	22.58%	77.42%
	Moderate vegetation	0	5	0	20	0	25	20.00%	80.00%
	Dense vegetation	0	2	0	0	28	30	6.67%	93.33%
	Total	40	54	24	20	28	**166**		
Omission error's		**0.00%**	**25.93%**	**0.00%**	**0.00%**	**0.00%**			
Producers' accuracy		**100.00%**	**74.07%**	**100.00%**	**100.00%**	**100.00%**			
Overall accuracy		**91.57%**							
Kappa coefficient		**0.892962417**							

- Kappa coefficient = (Total accuracy- random accuracy)/ (1 – random accuracy)

  Where P (a) = Total accuracy = 0.9156626 and P(r) = Random accuracy = 0.2120772