Comparative analysis of the effects of Land Use/Land Cover Changes on Hydrology and Sedimentation: The Case of Wabeand Meki Catchments, Central Ethiopia

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This is to certify that the thesis prepared by Mersha Alemu entitled: Comparative analysis of the effects of Land Use/Land Cover Changes on Hydrology and Sedimentation: The Case of Wabe and Meki Catchments, Central Ethiopia and submittedin partial fulfillment of the requirement for the Degree of Doctor of Philosophy in Earth Sciences(Hydrogeology) complies with the regulations of Addis Ababa university and meet the accepted standard with respect to originality and quality.

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Abstract

Wabe and Meki, located in southwestern and central part of Ethiopia, are adjacent catchments and flowing to Omo-Gibe and Rift Valley Lakes basins respectively.The total area coverage for Wabe and Meki catchments are $1763km^2$ and $2168km^2$ respectively.The land use/land cover changes observed in the catchments over the past 25 yearshave significantly impacted the hydrologic and sedimentation conditions of the catchments. In order to assess these impacts, land use/land cover maps of three-time series data were generated from landsat images of 1986, 1999, and 2011, using remote sensing and GIS tools. Based on the three land use/land cover maps and hydrogeological inputs, SWAT model was appliedto analyze the effects of these changes on hydrolologic components and sediment yields of the catchments. Hydrogeological characterization of the catchments was carried out using conventional hydrogeological, techniques. The results of change detection showed that,cultivation is expanding mainly at the expense of forested land and enchroachments into range lands for the periods of 1986-1999 and 1999-2011.The mean annual surface runoff increased from 164mm to 188mm and from 256mm to 259mm for Meki and Wabe catchments respectively. However, the baseflow decreased from 216mm to 145mm and from 370mm to 352mm for Meki and Wabe catchmentsrespectively. Similarly, the average sediment yield generated for Meki catchment decreased from 51t/ha to 31t/ha in the first period (1986-1999), but increased to 47t/ha in the second period (1999-2011). Whereas, it decreased from 37t/ha to 31t/ha in the first period, but increased to 49t/ha in the second period in the case of Wabe catchment.The general increase in surface runoff and sediment yields and decrease in baseflow from 1986 to 2011 is largely due to the expansion of agricultural lands by 10% and 8% as well as deforestation by 15% and 11%for Wabe and Meki catchments respectively. For prediction years of 2012 to 2026, agricultural land expanded by 17% and 11%, but deforestation is increased by 30% and 5% in Wabe and Meki catchments respectively. Conversely, surface runoff shows a decline in both catchments whereas the predicted baseflow indicates an increasing trend in Meki, but a decreasing in Wabe catchmenet due to large variation in the rate of deforestation between the catchments. However, the effects on both surface runoff and baseflow can be attributed to changes inbothland use/land cover and climatic factors.

Key words:Baseflow, Meki catchment, Land use/land cover, Sediment yield, surface runoff, SWAT, Wabe catchment,

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Acronyms

LMWL	Local Meteoric Water Line
GMWL	Global Meteoric Water Line
LULCC	Land use Land cover change
LULC	Land use Land cover
SWAT	Soil Water Assessement tool
GIS	Geographic information system
BH	Borehole
CER	Central Ethiopian Rift
SP	Spring
DEM	Digital Elevation Model
EC	Electrical Conductivity
GPS	Global Position Space Elevation
HD	Hand Dug
ICTZ	Inter- Tropical Convergence Zone
m.a.s.l	Meter above Sea Level
MER	Main Ethiopia Rift
MWIE	Minister of Water ,Irrigation and Electricity
PH	Negative Logarithm of Power of Hydrogen
RSC	Residual Sodium Carbonate
SAR	Sodium Adsorption Ratio
TDS	Total Dissolved Solid
UNESCO	United Nation Educational, Scientific and Cultural organization
USAD	United State of America Development
WFB	Wonji Fault Belt
WHO	World Health Organization
BF	Baseflow
GW	Groundwater delay
CN	Curve Number
E_{NS} (ENS)	Nash-Sutcliffe efficiency coefficient
R^2	coefficient of determination
WRM	Water resource management
GTP	Growth and Transformation Plan
FAO	Food and Agricultural Organization of the United Nations
UNICEF	United Nations infants and children Fund
WRD	Water Resource Department
MCDE	Multi-Criteria Decision Evaluation
SW	Soil water contents
SUR	Surface Runoff
ET	Evapotranspiration
ha	hectar

PA	peasant association
USDA	United states department of Agriculture
HWSD	Harmonized world soil database
SUFI2,	Sequential Uncertainty Fitting.ver2
PSO	Particle Swarm Optimization
GLUE	Generalized Likelihood Uncertainty Estimation
MCMC	Markov Chain Monte Carlo
PPU	Percent prediction uncertainty
HRU	Hydrologic response unit
CSA	Central Statistics Agency
GCP	Ground Control Points
GPS	Global positioning system
IWRM	Integrated Water Resources Management
SCS	Soil Conservation Service
UTM	Universal Transverse Mercator
IGBP	International Geosphere-Biosphere Program
IHDP	International Human Dimension Program

CHAPTER ONE

INTRODUCTION

1.1 Background

Land use land cover change interacts with hydrology cycle in many ways. Hydrological cycles are highly influenced by changes in land use caused by human disturbances as a result of expansion of agriculture, urbanization and industries (Dazhong et al. 2014). As a result any impact on land use change in return affects hydrological functions at various levels. Land use and hydrological processes undergo complex dynamic interactions. Similarly, the findings of several studies have also revealed the impacts of climate change on water resources of the Ethiopian Basins (Conway, 1997; Z. M. Easton et al., 2010; Tsehayu, 2008).

As compared to climate change, land use change can be a major issue for this century. However, some suggest that the consequences may outweigh those from climate change (Sala et al., 2000). All forms of land use conversion particularly, deforestation caused several hectares of land subjected to erosion, it is estimated that fertile topsoil is lost at a rate of one billion cubic meters per year (White et al., 2008), resulting in massive environmental degradation and constituting a serious threat to sustainable agriculture and forestry. In the same notion, (Tekleab et al., 2010)discussed that agriculture land use in highlands of Ethiopia are the main source of erosion. Soil erosion by water represents a major threat to the long-term productivity of agriculture in the Ethiopian Highlands where the estimated soil erosion rates range from as low as 16 t ha^{-1} y^{-1} (Gizachew, 1995) to as much as 300 t ha^{-1} y^{-1} (Hurni, 1993; FAO,1986).

The major development goals of the country are poverty reduction and economic development that contribute significantly to the betterment of livelihood. Hence, the country's development policies and strategies are geared towards this end.(National Investment Brief,2008).

The current economic and developmental activities of the country indicate that it has been engaged in exploiting its resources, and seize the opportunities to alleviate poverty, rise income of itspeopleand register rebust economic growth in the country. In this regard, the water resources of the country will play major role in domestic use and bosting agricultural production.

According to Ethiopian WRM policy,1999, the overall goal of Water Resources Policy is to enhance and promote all national efforts towards efficient, equitable and optimum utilization of thewater resources of the country for significant socioeconomic development on sustainable basis. This was emphasized in the Growth and Transformation Plan(GTP) that aimed at increasing drinking water coverage, based on the government's definition, from 68.5% to 98.5%.

Awulachew et al.(2007), indicated that the Ministry of Water, Irrigation and Electricity has already identified someareas in main river basins to implementing irrigationbased agriculture. In Ethiopia agriculturecontributes about 45% of GDP and 85% of theincome from exports. However, agriculture largely depends on the unpredictable rainfall. Coupled with severe land degradation, the annual and seasonal variation in rainfall highlyinhibits agricultural productivity. In the face of the ever rising price of global foods, importing agricultural products is becoming more and more challenging. This entails a substantial enhances of water and land resources forinvestment in a productive way (Tilahun etal.,2011). Thus, it is clear that utilizing the available resources requires knowledge and understanding to overcome the negative repercussions of unwise utilization of these resources.

Rapid increases in the world's population have made the efficient use of irrigation water vitallyimportant, particularly in poorer countries, where the greatest potential for increasing food production and rural income is often to be found in irrigated areas. It has therefore become a matter of serious concern in recent years that, despite their very high costs, the performance of many irrigation schemes has fallen far short of expectations(FAO, 1986). Observations and experiences in different landscapes of the country show that there have been changes to these resources, especially forests, land and water, attributed to natural and antropogenic effects.

According to Getachew (2004), the recurrent drought occurring in the country has greatly affected the water resources in that most perennial rivers dried up and a number of springs significantly decreased their yield. As per the recent assessment conducted by UNICEF in 196 drought affected woredas of the country, the result of the 2002/3 drought led most perennial rivers to dry up while most seepage type springs decreased their yield considerabily. Although there is a decline in dynamic water levels of some wells, shallow and deep drilled wells were able to survive the drought and serving people critically in need of water and saved lifes.

At a Ministerial Conferenceheld at Kyoto (2003) emphasis was put on groundwater resources as: “Whilst groundwater storage is vast (over 99% of fresh water reserves), itsrate of replenishment is finite and mainly limited to the shallower aquifers, whose quality can also be seriously (and even irreversibly) degraded. Excessive resource development, uncontrolled urban and industrial discharges, andagricultural intensification are causing increasingly widespread degradation of aquifers.”

Some documents and researches(Nyssen et.al.,2010; HALCROW,2007;Ayenew and Becht,2007; Awulachew and Tenaw, 2011) conducted on the above problems and challenges showed that most ofthese impacts are often associated with changes in land and climatic conditions.

According to the study conducted by Jimma University on Gilgel-Gibe site(2011), there has been intricate and multifaceted problems of sedimentation, landslide and degradation of land surrounding the Gilgel-Gibe-I dam. Human activities like burning of wood for charchoal, deforestation, changes in land use, mismanagement of land and grazing have also played their own roles to alter the dynamics of the atmosphere contributing to climate change.

This paper also suggested that changes in climate conditions resulting in huge form of flooding and raise in evaporation, geo-hazard problems and siltation are some of the anticipated challenges and environmental impacts threatening the long benefits of the dam. However, there is no agreement among the results of the future changes in climate conditions as projected using different models (Ward and Lasage, 2009).

The impact of land degradation is widespread as it threatens not only the productivity of agriculture but also water, biodiversity and the fundamental ecological processes on which life depends (Conacher, 2001).

There are endeavours towards developing WRM policywhich emphasizes the necessity of an IWRM approach andall aspects of water resources management, including the management of surface water and groundwater resources, as well aswater quantity and quality issues. It also underlines the need for carrying out an integrated water resources management, natural resources management and inter-sectoralcoordination at all levels.

Inorder to address these challenges and problems,integrated methods have been employed with the objective of analyzing spatio-temporal variation of land use/land cover and its effects on the hydrologic factors at present conditions and in the future.After examining the aforementioned factors and existing problems in the catchments, the study tries to contribute to the knowledge gap as to how these problems are associated withthe interactive effects of land use/land cover and hydrologic conditions.

1.2 Statement of the problem

Most of environmental challenges and problems related to the research area include land degradation and erosion, landslides, siltation and sedimentation, changes to hydrological components, deterioration and destruction of vegetation covers and distribution, deforestation and reduction in agricultural productivity (Alterra, 2007; HALCROW,2008; PHE Ethiopia Consortium ,2011*;* Meeraph, 2006).

These impacts are often linked to changes in land use/land cover and climatic conditions. Effects of land use and land cover changes on both surface water and groundwater have been documented in various hydrological studies (HALCROW,2008; Zhang et.al,2005; Legesse and Ayenew,2006; La Frenierre,2008; Scanlonetal.;2005).These effects included groundwater table and recharge variation, impacts on soil moisture and evapotranspiration, changes related to characteristics of basin and influence on water requirements of ecosystems.

These changes in land and water bodies due tohuman activities, have pushed researchers to think logically in applying ecological restoration and land management principles. Thus, conditions are created in the process of fixing serious problems towards restoration of the area (Apfelbaum and Thomas,2008;Craul etal.,2008).In relation to the current activities and initiations in the study area, it requires the implementation of integrated water resource managemnt approaches that include all aspects of water resource management, watershed management, and other natural resource management being coordinated at all levels.Accordingly, this study investigates the land use/land cover change and its effect on hydrological components and sedimentation of the catchments taking the current aspects of water resources management in to consideration.

Research questions

Considering historical trends and the existing environmental changes in the study catcchments, anthropogenic activites constitute more influential factors than the natural conditions in affecting the hydrologic behaviour of the catchments. While assessing the effects of land use/ land cover changes on hydrologic features, the following major research questions have been addressed:

- What are the effects of the interactionbetween hydrological factors and land use/land cover changes on the environment?
- How do land use/land cover changes and hydrogeological behavior of the catchments influence hydrologic conditions of the catchments under study?
- What are the major factors to be considered to characterize the hydrology of the catchments and existing problems in the research area?
- Considering the present conditions continue, how does the hydrologic system respond to the future land use land cover changes?

1.3 Objectives

The general objective of the research is to evaluate the effect of landuse/landcover change on the hydrological system and sedimentation rate of the different sub-catchments in Wabe and Meki river basins.

The specific objectives mainly includethe following:

- To evaluateland use and land cover changes and their subsequent effects in different sub-catchments
- To evaluate spatial and temporal variability of hydrometeorology
- To assesss the impacts of land use/cover change on predicted flows
- To analyze the effect of land use/land cover and othercatchment factors(for instance, hydrogeology) in the hydrological responses and sediment yield

1.4 Significance of the study

This study will have important implications in the conservation soil and water and restoration of the two catchments. First, the data gathered during field visitand the results of the analysis help to understand the aspects of water supply and can also support the integrated water resource management of the catchments. Second, the results of this study can be used in formulating land use planning policy and developing approach to the planning and implementation of ecological restoration in the context of watershed management(soil and water conservation). Third, the outputcan also give an insight into understanding how the hydrogeologic characteristics of the catchments affect discharges fromthe catchments and the subbasins(subcatchments). This can in turn provoke future watershed model developments to give appropriate considerationto hydrogeologic characteristics of the watershed unlike most of the existing watershed models.

1.5 Previous studies

Several hydrological and geological studies have been conducted in the Rift Valley Lakes basin by different researchers and institutions. Few of them, particularly in relation to this research have been reviewed and presented below. However, for the Wabe catchmentthere is hardly any detail works on land use/land cover, geological, and hydrogeological thathave been conducted. Very few MSc thesis works, and the integrated development master plan of Omo-Gibe by the Ministry of Water, Irrigation and Electricity are available for references in the Omo-Gibe basin scale.

Some of the more valuable works on hydrology and hydrogeology of the rift valley and adjacent highlands that paved the way for the later researches are Daniel Gemechu (1974) who described and discussed the aspects of climate and water budget in Ethiopia with the aim of providing the general picture of the regional variation of moisture resources in the country.

TesfayeCherinet (1978, 1985and 1988) attempted to produce the hydrogeological map of Ethiopia at a scale of 1:2,000,000. He also studied the hydrological and hydrogeological conditions of the central lakes.

Tenalem Ayenew (1998, 2002a, 2002b) analyzed the hydrogeological system of the Lake District basin in his PhD thesis. He also discussed the movement and occurrence of groundwater in the Ethiopia volcanic terrains using integrated approach. In addition to this, he (2003) also etimated the ET of the Ethiopian rift and adjacent highlands uing thematic mapper spectralsatellite data. His result showed the betterment of this approach in estimating ET over the conventional methods.Ayenew (2002a) also noted the recent changes observed in the level of Lake Abiyata.

Legesse, etal. (2000) demonstrated the sensetivity of stream flows to changes in climate and land cover in the case of Meki River.LegesseandAyenew (2006) investigated and showed the effectsof improper water and land resource utilization in the case of central Main Ethiopian Rift lakes.TheOmo-Gibe River Basin IntegratedDevelopment Master plan, 1996, FDRE Ministry of Water, Irrigation and Electricity gave highlight about the geology, soil, and water resources of the basin.

Recently, studies that were conducted on land and water resource conditions of this area include Alterra (2007); MWIE and Ethiopian Water Technology Center (EWTC), (2008 and 2012); and HALCROW, (1992 and 2008).

Some reaserches are also available on geology and geological structures of the rift valley and the Omo-Gibebasin, that include the works of Mohr P. A**.** **(**1967); Davidson.et.al, (1973); WoldeGabriel, et.al, (1990) and Giacomo Corti,(2009).

In some part of the catchments, there are few previous works (Ayenew,1998; Legesse, 2010; Alterra,2006**;**Abraham,2007;Seyoum,2013) who conducted research in relation to assessing the effects of land use and land cover changes on hydrologic factors. These effects were clearly observed on hydrological components like catchment runoff, groundwater recharge, ET, and soil water content.

CHAPTER TWO

2. DESCRIPTION OF THE STUDY AREA

2.1 Location

The Wabe river, a tributary of Gibe River, draining the Omo-Gibe basin, is located at the southwesternpart of the country. It is about 1763km^2 in area coverage and streaches from the western part of Guraghe ridge to the Gibe river. It is found in the Southern Nations, Nationalities and People's (SNNP) Region of Guraghe zone at average distance of 160Km from the capital Addis Ababa.The Wabe river is located between latitudes of 8^0 00'30"N to 9^0 00'25"N and longitudes of 37^0 04' 05"E to 38^0 00'00"E (Figure 2.1).

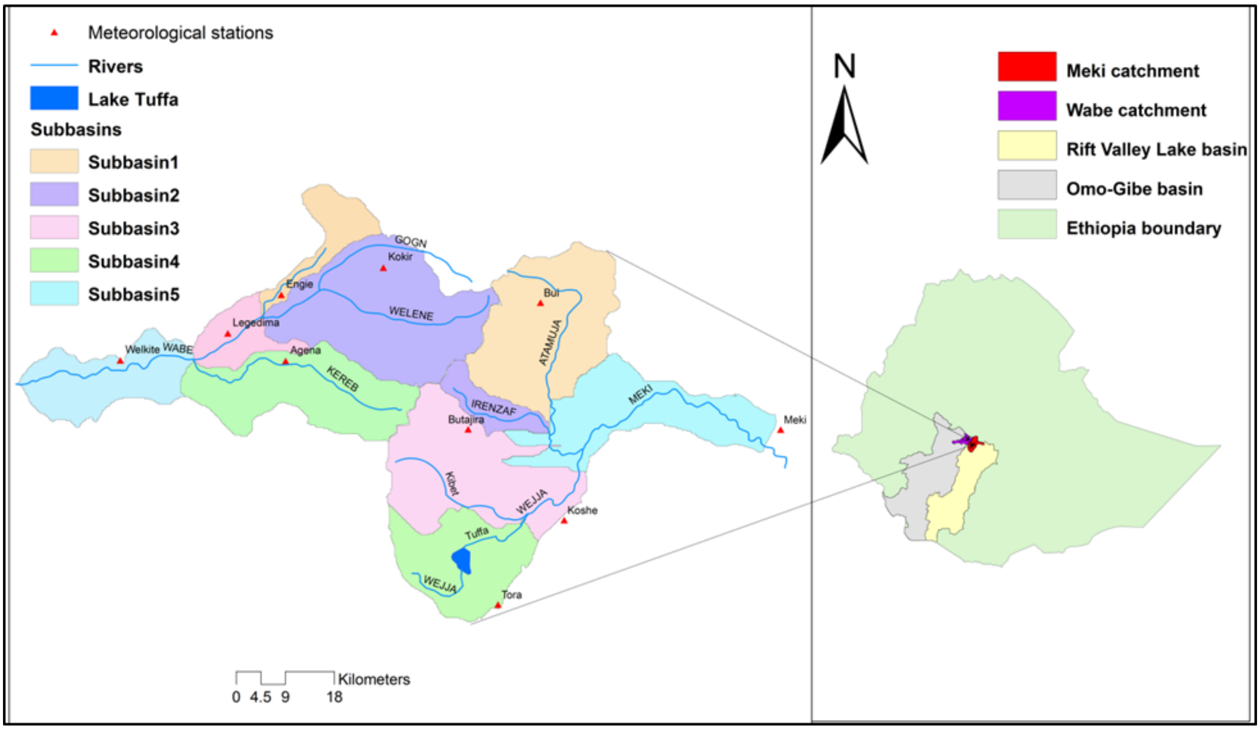


Figure 2.1 Wabe and Meki catchments subbasins, meteorologic stations and tributaries

Meki river catchment is located in the central Main Ethiopian Riftvalley and adjacent highlands. The area stretches from the eastern part of the Guraghe ridge and escarpment of the rift valley to Lake Ziway. Geographically, it is located between latitudes of 7^0 51'N and 8^0 27'N and longitudes of 38^0 15'Eand 38^0 51'E(Figure 2.2). The total area of Meki river catchment is about 2168 km^2 and is found both in the regional states of Oromia and SNNP.

2.2 Topography and drainage

The altitude of the terrain that Wabe drains ranges from about 1109m to 3548 m.a.s.l and the average altitude is about 2330m. Physiographically, the whole catchment can be divided into three regions. The highlands, the transitional zone and the low land(low-lying areas). The highlands cover areas close to the Guraghe ridge, the low land areas that include the western part of the catchment, and the transitional region extends from southeastern part of Woliso (Northern) to Agena area(Southern). Steep slopes with dissected hills characterize thehighlands while the lowland and transitional areas are characterized by relatively gentle and undulating slopes.

The catchment is deeply dissected and drained by perennial rivers of Gogni, Welene, Cheika, Demekash, Legedima, and Kereb river systems merging from these highlands to formthe Wabe River that finally flows to the deeply entrenched gorge of Omo-Gibe (Figure2.2a). They drain largely cultivated land, much of it with ratherimpeded drainage, whichis an area where erosion and sedimentation processes are important.

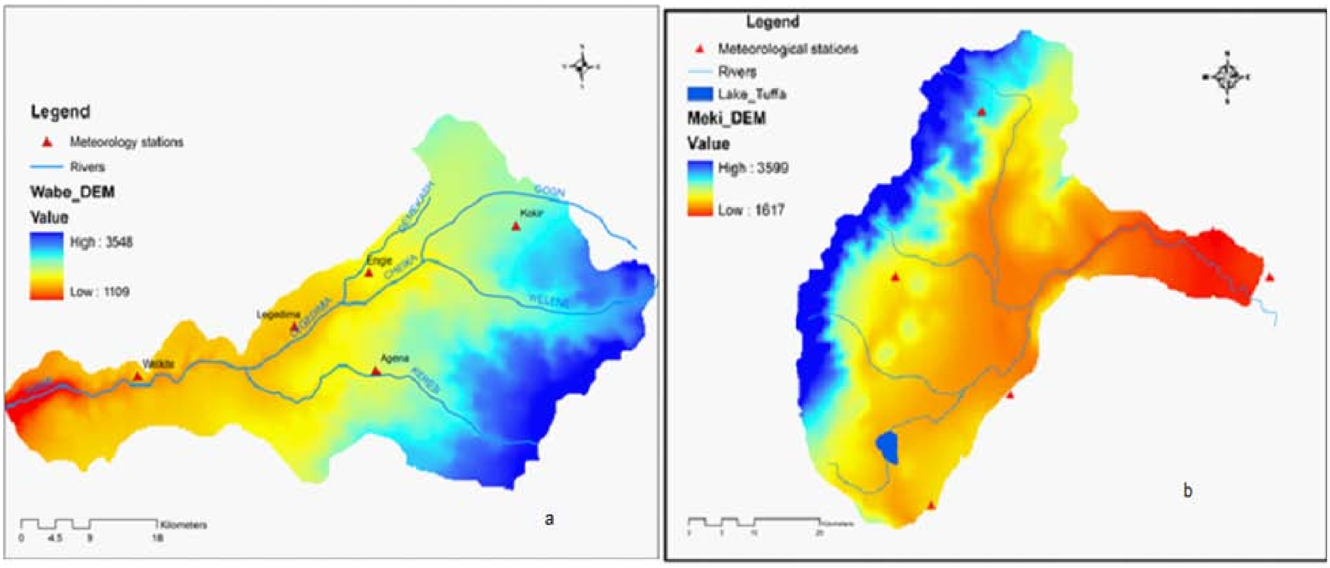


Figure 2.2 Digital elevation models of Wabe (a) and Meki (b) catchments

Similarily, the topography ofMeki catchment is primarily determined by the rift system of faulting. This catchment lies within altitudes ranging from 3554 in the west to 1617m.a.s.l to Lake Ziway with a mean elevation of 2150m.a.s.l(Figure 2.2b).The Meki river rises from the highlands and escarpments including a vast swampy area and travels about 100 km before emptying into the Ziway Lake. Physiographically, this is also divided into the highland areas, the transitional regions, and the wider rift floors. The main rivers that drain this catchment are Atamija, Irenzaf, Weja, Kebet, Tufa and Meki itself.

2.3 Hydrometeorology

2.3.1 Climate

The seasonal rainfall distribution of Ethiopia is explained by referencing to the positon of ITCZ (Inter TropicalConvergence Zone)(Gemechu, 1976). The ITCZ representsa low-pressure area of convergence between Tropical Easterlies and Equatorial Westerliesalongwhich equatorial wave disturbances take place. This low pressure, which may not be continuous in space and time, is often traceable in Ethiopia between May and November. The movementofITCZfrom south to north of Ethiopia in certain months govern theavailability of rain driving wind direction.

Rainfall

The weather variables used were collected from NMA for the period of 1986 to 2011. The annual rainfalls in both Wabe and Meki catchments computed from the average values of all five stations which were considered and assumed representative of respective subbasins of the catchments. Accordingly, the mean annualrainfalls of Wabe catchment was 1265 mmand that of Meki was 908mm. Climatically, Wabe catchment is classified as lowland (10%) and middle highland (90%)(AWANRDPO, 2004). The highlands are mostly categorized under tropical humid to sub-humid and the lowlands are dominantly semi-arid climate characteristics.

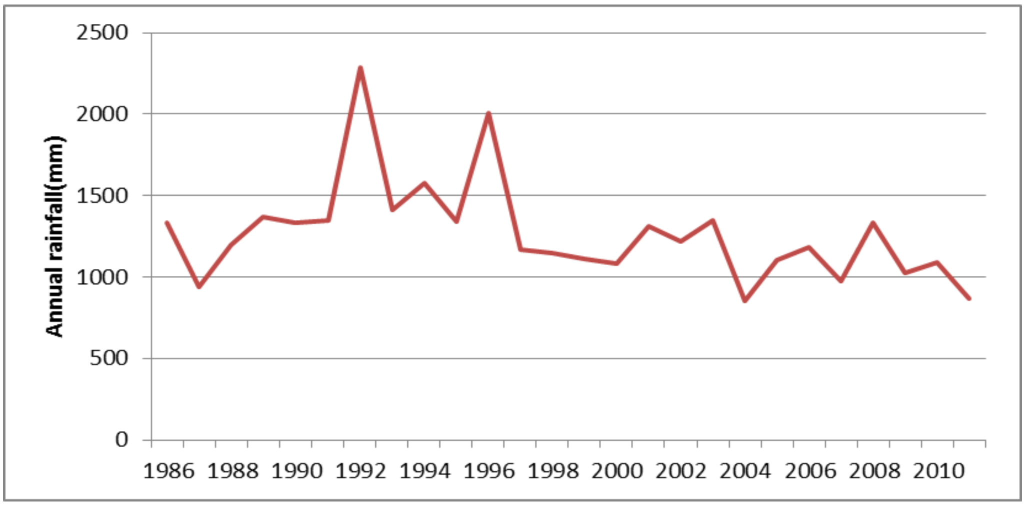


Figure2.3 Mean Annual rainfall of the Wabe catchment (1986-2011)

The climate of Meki catchment consists of three ecological zones: humid to dry humid, dry sub-humid or semi-arid and semi-arid or arid lands (Makin et al., 1976).

Table 2.1Summary statistics of the monthly rainfall(1986-2011) of Wabe catchment

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Minimum	0.60	8.70	16.60	7.30	60.80	128.10	55.80	3.20	1.00	3.40	3.40	4.10
Maximum	105.40	156.00	233.00	319.90	325.50	420.60	379.80	717.10	300.80	116.60	115.60	80.30
Mean	36.88	71.72	95.11	154.66	172.72	239.67	220.06	182.26	96.92	33.55	25.53	32.63
STD	32.33	43.16	59.11	79.32	71.83	74.96	84.91	159.03	82.81	32.20	27.07	27.59

The average annual rainfall of Meki varies largely spatially from rift floor (715 mm) to the extreme highland areas (1100 mm).The changes in forest coverages of these catchments could have impacts on the local climatic conditions of the catchments as it can be observed from the decreasing of annual rainfalls.

Table 2.2Summary statistics of the monthly rainfall(1986-2011) of Meki catchment

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Minimum	0.15	0.34	42.32	16.32	45.66	58.40	109.60	65.96	56.26	0.40	0.00	0.92
Maximum	116.74	260.82	203.02	247.48	219.40	218.44	253.98	279.72	152.12	174.68	116.30	58.38
Mean	21.67	61.69	89.72	99.49	93.73	122.66	173.37	149.76	102.15	44.55	18.10	18.81
STD	28.61	56.22	56.15	64.43	50.28	43.84	41.02	49.15	25.58	42.94	30.62	18.91

Table 2.3Summary statistics of the monthly Temperature(1986-2011) of Wabe catchment

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean of Maximum	25.68	26.06	25.92	26.10	26.38	26.43	26.44	25.75	26.75	26.90	27.07	26.60
Mean of Minimum	11.69	11.81	12.10	11.95	12.53	11.88	11.55	11.63	11.83	11.43	10.80	10.64
Average	18.68	18.93	19.01	19.03	19.46	19.16	19.00	18.69	19.29	19.17	18.94	18.62
STD of Maximum	1.00	0.60	0.70	0.66	0.60	1.49	1.63	2.50	1.25	1.50	1.27	0.67
STD of Minimum	2.56	2.31	2.25	2.57	1.96	2.33	2.59	2.57	2.34	3.01	4.05	4.05

Table 2.4Summary statistics of the monthly Temperature(1986-2011)of Meki catchment

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean of Maximum	26.01	26.62	26.68	26.87	27.05	25.81	24.70	24.04	25.29	25.32	25.46	25.53
Mean of Minimum	10.95	11.00	11.83	12.09	12.40	11.53	11.50	11.47	11.62	11.15	10.64	10.49
Average	18.48	18.81	19.26	19.48	19.73	18.67	18.10	17.76	18.45	18.24	18.05	18.01
STD of Maximum	9.83	10.06	10.09	10.17	10.24	9.76	9.36	9.13	9.58	9.57	9.63	9.66
STD of Minimum	7.53	7.81	7.42	7.39	7.32	7.14	6.60	6.28	6.84	7.09	7.41	7.52

The temporal distribution and variability of the rainfallsfor thecatchments were determined and presented in figures 2.3 and 2.4 . For both catchments, the trends showed the general increases in rainfall from 1986 to 1996, but decreases between 1996 and 2011. The maximum and minimum rainfalls were recorded in 1992 and 2011 for Wabe, and in 1996 and 2011 for

Meki respectively. The differences between these exetrems reached up to more than 1400mm in the case of Wabe, but reached up to 400mm for Meki catchment.

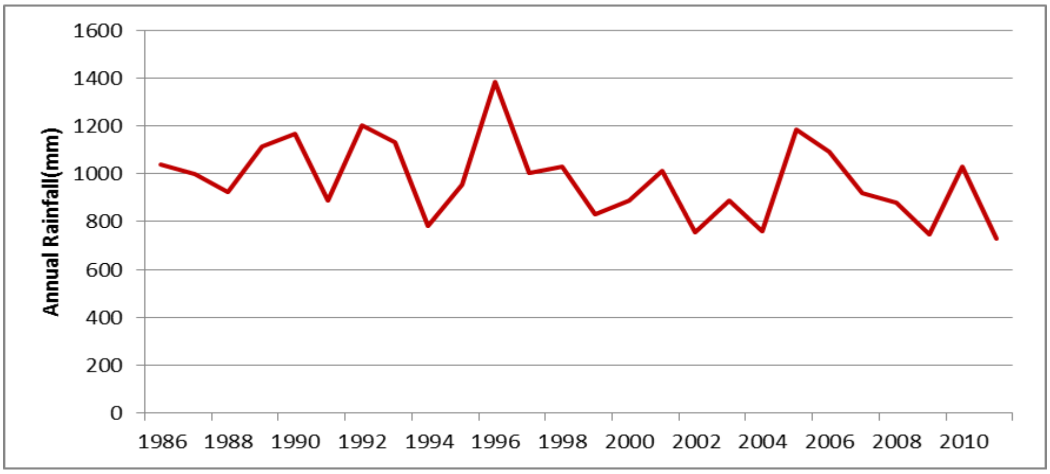


Figure2.4 Mean Annual rainfall of the Meki catchment (1986-2011)

The spatial distribution of the mean annual rainfall of the cachments are showed in Figure 2.5. Both isohyetal and Theiessen polygon maps were utilized to demonstrate variation of rainfalls in the subbasins. The rainfall amount was generally higher than the mean in the eastern and western parts of the catchment. The central parts of the catchment received rainfall of less than 1265mm. This distribution was observed that it was not highly dependent on the elevation variations of this catchment. The maximum rainfall was received in the western part which is close to Legedima and Welkite stations. It is at substantial distance from Guraghe highlands. This corresponds to the general absence ofsystematic variations between the amount of rainfall and elevations.(Gemechu,1976).

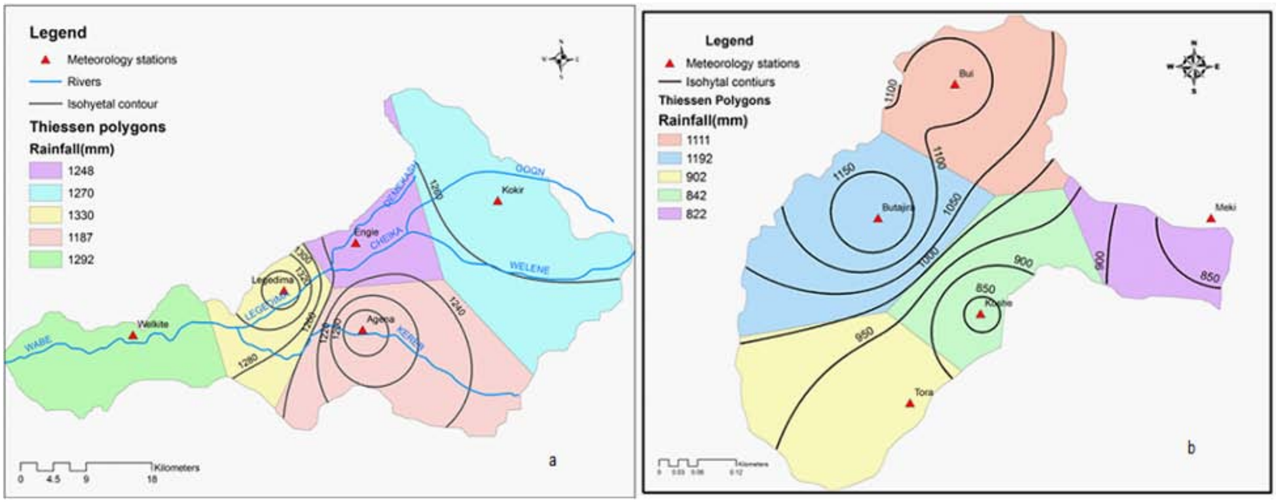


Figure2.5 Isohyetal maps and Thiessen polygons of Wabe (a) and Meki (b) catchments

In contrast, in Meki catchment, areas adjacent to the Guraghe highlands received rainfall amount of greater than 974mm which is the average rainfall for the whole catchment. The rainfall amount decreased from these highlands towards the central and rift floor of the catchment. Unlike in the case of Wabe, here, systematic variations were observed between the amount of rainfall and elevation.

Temperature

The mean annual temperature of the Wabe catchment varies between 15 ^{0}C, and 27 ^{0}C. Wheras for Meki catchment, the average annual prevailing mean temperature ranges from about 11 ^{0}C in the highlands to around 26 ^{0}C in the rift. The temperature in this area shows strong altitudinal variations. The hottest month is November for Wabe, but May for Meki catchment. Whereas, the coldest month is Decemder for both Wabe and Meki catchments(Tables 2.3 and 2.4).

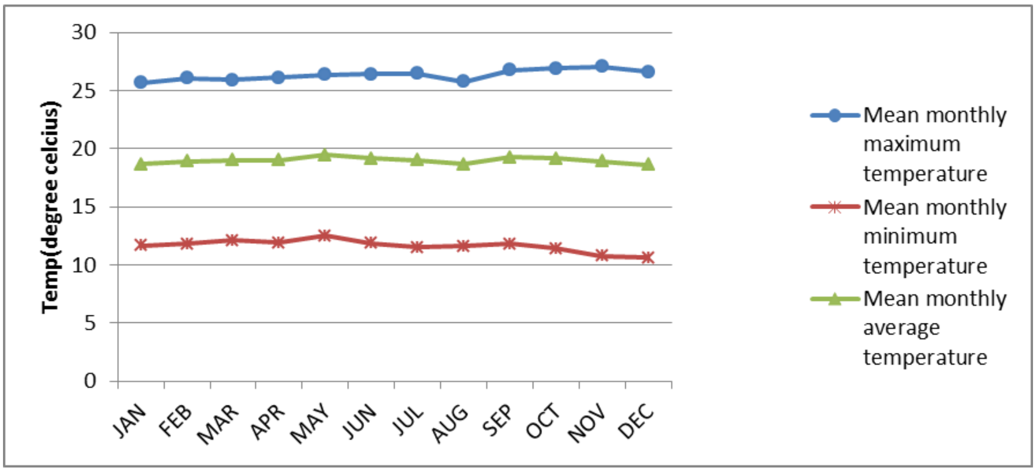


Figure 2.6Mean monthly temperature of Wabe catchment (1986-2011)

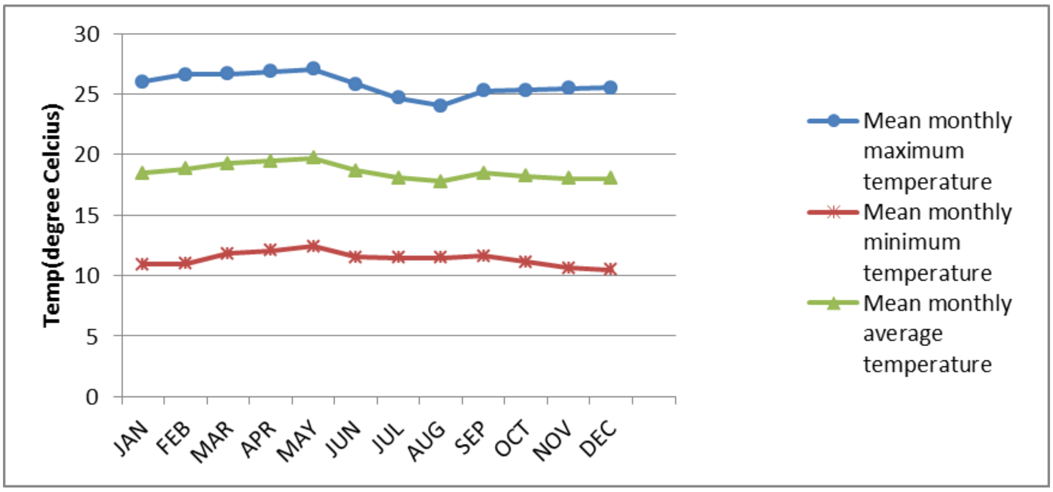


Figure 2.7 Mean monthly temperature of Meki catchment (1986-2011)

River discharges

The gauging stations for Wabe and Meki catchments are located at Welkite and Meki towns repectively. The river discharges of these stations were collected from the Ministry of Water, Irrigation, and Electricity. These discharges are observed mostly as the manifestation of the physical characteristics of the catchments. Both Wabe and Meki rivers are joined by several tributaries at various location of the catchments(Figure 2.1).The major tributaries of Wabe river are Gogni, Welene, Cheika, Demekash, Legedima, Kereb, and Wabe. Most of these rivers are perennial and contribute significant flow to Wabe river which is one of the major tributaries of Omo-Gibe river. Wabe joins Omo-Gibe river in the vicinity of Welkite town. Similarly, the major tributaries of Meki river include Atamuja, Irenzaf, Kibet, and Weijja which drain different toporgaphic location of the catchments before joining Meki river.

The river discharges are mainly determined by the amount of rainfalls in and around the catchment areas. However, the relationships between the annual rainfalls and river discharges(Figures 2.8 and 2.9) indicate the significant roles of ET and other physical characteristics of the catchments. It is obvious that the amount and variations of temperatures in the catchments have also strongly affected the amount of water lost to atmosphere and the river discharges.

The Wabe riverdischarges at gauge station is moderately representative of the rainfalls of the catchment. As there are other large rivers in this catchment, it requires installation of additional recording stations to have better understanding of the hydro-meteorological conditions of this catchment. It lags two months behind which indicates slower response as compared to Meki catchment. This also shows higher retaining capacityof the catchment which is associated wth the hydraulic properties of the geological formations and other physical characteristics of the catchment.

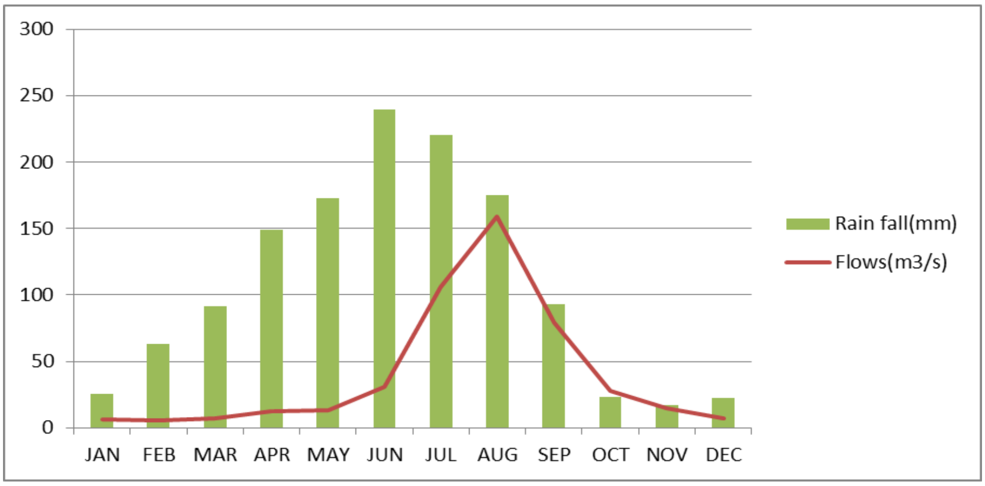


Figure 2.8 Monthly average Rainfall and runoff for Wabe (1986-2011)

The discharges of Meki river at the gauge station indicates less representation of the rainfalls (average of the five stations) of the catchment. It has relativelyfaster response than Wabe catchment which is the characteristics of the abrupt changes in elevation. In order to understand and characterize the hydrometeorological conditions in detail, installation of additional recording stations and proper monitoring is required.

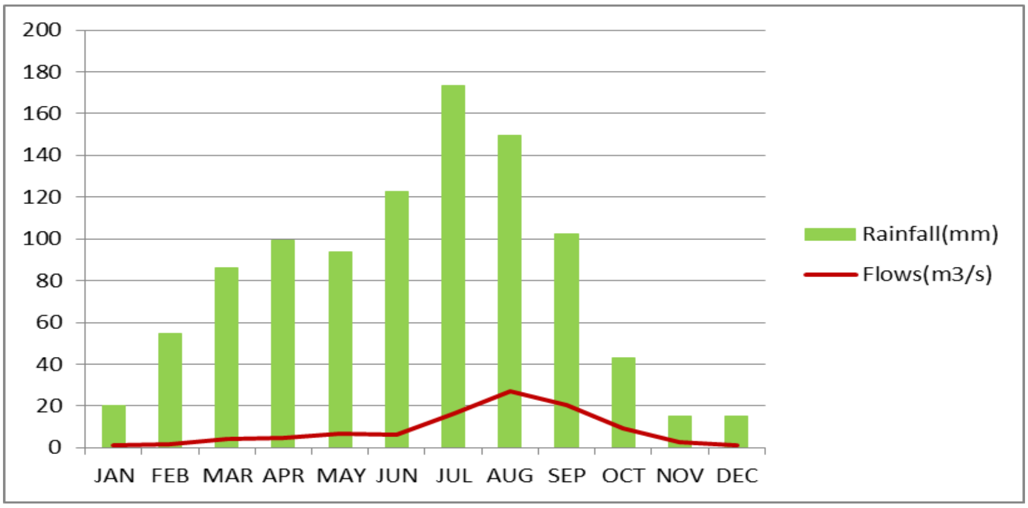


Figure2.9 Monthly average rain fall and runoff for Meki(1986-2011)

The river discharges between the period of 1986 to 2011 for both catchments were anlyzed using RAR and TimePlot tools and compared with the observed values (Figures 2.10 and 2.11).

Table 2.5 Rainfall and River flows of Wabe (a) and Meki (b) catchments

a

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rainfall(mm)	36.88	71.72	95.11	154.66	172.72	239.67	220.06	182.26	96.92	33.55	25.53	32.63
Flows(m3/s)	5.97	5.69	7.17	12.54	13.36	31.21	106.12	158.73	78.79	27.83	14.36	7.34

b.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Rainfall(mm)	20.00	54.57	86.27	99.49	93.73	122.66	173.37	149.76	102.15	42.84	15.31	15.19
Flows (m3/s)	1.08	1.67	4.23	4.77	6.91	6.10	16.23	26.97	20.26	9.16	2.55	0.95

Based on the analysis from RAP tool, the mean daily baseflow estimated for Meki catchment(46.35mm) was much less than that of Wabe catchment(223.34mm) which indicates the larger coverage of forests in the latter catchment. wheras the percentage contribution of baseflow to total flow is larger in Meki (38%) than in Wabe catchment(32%). Similarly, the flood flows of Wabe catchment(476.86mm) was larger than that of Meki catchment(75.70mm).

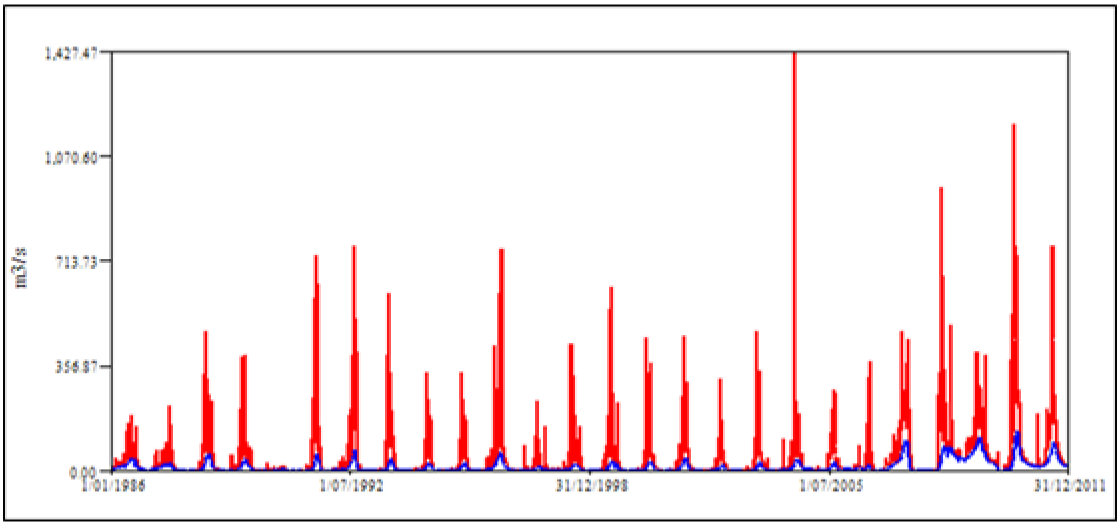


Figure 2.10 Stream flows and baseflows(m3/s) of Wabe catchment near Welkite town(1986-2011) using RAP

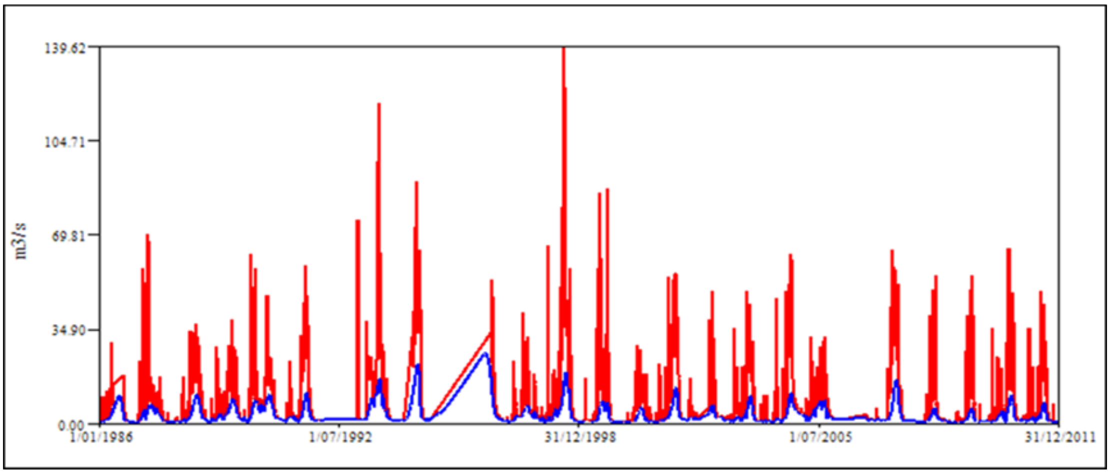


Figure2.11 Stream flows and baseflows(m3/s) of Meki catchment at Meki town(1986-2011) using RAP

Based on the same data and analysis using Timeplot tool (Figures 2.12 and 13), the baseflows computed for Meki catchment (70.47mm) was much less than that of Wabe catchment (255.32mm). The runoff computed for Wabe (259.77mm) was more than four times higher than that estimated for Mecki catchment (43.15mm).

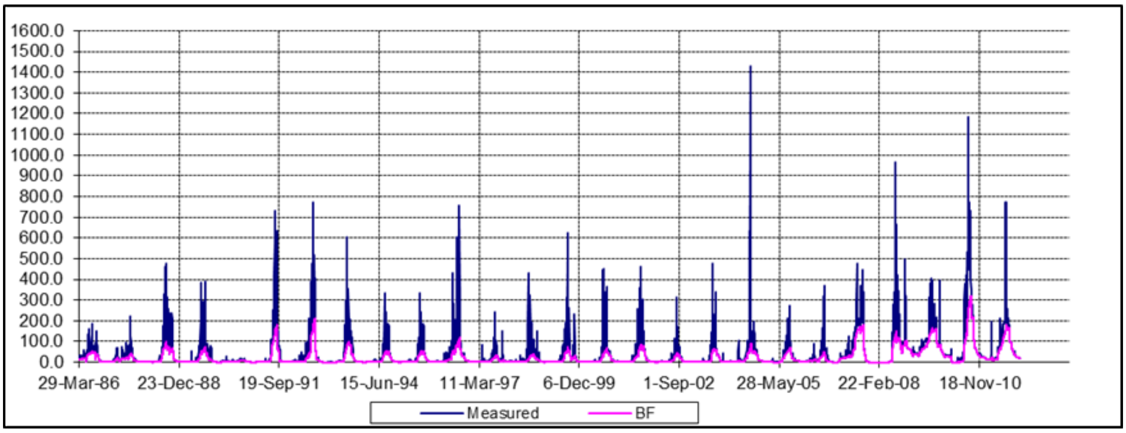


Figure 2.12 Stream flows and baseflows(m3/s) of Wabe catchment near Welkite town(1986-2011) using Timeplot

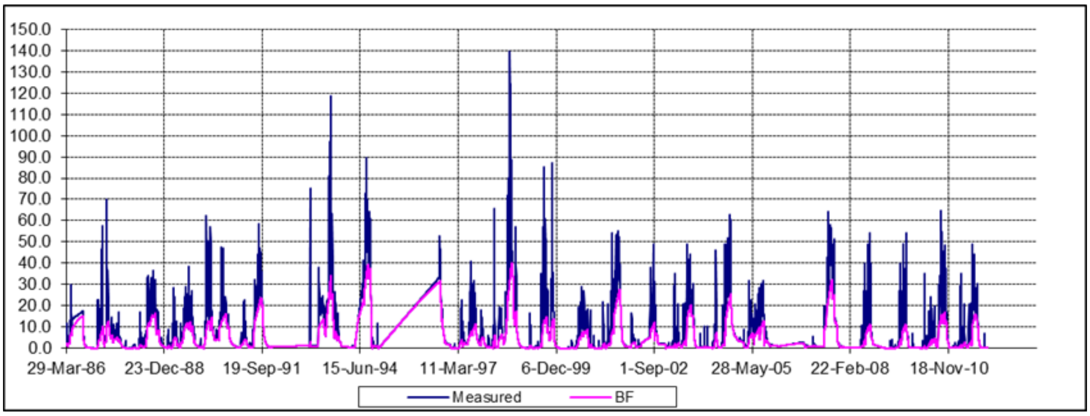


Figure2.13 Stream flows and baseflows(m3/s) of Meki catchment at Meki town(1986-2011) using Timeplot

2.4 Soil and Land use/land cover

The natural vegetation in the Wabe catchment is characterized by riverine vegetation, bushy-grass land and open grassland. One can find livestock in all vegetation types.According to AWANRDPO (2004), the major land uses of the area include seasonal(annual) field crops, permanent (perennial) crops, forest and bushland, area occupied by construction (village), grazing land, and uncultivable land (Figure 5.1). Broadly speaking, most parts of the catchments are underextensive cultivation with increased land pressure. The majority of forested areas are now confinedto landswhich are too steep and inaccessible to farm and are also situated close to rivers. The flatter poorer drained bottom lands of thecatchments are usually not cultivated but are used for dry season grazing and eucalyptustree plantations.More than 90% of the catchment is covered by FAO soil types of vertisols, cambisols and andosols.(Figure 6.1)

In Meki catchment, the land use/land cover is dominated by cultivation that covers about 60% of the catchment. This is followed by vegetation (including forests, grassland, shrubland)covers that account for about 20% of the total area. The mojority of the remaining part is occoupied by barren land and built-up areas with considerable amount of water bodies.

Its soil cover types reflect the nature of parrent material. Generally the dominate soil types of this catchment are cambisols, vertisols, luvisols, leptosols, and andosols of FAO soil classes.

2.6 Settlement and water use

The Guraghe zone is densely populated leading to high population pressure and unbalanced growth. This situation has resulted in severe erosion and environmental degradation. In the last 20 year (1994-2014) the population of this catchment has increased by significant number.The highest and the least population number are found in districts of *Enemore* and *Welkite* of Wabe catchment and and *Meskan* and *Butajira* of Meki catchmentrespectively. Guraghelima(2013) study noted that theper capita consumption of water in the areas has been found very low as compared to the countrystandard although the potential of watersources in the Zone is generaly huge.In addition to domestic purpose, irrigation is moderately practiced in both catchments.The total area irrigated in two rounds is 35,012 hectars which cover only 15% of the total crop land. The irrigation scheme uses different sources of water in which the rivers diversion and springs are the main water sources. Water use is allowed to vary from season to season and for each month in the year, and the volume of water removed is specified. Considering the assumptions that is considered in the study area, the average per capita of water for daily use is 15liters for rural areas of within 1.5km distance wheras for the towns, it is 20 liters within average distances of 500m (personal communication to experts in the water office). Accordingly, the daily water use for domestic purpose in rural areas is 13,860,105 L/day and 3,097,660 L/dayfor that of urban. The major sources of water for both urban and rural areas are springs and boreholes.

Table2.1Population of both catchments (Remark: Projected based on 2007 censususing annual growth rate of 3%. Pop= total populaation)

Catchment	**1994_pop**	**2007_pop**	**2014_pop**
Wabe	703,935	1,204,137	1,704,333
Meki	1,032,218	1791696	2,823,914

2.6 .Geology

2.2.1 Regional geology

Based on the descripions and compilations made by Davison, 1983, and Woodroofe, 1996, the geology of the Omo-Gibe basin can be sub-divided in to the following major groups of rocks, based on their age, relative to the formation of the rift valley system. These are: the Pre-cambrine crystalline basement rocks, the early 'Flood Basalts' of late Eocene to early Miocene age, a transitional series of intercalated basaltic and felsic volcanics of late Oligocene to early Miocene, a series of felsic volcanics ranging from early Miocene (pre-rift') to late Miocene ('post rift')in age, and the 'post rift' sedimentary succession of Pliocene to Holocene age .

Approximately 11% of the Omo-gibe Basin is underlain by Pre-cambrian metamorphic gneissesconsisting of felsic meta-sediments and mafic meta-volcanics that represent the older 'cratonic'granite-gneiss terrain to the west and a younger 'oceanic' to the east. The younger oceanic 'greenstones' have been overthrust to the west onto the older craton.The main thrust zone, in the Sharma region west of the lower Omo River is marked by intense shearing and cataclasis.

Approximately 80% of Omo-Gibe Basin is underlain by Tertiary volcanic rocks. Also the basinoccupies the combined Omo and Usno rift valleys which are falling out north extension of the lakeTurkana-Ethiopian Rift system. In the north part of the basin, the rivers have exploited theextensive fault zones to cut deep gorges. The eroded material has been deposited in the lowerpart of the Basin as a thick sequence of Quaternary alluvial deposits. Davidson (1983) has described the spatial distributions of various basaltic and felsic units of the basin vividly.

Accordingly, the flood dasalts, covering the central part of the basin, represent the thickest and most wide spread rock type of the tertiary volcanic sequence. They are the products of fissure eruptions and are characterized by thin, extensive flows, locally columnar jointed, or with jointing parallel to the flow layering. In places, the basalts include thin inter flow sediments, ignimbrites and minor felsic volcanics. They overlie the basal red sandstone (Paleozoic and Mesozoic) and where the sandstone is missing, they rest directly on the Precambrian basement.

The Makonnen basalt in the north-west of the basin reaches up to 700m thick sequence of columnar basalt and the Surma basalts which are massive basalt flows crop out on the Surma plain along the south-west water shed of the basin. On the other hand, the Assille Group, consists of the Fejij basalt Langaria volcano-clastics and Bakate basalt covers the south-east area of the basin.In parts of the basin the geological relationships can be established clearly. The floodbasalts are overlain by a series of more felsic volcanics although the latter includes intercalatedbasalts and pyroclastic rocks.Many small intrusions of rhyolite, trachyte, phonolite micro-syenite and micro-granite occurthroughout the basin, in the form of plugs and dykes ranging in size from 100 m to 3500 m indiameter. Both the Precambrian rocks and the tertiary volcanic succession form prominent round to conical hills that rise above the surrounding areas. These intrusive rocks appear to be co-magmatic with the surrounding felsic volcanics, however, they appear to show a wide range of ages.

The Nazaret group name is assigned to the series of rhyolite-trachyte plugs stratoid flows, ignimbrites, pumice, ash fall tuffs and characteristic lacustrine sediments containing coal and lignite deposits along the main Ethiopian Rift and adjacent plateau margins. The Nazareth group attains a thickness of 200-300m in the Ethiopian Rift, but is thinner on the adjacent plateau margins. The group crops out along the north-east water shed of the basin over a large tract of land stretching from south of Weliso to Welkite - Hosaina - Sodo and Selam Ber, the rift escarpment, which unconformably overlies the early flood basalts, with minor intercalated basalts being found at the base of the group.In the northern part of the basin, deposition of the younger sequences of the Nazareth group was accompanied by the formation of shield volcanoes of late Pliocene age on the main Ethiopian Rift escarpments (Kazmin et al., 1978, 1980).

On the western escarpment, the volcanoes of Wachacha, Yerer, Gash Megel, Tembero, Damota and others, form prominent landmarks these days. These young volcanoes are well preserved with little erosion of the cones and craters, and some contain small crater lakes. Several of these centers, Teza, Ambricho Wagebessa and Tembero, lie on a NNE alignment suggestive of formation along a major fault line. The ejecta from these volcanoes, both rhyolite-trachyte flows and felsic ignimbrites, cover the surface of the Ethiopian rift and most of the north-east watershed of the basin. The dominant rock type is a highly porphyritic trachyte with sanidine phenocrysts, which shows flow structures.

The main Ethiopian rift is characterized by active extensional tectonics and it is seismically, tectonically and volcanically active (WoldeGabriel et al., 1990). Volcanic rocks of Pliocene and Pleistocene age such as rhyolites, trachytes, and ignimbrites are abundant within the rift floor and on the adjoining plateaus (Kazmin, 1975 in Mahatsente et al., 1999).In the rift, a number of major centers of silicic volcanism occurred in relation to the zone of intense faulting (Mahatsente et al., 1999). The main trend of tectonic structures in the main Ethiopian rift is dominantly NNE-SSW direction (Mohr, 1962b in Mahatsente et al., 1999) and in some places NE-SW direction (Meyer et al., 1975 in Mahatsente et al., 1999). Woldegabriel et al. (1990) have distiniguished the geochronological sequence of the westernescarpment of the Main Ethiopian Rift valley at Gurage in to differen stratigraphic units:

The crystalline basement:This is represented by altered biotite gneiss intruded by groups of northwest trending quartzofeldspathic pegmatites. This basement around Guraghe was not dated but radiometric dates on crystalline basement elsewhere in Ethiopia ranges from 1.1Ga – 470 Ma (Asrat et al., 2001 in Meeraph H,2006).

The Mesozoic sequence: It is widely found in Ethiopia and unconformably overlies the crystalline basement in Guraghe. The Mesozoic sequence is much thinner here: 150 m of Early Jurassic Adigrat Sandstone, 20 m of variegated shale, and 30 m Of Jurassic Antalo Limestone (Arno et al., 1981 in WoldeGabriel et al., 1990). The cretaceous strata present elsewhere in the platform Mesozoic sequence of Ethiopia, is absent.

The pre-Tertiary Oligocene basaltic flows and fluvial strata: Fine-grained Oligocene basaltic flows (32 Ma.) having 40 to 60 m. thickness are overlain by fluvial strata of 2 to 10 m.

Pliocene basalt flows, crystal rich welded tuff and ash fall tuffs: The pre-tertiary rocks, the Oligocene basalt, and the fluvial strata are unconformably overlain by a thick sequence of Pliocene basaltic flows of 4.2-2.5 Ma. age and by a crystal rich welded tuff having a thickness of 200-250 m. and age of 3.2 Ma. A number of Late Pliocene ash fall tuffs having an age between 3.72 and 2.59 Ma. cover the sequence.

WoldeGabriel et al. (1990), summarized the sequence of volcano-tectonic events that formed the western rift margin at Guaghe, receding from old to young as in: Block faulting and tilting of pre-Tertiary rocks and mid-Oligocene basaltic eruptions, Sedimentation and faulting, Eruption of thick, late Miocene, flood basalt, Late Miocene faulting, eruption of an 8.3 Ma. Ignimbrite and Pliocene flood basalt and ignimbrite formation and Plio-Pleistocene faulting.

2.2.2 Local geology

The geology of the study area for this work was mainly based on the regional works of Davidson et.al (1983), Merla G et.al,(1973) and Mengesha (1976). Observations of river cuts, quary sites, and exposed areas during field works were also considered for modifying their works to down scale for the research area. Except for Wabe catchment, more detail geological works have been done by different researchers and instituitions and are available for Meki catchment.

Lithologic units and geological structures are the major factors in characterizing the hydrogeology of the catchments. In order to understand the hydrogeology (geology) of the areas and characterize them, field visit was carried out and various hydrogeologic features were observed and identified. The main lithologic units(Figure 2.14) that are outcropped in the study area comprise of teritiary volcanics as well as quaternary volcanics and sediments.Theseunits aredescribed below.

i. Jimma volcanic(lower)

It comprises flood basalts with minor salic flows of late Eocene to late Oligocene. It is a very extensive unit covering most parts of the southwestern highlands. In the study area, it is out cropped in the western part, around the confluence of Wabie and Gibe rivers. The basement rocks generaly underlie it, but in few places the Omo basalts are underlying (Merla G et.al,91973). According to Tefera et.al(1996), it is correlative to Magdala group and this unit reaches a thickness of several hundred meters.

ii. Tarmaber Megezez formations

They are composed of alkaline basalts of middle Miocene which erupted from shield volcanoes. They consist of basalts with tuffs, scoraceous lava flows and paleosoils. They overlie the Jima volcanics and occupy small parts of the Wabe catchment and the units are distributed in association with fractures on Gurage ridge.

iii. Nazareth group

The group name is assigned to the series of rhyolitte-trachyte plugs, stratoid flows, ignimbrite, pumice, ash, tuffs, and characteristic lacustrine sediments containing coal and lignite deposits along the MER and adjacent plateau margins. According to the classification based on the ages of the units made by Davidson, (1983), the Nazareth Group is classified as the age of Miocene to Pliocene and it is cut by fractures and faults of variable sizes and it is the dominant unit that widely covers both catchments. It attains the thickness of 200-300m in Ethiopian Rift, but is thinner on the adjacent plateau margins.

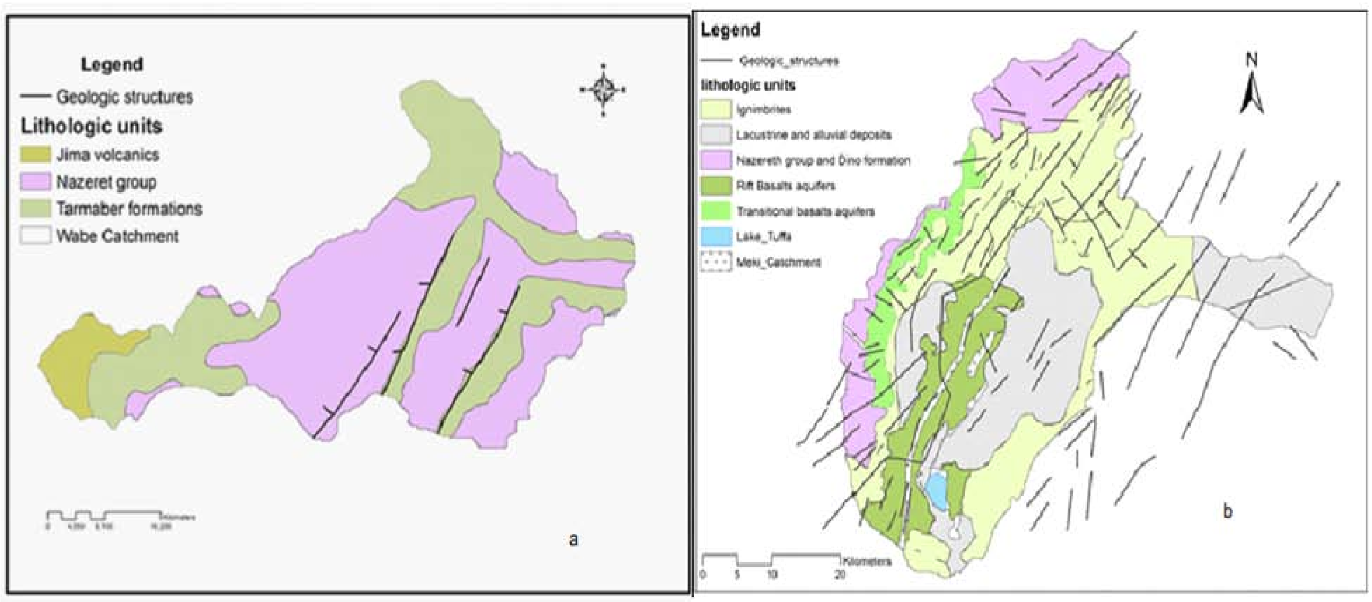


Figure 2.14 Geologic map of Wabe(a) and Meki(b) catchments(adopted from Tefera et.al.1996 and Kazmin et.al.,(1981)

iv. Dino formation

It is composed of pliestocene ignimbrite, tuff, coarse pumice, water lain pyroclastic rocks with rare intercalations of lacustrine sediments. According to Tefera et al,(1996), Its possible thickness reaches 50m. This formation covers extensively the Meki catchment and it is overlain by alluvial deposits. The major faults seem to bound this unit and the Nazareth group.

v. Alluvial and lacustrine deposits

They are quaternary undifferentiated sand, silt, clay, diatomite, and beach sands. They cover some parts of the Meki catchment mostly along the streams. Lacustrine deposits in the study area occur in two areas. The large part is the Ziway plain deposit and the second one, which is composed of lacustrine, alluvial, and pyroclastic deposits, forms the Kuntane-Inseno-Kela plain fan and talus deposits occur in the Butajira crescent and along the pediment plains of the escarpment (Ayenew,1998; HALCROW,2008;EWTC,2008)

2.2.3 Geological structures

The geological structures (Figures 2.14) of this area areassociated with the tectonic events that formed the Main Ethiopian Rift, the Wenji Fault Belt, volcanism and collapse structures and Holocene faults. The present symmetrical rift was fully defined by 3.5 million years when a paroxysm of ignimbrite of the Munisa crystal tuff erupted from large caldera located on the rift floor (Caroline et al., 1999 cited in Dereje,2011). This is followed by a line of hundreds of young faults and volcanic centers along the rift floor close to the eastern escarpment initiated around 1.6 million years known as the Wenji Fault Belt (Mohr, 1971). In the western escarpment, fault lines oriented in W-NW direction cut the main NE and N trending fault systems of the MER. In Butajira area fault systems(Figure 2.3) form semicircular depression. This has resulted in the crescent shaped Butajira plain. The shape of the faulted basin and the transverse faults cutting the general NE trend of the MER in Butajira area indicates that the Butajira area is a tectonic collapse or caldera. Recent basaltic and cinder cones have erupted following the MER fault trend, which separated the Butajira–collapse structure from the Inseno-Kela plain. Therefore, the sediment fluxes from the western escarpment mainly coarse sediments remain in the Butajira-Crescent, while very fine and limited sediment reaches the Kuntane swamp(Dereje,2011). From hydrogeological perspectives, these faults and fractures are observed affecting the hydrogeologic conditions of both catchments. This effect is largely manifested in Meki catchment where the roles of these structures were challenging the applicability of the SWAT model in this geological setting. In these catchments, most of the boreholes and springs with good yields are located along and nearby the faults and fractures.

CHAPTER THREE

3. METHODS AND APPROACHES

3.1 Introduction

Through comparative analysis techniques, possible impacts of land use/land cover changes on hydrologic factors of the catchments have been analyzed with in the context of the existing land management problems and their adjecent location to one another.In addition, in order to understand the groundwater conditions and generate groundwater related SWAT inputs, the catchments have been characterized hydrogeologically.

The comparative analysis focuses both on differences and similarities of the catchments. In this approach, the two basic ways of organizing paper body- a text-by-text and a point-by-point schemes have been applied in an appropiate situation(Walk,1998).

The following methods are integrated and applied to meet the objectives of this study. These are Remote Sensing, GIS, SWAT hydrological model,and hydrogeological techniques. Most of the primary data were collected from field visits andUSGS satellite imageries. Similarily, the secondary datawere gathered from previous studies conducted in the study area, database, and technical reports prepared by different organizations. The details of these methods and approaches are given in Figure 3.1

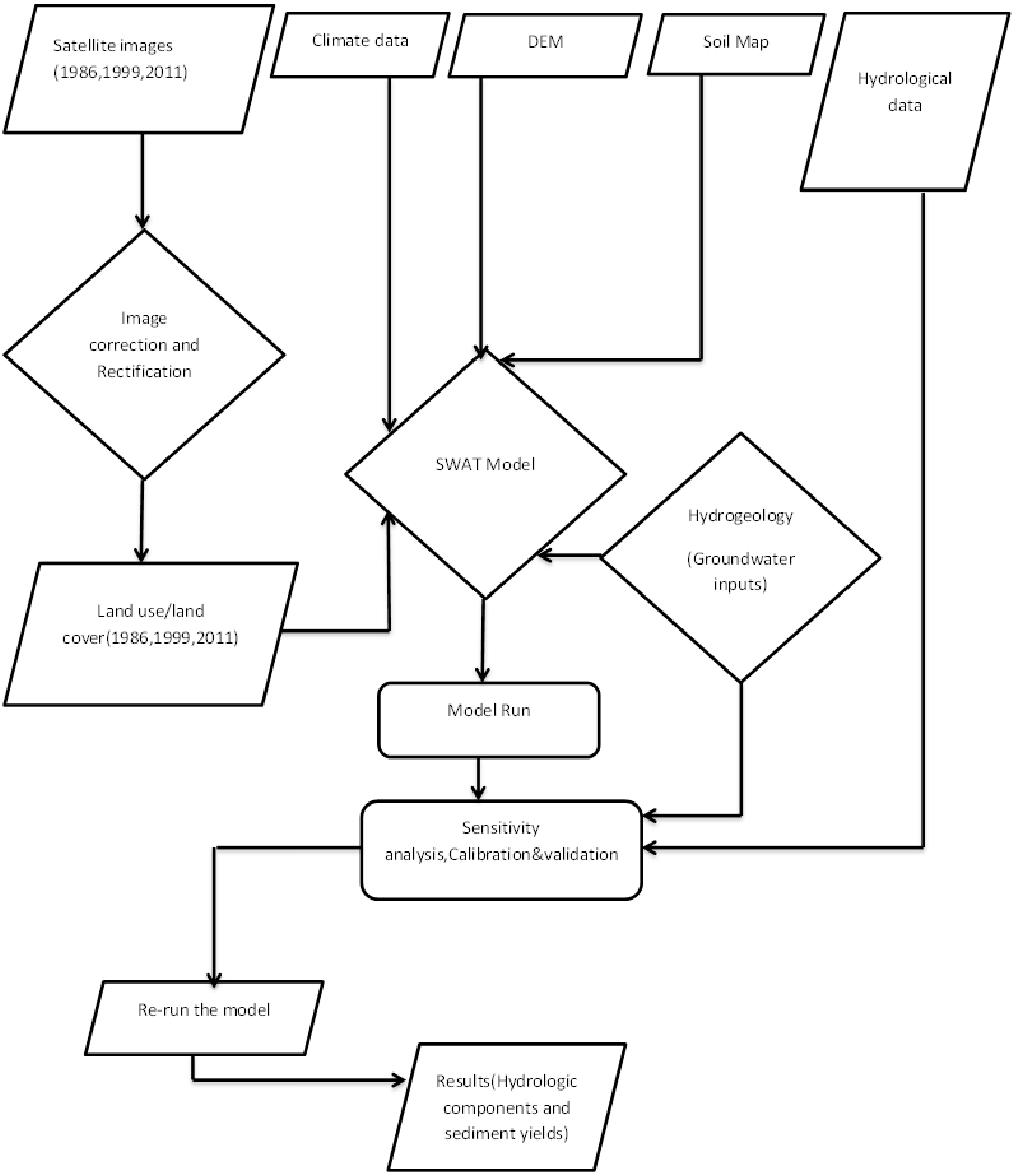


Figure3.1: Flowchart showing the methodology

3.2 Remote Sensing and GIS

Remote sensing imagery technologies and applications are based on photogrammetry and photo interpretations. In this study, land use/land cover changes of the catchments are classified and evaluated using remote sensing(ERDAS software) and GIS. In order to assess the impacts of land use/land cover changes on the hydrologic factors, multitemporal satellite data were gathered. Here, information which is utilized to analyze the changes of a certain area has been gained by looking into images of the same area repeatedly. Considering these issues and other historical conditions, inorder to investigate the spatial and temporal variability of the land use/land cover changes of the catchments and their subsquent effects on the hydrologic components, three periods of satellite images were selected. These are Landsat TM and ETM+ of 1986, 1999, and 2011.

Table 3.1: Description of landsat imageries

Sensor	Spatial Resolution	WRS Path/raw	Date acquisition
Landsat TM	30m	168/054 and 55 and169/055	February, 1986
Landsat 7 ETM+	30m	168/054&55 and 169/055	February, 1999
Landsat7TM/ETM+	30m	168/054&55 and 169/055	February, 2011

Prior to selecting these periods, attempts were made to identify and relate the images with the physical condtions observed in these times. On top of that, the objectives of this study and existing problems in the catchments were another considerations that were used as background. From the 1986 image, it has been possible to identify and assess the status of land use/land cover immediately after the 1984/85 drought and famine that hit some parts of the country, particularly areas of catchments. During the second period (1990s), the incumbent was already in place which gave rise to changes in socio-economic activities. In the year 2011, and close to this time, there were various changes and developments in Ethiopia, specifically in the catchment under study.These include the beginning of new millennium of the country which also necessitated various initiations in the economy of the country. In connection with this, new practices such as soil and water conservation measures in few districts of the study catchment area, and small-scale irrigations, especially using Meki and Wabe rivers and their tributaries were introduced. These practices were taken into consideration as factors (confounding conditions) in the process of this study.

The Landsat images of these years for study catchments were downloaded from the Earth Explorer-USGS archive (at https://earthexplorer.usgs.gov/login/). During downloading process, imageries of similar season of anniversary dates were considered to minimize reflectance variation of features that might be caused due to seasonal variation and sun-angle differences

Based on the nature of the classification problem it requires, the appropriate remotely sensed and ground reference data were collected. These images had been corrected and rectified geometrically and radiometrically before the various image enhancement techniques which improve image classification were applied. Successful mapping depends on knowing what the characteristics of each land cover type is, and using that information to define the appropriate classification methodology (King,2002).Sometimes, it is advisable to use more than one image classification methods. In connection to this, kowledge of the environmental conditions during image analysis and interpretation would help to relate each spectral classes to its inherent feature and improve classification accuracies. Different earth features can have similar pixel values if we fail to consider various conditions at which a certain feature may exist. Thus, during training site identifications for supervized classification, it would give the opportunity to learn what is actually represented by image reflectance and pattern. During classification (supervized), the images were evaluated to understand the changes with in the period of consideration and toextract thematic information. Before these results are ready to input into the SWAT model and analyze their effects, accuracy assessments were done to attain allowable quality assurances.

The applications of GIS and Remote sensing in hydrological system analysis become wide and variable. It ranges from simple presentation of results to advanced functions that incompass mathematical and statistical modeling. In most studies the conceptual models essential for the backbone of the investigations, need to be quantified. It is not sufficient to know where water is stored; amounts, quality and fluxes also need to be known. Here again the techniques combining RS, GIS and simple models can be used to estimate fluxes. Mapping units can be based on geomorphology, geology, soils and vegetation. Some of the components of the hydrological cycle, such as actual evapotranspiration and groundwater recharge potential, may be estimated for different mapping units(UNESCO,2004). In developing countries like Ethiopia, most hydrogeological investigations have been done using the conventional techniques with limited use of the low cost application of Remote Sensing and Geographic Information System (GIS).

Systematical organization of data on the terrain characteristics, evaluation of inter-thematic and interclass dependencies and variability operating in nature, analyzing their cumulative effects on the development of hydrologic regime is the best approach which the current situation requires. This can be achieved by generation of the thematic information on the governing factors through integration of remote sensing technique , GIS and Multi-Criteria Decision Evaluation (MCDE) techniques with conventional methods.

Satellite remote sensing and photogrammetric provide efficient data and effective method for groundwater exploration. These tools provide up-to-date information on spatio-temporal variation basis for the area under investigation particularly, ET, land cover/land use, geology, general topography, the presence of surface water and drainage system.

In hydrology, the four GIS functional components, namely, preparing data input, storage and management, analysis and interpretation, and presentations are commonly used in variousstudies. Hydrological models may be directly programmed in the GIS, or be linked to the GIS, facilitating the preparation of input files for the model and serving as a post processor to display the results of thecalculated models done by the model(UNESCO,2004)

Unlike other decision support systems, GIS provides capabilities to handle and perform functions on both spatial and nonspatial data. This is another advantage of using GIS for this research as the applications of SWAT model heavily rely on GIS environment. Among advanced GIS functions, geostatistical techniques are applied in determining hydrogeological parameters and characterize their spatial variability and correlations.

3.3 Hydrological modeling

SWAT model is a continuos time and distributed parameters hydrological and water quality model.The model is developed to simulate the effect of land management practices on water, chemicals, and sediment movement. It is applied to analyze the effects of LULC changes on surface runoff, baseflow, and groundwater recharges of the catchments. It was also used to assess the effects of various land management practices on sedimentations and soil erosions. The SWAT model is also applied to predict flows as a result of the future LULCC assuming the current rate of changes proceed. Generally, the output from the model helps set up conditions for considering appropriate intervention mechanisims in the catchments.

3.4 Conventional Hydrogeological Investigation method

The primary and secondary data required to conceptualize and understand the overall hydrogeological conditions of the study area were collected from fields and various sources of secondary data. During field visit, observations were made ongeological, physical and hydrological components with a view to obtaining information on the groundwater and surface water conditions of the catchments. These are geological and geomorphological data, the degree of weathering and status of outcropped rocks, local geological structures and stratigraphic position, estimating the thickness of the superficial materials, drainage conditions, water samples and hydrological features such as lakes, rivers, springs, irrigation canals; and other relevant information. Using data from the field and secondary data, especially from technical reports and pumping test data, it was attempted to develope a database in geodatabase component of GIS. Based on this database, aquifer types and extents, and aquifer properties such as transmissivity, hydraulic conductiviyt and storagecoefficient, were estimated.This database was also utilized in combining the aquifer classes and the lithologic units into various hydrogeological units with different level of productivity and extents.

CHAPTER FOUR

HYDROGEOLOGY

4.1 Introduction

The hydrogeology of a particular area is mostly determined by geology, geomorphlogy and climatic conditions. The document compiled by MWIE (2003)indicated that the hydrogeology of a country is characterized by regional factors such as geological processes (the swell, rifting and volcanism), the stratigraphy of alternating pervious and impervious formations, the development of secondary porosity and permeability through the fracturing and jointing of rocks and, the development of thermal groundwater and steam,mostly associated with rift valley. These factorsare ground to be putting serious impact on characterizing the challenges and problems in the catchments and the hydrogeological conditions of the study area.

In these catchments, the occurrence and movement of grounwater is strongly governed by topographical settings,lithological units and geological structures (Ayenew,2002). The main hydrogeological properties that have been used to characterize the catchments areporosity, yield and hydraulic conductivity. Due to the differences in mineralogy, texture and structure of volcanic rocks, water bearingpotential also varies. Groundwater circulation and storage in the volcanic rocks depend onthe type of porosity and permeability formed during and after the rock formation. All rockstructures possessing a primary porosity may not have necessarily permeability. In other words,without the original interconnection, the primary porosity may not give rise to the primarypermeability, but the latter’s connection, by means of weathering or fracturing may give rise to asecondary permeability(Alemayehu, 2006). The spatial distribution of the hydraulic conductivity of the area is highly variable due to the differences in geological settings. This section discusses the hydrological and hydrogeological features of the catchment so as to characterize and understand the hydrogeological conditions of the catchments. In addition to this purpose, the hydrogeological characterization of the catchments was used in determining the groundwater inputs of the SWAT model.

4.2 Catchment hydrology

The main water sources of the catchments are boreholes, springs and rivers althoughsmall contributions from few small lakes and ponds are also available.A number of small streams and few perennial rivers drain the area. Wabe river, one of the major tributaries of Omo-Gibe river basin,joins this river in the vicinity of Welkite town. Among the main tributaries of Wabe river, Kereb, Demekash, Gogn, Cheika, and Legedima rivers are perennial rivers that sustain the Wabe flows during dry period. The main source of these rivers is from the northern and eastern parts of the catchment. Both the majority of large discharge springs and these rivers are being used for irrigation purpose in recent times. When compared to tributaries of Meki(Weja, Irenzaf, Atamuja), the tributaries of Wabe river are less affected by human and natural conditons and hence higher discharges are observed at Wabe catchment(Figure 4.1). Based on data from baseflow analyzed for river discharges of the catchments, it was observed that there exists significant interactions between surface water and groundwater(section 2.3) in both catchments.In turn, this condition has significant effects in the determination of the groundwater related parameters of SWAT model inputs.

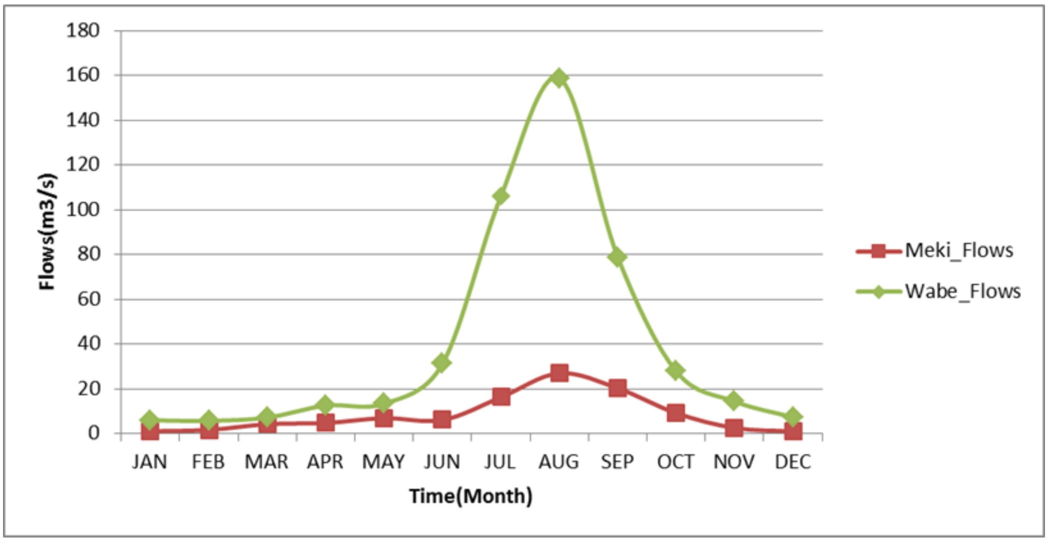


Figure 4.1 Long-term(1986-2011) average monthly flows of Meki and Wabe rivers

Concerning surface water,springs(Figure 4.2) seem typical characteristics of the Guraghe ridge in which high discharge springs are common in both eastern and western directions of the ridge.In Wabe, the majority of the high discharge springs are found to the west and few of them are in the southernand easternparts of the catchment. Some springs are clustered in western parts of the catchment and are associated with the dissected land forms of this region.

Table 4.1 Summary of spring discharges of the catchments

Wabe catchment		Meki catchment
	Q (l/s)	Q (l/s)
Maximum	33.00	78.00
Minimum	0.04	0.10
Mean	2.33	5.42
STD	5.64	13.82

Most springs of this catchment are hardly associated with its geologic structures. Therefore, it is likely that the origins and types of these springs are dominantly related to land forms and lithologic contacts.Observations during field work also indicated that few springs are observed following a certain alignment. However, this couldn't show to be necessarily related to structures. Two springs are observed to be associatedwith geologic structures. Thus, in general, springs of these catchments could be related to either geologic contacts or to geologic structures and mostly classified as contact and fracture type springs. The contact springs emanate from beneath thick coverage of ignimbrites and superficial deposits. They provide water only during wet season and their disharge is relatively low. The other springs are of fracture type and emerged from fractures, and faults showing little seasonal variations and yield more water (Table 4.1).

The water sourceof most of these springs could be associated with both local recharge and recharge from the Guraghe ridge. The waters that infiltrate in the highland areas, moving laterally beneath the thick clay soils could feed some of these springs.

However, most springs of Meki catchment are found in the western part of the catchment and seem to have association with the geologic structures. In addition to such difference, springs ofhigher dischargeare found in Meki catchment. They are often used for irrigation practices in addition to domestic purpose. The typical ones are springs that are developed around Meskan (Butajira) areas and yield up to 78 l/s. The main water source of these springs is largely related to recharge from the Guraghe ridge.

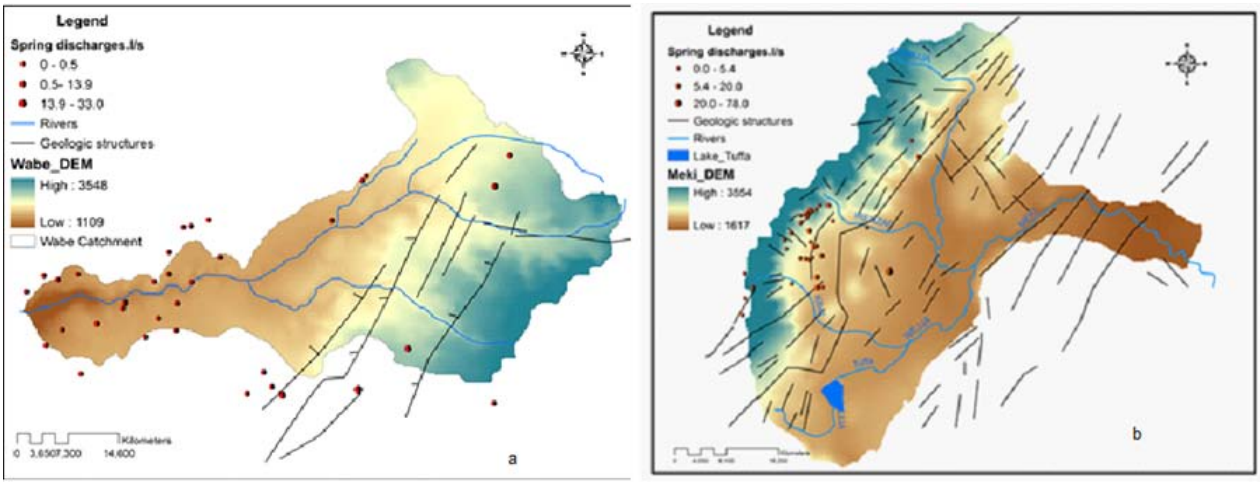


Figure 4.2Springs distributions and variations of their discharges in relation to geologic structures of Wabe(a) and Meki(b) catchments

4.3 Hydraulic properties

Determining the hydraulic properties of the aquifers in the study area are based on data collected and organized from different sources. These include pumping test data, existing database, drilling reports, geologic map, hydrogeological map, soil map, lithology obtained from well logs, aquifer thickness, water table depth, structures and surface water features. Based on these data, the spatial distribution and nature of the aquifers in the study area can be categorized. The spatial distribution and magnitude of hydraulic properties of the aquifers in Meki catchment have been studied by different researchers and companies.However, in the case of Wabe catchment, as far as my knowledge is concerned, hardly any study has been conducted to determine its aquifer hydraulic properties. Hence, their determinations are grossly relied on the sources of data presented in the above paragraph, particularly the drilling reports from various boreholes.

Most technical reports compute and provide transmissivity rather than hydraulic conductivity. However, by the time hydraulic conductivity was gained from some sources, the challenge was in working out the values of saturated thickness to compute the transmissivity. Consequently, the values of the saturated thickness was obtained either from geologic logs of the wells or from screen lengths. Although the use of the later approach has produced errors as a result of under or over estimations,the general saturated thickness for unconfined aquifers is the depth from the water table to the base of the aquifer. On the contrary, for the confined aquifers, the saturated thickness is equal to the physical thickness of the aquifer between the aquicludes above and below it. The same is true for the confined parts of a leaky aquifer bounded by an aquitard and aquiclude. In these cases, the saturated thickness is constant through time because the position of the water table changes over time while the saturated thickness of unconfined aquifer is not constant over time.

Based on the given pumping test data and field observations, the potential aquifers were identified (where it was not clearly identified) from geologic logs and by adding the thickness of each candidate lithologic unit for potential aquifer,the total saturated thickness was determined. Where transmissivity values were computed using appropriate model, the hydraulic conductivities were calculated directly from the transmissivity and the saturated thickness. However, there were occasions in which the transmissivity was not computed. In such cases, transmissivity values were obtained either from literature review of the previous studies or from similar aquifer characteristics available elsewhere in the country with analogous geologic units.

In Wabe cachment, the high values of transmissivity are characteristics of geologic formations which cover the small portion of the southern part of the catchment. Most of the geologic structures of this catchment correlate with the intermediate values of transmissivity. They cover larger parts of the catchment which include the southern- central and southeastern parts of the catchment. These characterize somelithologic units from both Nazereth group and Tarmaber formations.

The western, northern, and northwestern parts of this catchment have shown relatively low values of transmissivity. These areas are composed of some lithologic units from Jima volcanics, Tarmaber formations and Nazereth groups.

In Meki catchment, the high values of transmissivity in rocks, which cover the west-central parts (Figuer 4.3), dominantly correspond to basaltic aquifers. Relatively speaking, lowertransmissivity values characterize lithologic units from Tora-Koshe ridges, rocks which are found in the southwestern part of Butajira and northern parts of Bui. These rocks are mostly parts ofthe aquifercharateristicsof lithologic units of ignimbrites, and lacustrine andalluvial deposits.

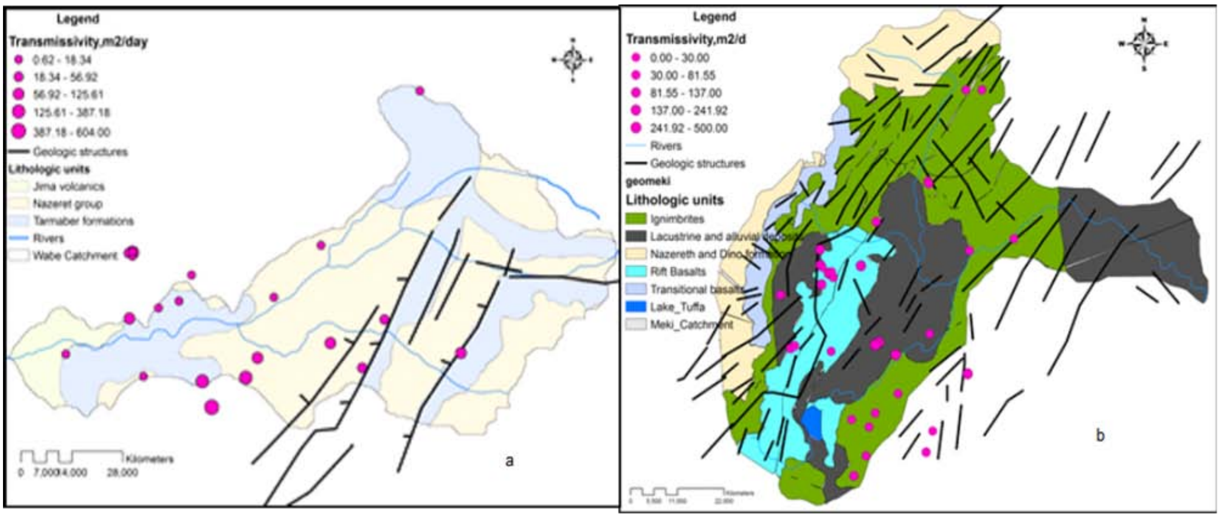


Figure 4.3 Transmissivity variations of Wabe (a) and Meki (b) catchments

The intermediate values of transmissivity are observed in lithologic units which covers large parts of the catchment and correspond to aquifers from the northern and western ignimbrites, some parts of lacustrine and alluvial deposits, and, ignimbrites from southeastern part of the catchment. These are densely populatedareas characterized by high agricultural activities utilizing water resources of the catchment. Most parts of the intermediate values and few areas of higher values of transmissivity are correlated with geological structures of this catchment.

By assessing the transmissivities variationsand distributions in the lithologic units of the catchments, it is posible to coclude that these variations are mostly related to the geological settings of the area. This situation was also stated and associated with the characteristics of the fractured volcanic sequences(Ayenew, 1998).

This would also indicate large local variation of the hydrolgeologic properties of the lithologic units in the catchments. Most of the higher values of transmissivities are observedin aquifers from Wabe catchment than from Meki catchmentin which higher values are prevalent in the vicinity of the geologic structures. In the Wabe case, the higher values are mostly related to the aquifernature of the lithologic units rather than the geologic structures. This is not to undermine the roles of the geologic structures in the intermediate values of transmissivity in both Meki and Wabe cachments. This can also be evidenced by the presence of many and high discharge springs that are found in the Wabe catchment which are hardly related to these geologic structures.

The hydraulic conductivities that were obtained and computed for the aquifers of the catchments showed that the aquifers of the Meki catchment have larger mean K values(about 2.32m/d) than those (0.86m/d) of the Wabe catchment. The presence of larger values could be attributed to lithologic units and geologic structures in the Meki catchment. Observations made during the field works showed that the geologic structures of Wabe catchmentwere mostly filled with less permeable materials than those found in Meki catchment. In addition to this, most of the boreholes in the latter were well correlated with the faults and fractures that exist in the catchment.

4.4Groundwater level and movement

Groundwater levels and flow directions are estimated based on data obtained from different sources (appendix-4). The groundwater level was computedon the basis of ground elevations of the well location and the water levels observed (and obtained) from wells (whether it is shallow or deep) that are found in the cacthments. In general, it is the balance beteween recharge and discharge that controls the groundwater levels of these wells. Often, water levels are observed below ground surface. However, there are situations in which the water level is observed above ground surface.

Groundwater flows from areas of recharge to areas of discharge and the areas between the two usually considered as intermediate zone. Discharge may happen to the atmosphere, to rivers, lakes, and other surface-water bodies, or to pumping wells. Based on the well construction traditions in Ethiopia, it would be very hard to associate the water level determination to a particular lithologic unit as the screen is often placed at different depths of the borehole. Hence, the water levels, and in turn, the generated groundwater contours are usualy assumed to represent the groundwater conditions in the aquifer(s) that surround the wells.In this case, the the Static Water Level (SWL) was subtracted from the elevations in order to get the groundwater levels above mean sea level. A SWL is a stable water level in a well not affected by withdrawal(pumping) of ground water. This water level is cheiflya manifestation of the surrounding aquifer conditions(Oregon WRD, 2009). Due to inconveniences during the field work, water level observations were made only in few boreholes. Hence, most of the water levels data were obtained from technical reports and other sources.

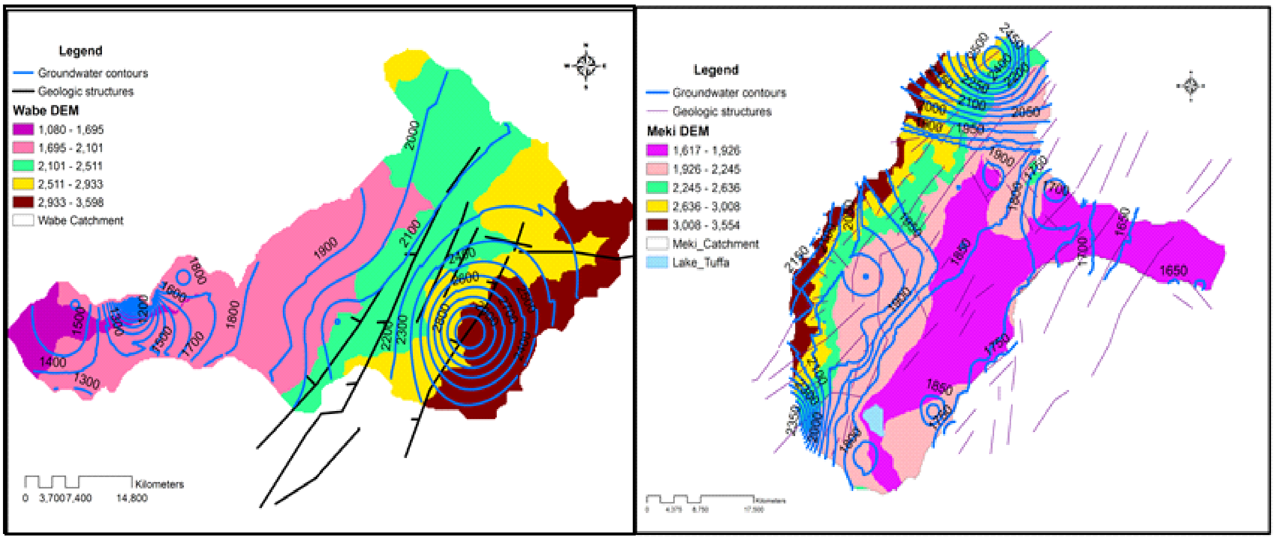


Figure 4.4 Groundwater contours of Wabe (a) and Meki(b) catchments(Remark: The groundwater countours are established based on very limited head observations. Hence in mountainous area the contours may not be as such realistic).

In Wabe catchment, the groundwater contours (Figure 4.4) of the water-level elevations vary across the study area in different lithologic units. For instance, in Nazeret group formations(beneath the recharge zone of the eastern and southeastern parts of the catchment), this variation ranges from more than 2900m to 1700m. Wheras, in Tarmaber formation this range lowered up to 1400m in the western part of the catchment. In Jima volcanics, the goundwater contours range from 1500m to 1300m.

Thus, one could conclude that differences in water-level altitudes within theselithologic units(continuous aquifers) can reach up to 1600m between recharge and discharge areas of the catchment.

In relation to specific localities of the Wabe catchment, the water level contour shows the general decrease from *Weliso*(northern) areas towards *Tawula-Welkite*.In addition to this, starting from *Welkite-Gubre* towns, it also shows an increase in waterlevels towards*Mehalanba-Hawariyat-Agena* towns in the eastern and southeastern parts of this catchment.This trend even continues until *Kechen kebele* of *Muhur Aklil*district where the highest water levels were observed. In the east-west direction, the water level contour indicates the general decrease from the southern part of Guraghe ridge towards the confulence point of Wabe and Omo-Gibe rivers following the topographic variation ofthe catchment. Based on the water level contours,observations made during field data collections and discharges from boreholes and springs, the groundwater flow directions are conceptualized. Accordingly, two flow directions are expected. The first is from *Weliso* areas(northen) towards *Tawula-Welkite(*western) indicating that this area is one of the recharge sources in the catchment. The second one is the main flow direction and expectedfrom southeastern and Guraghe ridge towards the western and northwesternparts of the catchment. In addition to the high discharge springs, recently, drilling of boreholes that provide high discharges were undertaken very close to thesewater source areas (southeastern). These arethe main sources of water for people living in theseparts of the catchment. They are also being used for irrigation purposes in some places of the catchment. In any case, this implies that the Guraghe ridge is one of the main water source in the catchment.

In Meki catchment, the groundwater contours (Figure 4.4) generally vary across the study area. In relation to specific localities and lithologic units, the contours range from more than 2500mup to 2000m in Nazeret group formations and from 2300m to 1700m in ignimbrite rocks.However, in lacustrine abd alluvial deposits, it varies between 2100m and 1600m.

In rift and transitional basalts, the groundwater contours are observed showing the range from 2100m to 1800m. Some of these observations are made in areas beneath a recharge zone that is adjacent to the escarpments and the others are in the areas of discharge.

In relation to specific localities, the water level contour shows the general decreases from Kondaltiti-Bui (Northern) areas towards Butajira(Central). Begining from Butajira-Kibet, it shows increases in water levels contours towards south west and this trend stretches until the catchment boundary. In this part, the contours are observed as the extentions of some contours from the southeastern part of Wabe catchmnet indicating a cerain form of inter-catchment water transfer. This could be used as the initial insight for further investigation. In west-east direction, the water level contour indicates the general decreases from the Guraghe ridge and escarpement towards lake Ziway following the topographic characeristics of the catchment. Based on the water level contours, field observations and discharges of springs, it can be highly deduced that the groundwater flow directions are from Kondaltiti-Bui towards Kela-Butajira indicating that the area is one of the recharge sources in the catchment. In addition to the main flow direction which is from Guraghe ridge and escarpement towards

Lake Ziway. There are also local flow directions from Tora-Koshe and southwestern towards the low lying areas.

In both catchments, the groundwater level contour varies from flat to steep slopes(Figure 4.4). Areas that include relatively flat slopes incude south of Butajira, Meki-Ziway (Meki catchment),and Tawula-Welkite(Wabe catchment). Steep slopes are observed in localities of Kondaltiti-Bui, Kibet-Arekit (Meki), Jembero-Arekite(Wabe), and areas surrounding the ridge. The water levels of the remaining localities in the catchments show gentle slopes. In general, groundwater flow directions in both catchments are observed imitating the topographic settings of the Guraghe ridge and the rift.

4.5Groundwater recharge

Recharge is the volume of the water that joins the saturated zone of the aquifer. It is a term used to describe many of the processes involved in the addition of water to the saturated zone (Wilson and Miller, 1978). Groundwater recharge to the aquifer may occur naturally from precipitation, rivers, canals, lakes, and /or as human induced phenomena (irrigation, urban recharge). Recharge could also be direct, indirect or localized based on the source and mechanism by which water reaches the water table. The quantity and type of recharge depends on topography, geology, climate, soil zone, land use and cover, drainage, geographic location, vegetation, and structure, among others.

The Guraghe ridge and the rift escarpment are the main source of recharge in the study area. These areas receieve the highest recharge due to its high amountof precipitation, chain of mountains and escarpment slopes which situated vertical to steep slopes and strongly dissected. This facilitates infiltration instead of runoff.The fractures and faults that are found in both sides of the ridge have significant contributions in recharging the aquifers. The number of springs(being most of them are descending)that emanate in these areasare good evidences for the replenishing roles of the Guraghe ridge and geological structures.

For instance, assuming the baseflow as representation of recharge, the baseflow determined for Wabe catchment using Timeplot tool indicated that the baseflow decreased from 14.29m3/s between 1986 and 1999 period to 13.20m3/s in the second period(1999-2011). In contarast to this method, the Baseflow Index(BFI) computed applying RAP technique showed an inacrease from 0.25 in 1986 to 0.27 in 2011. Unlike these two methods of baseflow computing, the SWAT model considering explicitly the physical characteristics of the watersheds and it estimated the baseflows that showed insignificant changes to be370mm, between 1986 and 1999 which declined to 352mm in 2011.In the case of Meki catchment, the baseflow calculated using Timesplot software shows that the baseflow decreased from 4.94m3/s between 1986 and 1999 period to 3.67m3/s between 1999 and 2011.In the same manner, the Baseflow Index(BFI) computed applying RAP technique showed a decline from 0.39 in 1986 to 0.25 in 1999 but showed a slight increases to 0.26 in 2011. The baseflow determined using SWAT model for this catchment estimated a value of 322mm in 1986. This value decreased to 106mm in 1999 but increased to 216mm in 2011.

This indicates that the recharge of both catchments(as computed by Timeplot and SWAT model) generally showed a decreasing trend between 1986 and 2011which expresses the impacts of land use/land cover over this period.

Table 4.1 Recharges (mm) and Baseflows (mm) of Wabe and Meki catchment using SWAT model

	Wabe catchment		Meki catchment	
Year	**Recharge**	**Baseflow**	**Recharge**	**Baseflow**
1986	401.87	370.20	232.49	215.74
1999	401.96	370.24	76.38	71.38
2011	382.10	352.19	155.44	144.72

4.6Groundwater discharge

Groundwater discharge is the release or flow of groundwater from the saturated zone or aquifer to the surface through streams, rivers, lakes, springs,and oceans.Groundwater is removed from aquifer system in different forms and these include abstraction of water wells, springs, baseflow to surface water body, inter basin or aquifer system transfer and evapotranspiration. Groundwater outflow to streams occurs as springs and seeps. Well yields in Meki catchment vary from 0 to 10l/s, however, in Wabe catchment there are fewwells that give up to 25 l/s. In the same way, spring discharges from these catchments range from 0 to 60 l/s in which higher discharges are found in Meki catchment. Another means by which groundwater is removed from the catchments is through consumptive water use. Consumptive water use is a management tool that removes water from the basin. This can be removed from shallow aquifer, deep aquifer,streams or ponds within the subbasins of the watershed. Generaly, this removal can be for domestic or agricultural uses. Considering assumptions that set by concerned bodies in the study catchments to estimate the amount of water use, the average per capita of water for daily use is 15L for rural areas of within 1.5km distance and 20L for towns, within average distances of 500m, according to experts working in water office. Accordingly, the average daily water use for domestic purposes in rural areas is 13,860,105 l/day whereas for that of urban areas it can reach to 3,097,660 l/day. This entails that the major source of water both for urban and rural areas are springs and boreholes.

4.7 Hydrogeologic units

There has been experiences of grouping different lithologic units into hydrogeologic units mainly depending on the hydraulic properties of these lithologies. Ayenew (1998) described the combination of different geologic formations into hydrostratigraphic units regardless of their local variations. In similar context, Cherinet (1990)noted that the different geological units of the country were grouped into dominant permeability types such as intergranular, fracturae, and fracture/karstic permeability. With the support of field observations on hydrogeological characteristics of the formations, the aquifer productivity was also considered for further aquifer classification. The 1996 Integrated Development Master Plan of the basins considered hydrochemical data besides the above information to regroup different lithologic units into aquifers. Based on this document, the lithologic units of the Wabe catchment were grouped into the following aquifer classes: Fissural with intergranular permeability of high productive variable aquifers, Fissural with intergranular permeability of moderate productive discontinuous aquifers, Fissural with intergranular permeability of low productive aquifers, and Intergranular permeability with low productive aquifers.

Similarly, the different geologic units of the rift valley can also be categorized into aquifers of a certain characteristics. In the rift valley, potential aquifers are highly fractured and jointed basalts and ignimbrites. The weathered tuffs and paleosols are impermeable layers inhibiting vertical movement of groundwater, thus forming perched water bodies locally.

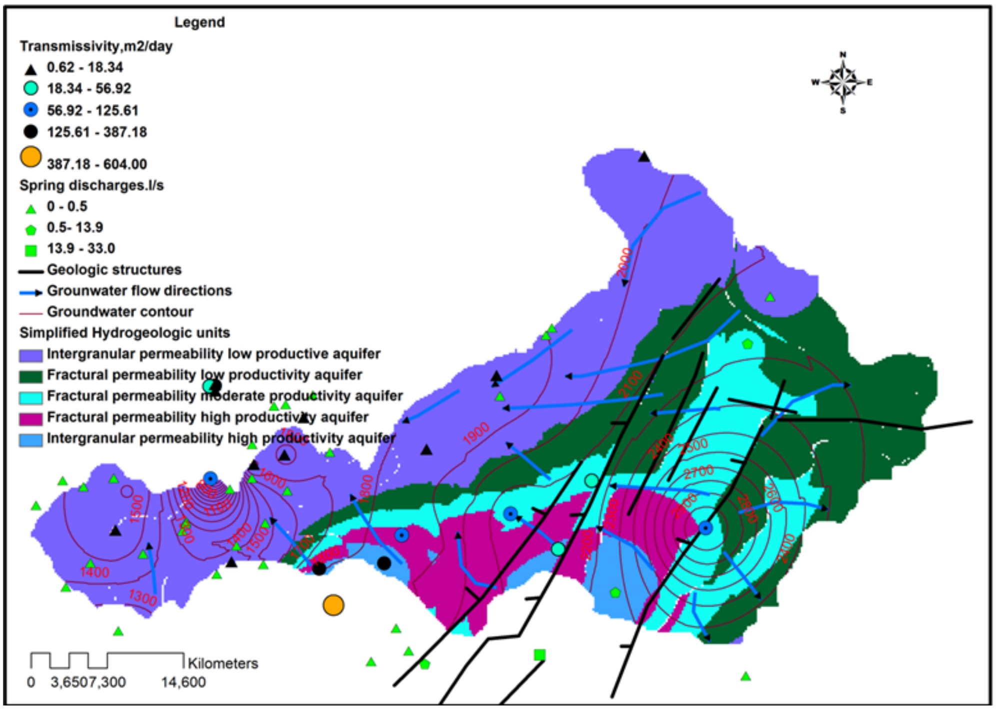
Extended permeable zone consisting of alluvial and colluvial deposits associated with lacustrine soils, and weathered and fractured volcanic rocksexist at shallow depth (Ayenew, 1998; Alemayehu, 2006). Based on the above discussion and litrature review, the geologic units of the catchments can be categorized into hydrogeologic units by identifying and defining the possible aquifer classes and combining themwith these lithologies.

4.7.1 Group one: Intergranular/Fracural permeability low productive aquifers

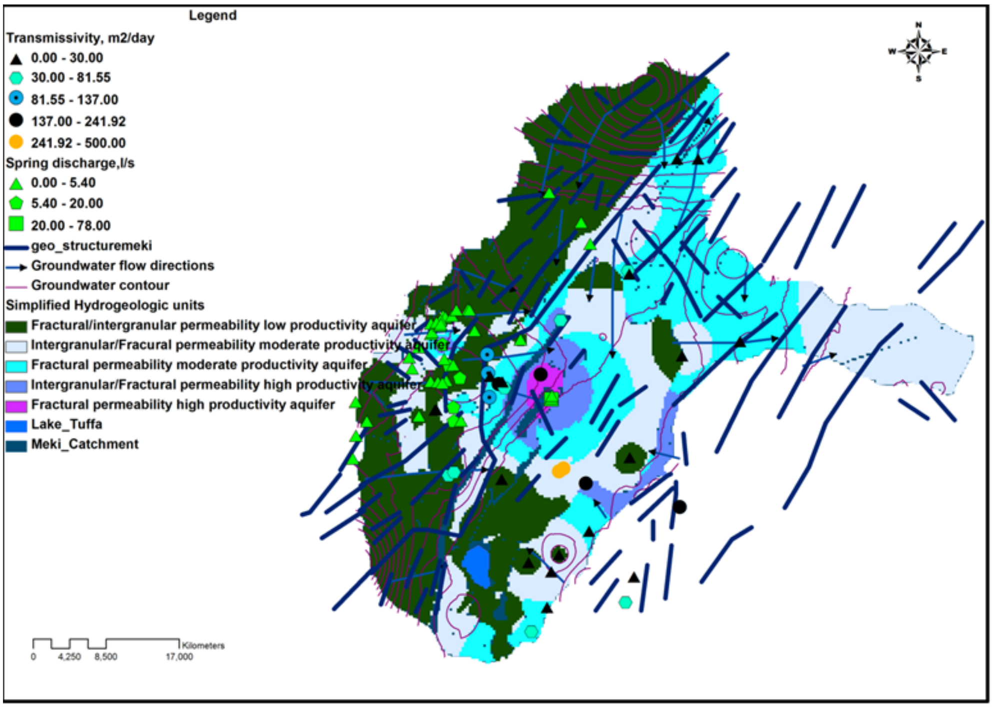
Lithologic units included in this group aredominantly Jimma volcanics and some units from Nazereth group and Tarmaber formations. Flood basalts, with minor salic flows which generally overlie the basement rocks are the extensive unit in the sothwestern highlands. The Jima volcanics of this unit cover onlythe western parts of the Wabe catchment. Mengesha (1996)indicated its average thickness was 100m and correlated it with Magdala group of trap series. The Tarmaber-Megezez formation which is predominantly composed of alkali basalts, cover large parts of Wabe catchment but it has small coverage in the western parts of Meki catchment. Few wells have been drilled in these aquifers, especially around fractures bounding this formation and the Nazaret group. Generally, the transmissivity value of this unit varies from 0 m^2/d to 18 m^2/d in Wabe, but increased up to 30m2/day in Meki catchment. A number of springs with dicharges of less than 0.5l/s are found in the unit. Few wells that have yields which range from 0 to 2.5l/s are source of water for residents in this part of the catchment.

4.7.2 Group two:Fractural/Intergranular permeability moderate productive aquifers

This is composed of some lithologic units from Nazereth group as well as lacustrine and alluvial deposits. The later is largely found in the eastern part ofof Meki catchment. Structuraly affected discontinuos exposures of this unit are found largely in the eastern direction of Guraghe ridge. The transmissivity value of this unit is variable and in few places values that range from 240m^2/d to 500m^2/d was estimated, but in most cases values between this range has been reported. The dominant lacustrine and alluvial deposits large tickness and often characterized as having good groundwater potential.



a.



b.

Figure 4.7 Hydrogeological maps of Wabe(a) and Meki(b) catchments

4.7.3 Group three: Fractural permeability moderate productive aquifers

This group consists of a range of lithologic units which extend from ignimbrites of the Nazereth group to rift basalts and lacustrine and alluvial deposits. The weathered and fractured ignimbrite included in this unit covers the south-centra part of Wabe cathment.The transmissivity values of this lithology in this part of the catchment varies between 18m^2/day and 125m^2/day. Discharges of springs and wells from this unit variesbetween 8 l/s and 25 l/s in this particular area. These are often found associated with the fracrures that cut this lithologic unit. The ignimbrites and basalts as well asfew lacustrine and alluvial deposits categorized under this group of aquifer covers the northeastern and eastern-central parts of Meki catchment. The groundwater flows from norhern and wsetern seem to converge locally in this part of the catchment. The transmissivity values of this unit range from 0 m^2/day to 80 m^2/day. The boeholes drilled in this area were found moderately productive with yields that vary from 4l/s to 10l/s. Similarly, springs emerging from these units provided high discharges which ranging between 20 l/s to 50 l/s and they have been tapped for irrigation purposes.

4.7.4 Group Four: Fractural permeability high productive aquifers

This group constitutes some lithologic units from Nazeret group and Tarmaber formations, and Quaternary sediments of lacustrine and alluvial deposits. Highly fractured ignimbrites and slightly weathered basalts of this group cover the central east and southeastern part of Wabe catchment whereas the fractured basalts andignimbrites of this group cover dominantly localized to the southern part of Butajira in Meki catchment. These lithologic units are cut by geologic structures and often treated as relatively extendedaquifers in Wabe catchment.The average transmissivity values of the lithologic units in the Meki catchment vary between 130m^2/d and 240m2/d.However, the lithologies from Wabe catchment show values of transmissivity which range from 56m^2/d to 125m^2/d. The discharges from springs that have been developedin both catchments show values that vary between 8l/s and 13l/s. However, drilled wells in these lithologies yield up to 5.5l/s. Therefore, based on these features, these units are classified as highly productive aquifers. Most of irrigation activities between Butajira and Ziway areas are directly or indirectly dependent on these aquifers.

4.7.5 Group five: Intergranular/Fractural permeability high productive aquifers

This group consists of lithologic units which include ignimbrites of Nazereth group as well as lacustrine and alluvial deposits with minor rift basalts at places. The weathered and fractured ignimbrites of this unit covers significant parts of the southern Wabe cathment. In Meki catchment, the lacustrine and alluvial deposits of this group cover largely its central part which includes the Inseno plane with little extension to Koshe area. The effects of these fractures in ignimbries are identified with high transmissivity value that ranges from125 m^2/day to 380 m^2/day in this aquifer class. The transmissivity values of lacustrine and alluvial deposits vary from 10m^2/day to 100m^2/day. Most of the boreholes are drilled in area where it has been faulted and provided it with this amount of discharges. Accoringly, the analyzed data reveals that the boreholes and springsfrom these aquifersgenerally yield upto 25 l/s. Hence, they are classified as among the highly productive aquifers in the catchments.

CHAPTER FIVE

5. LAND USE/LAND COVER CLASSIFICATION AND CHANGE

5.1. General remarks on land use/land cover changes

Studies on land use change do not always employ clearcut definitions of the principal terms such as land, land-use, land-cover, land-use and land-cover changes. Definitions and descriptions of these terms mightvary with purpose of application andcontext of their use (EOE, 2014; Briassoulis, 2000). Hence, it is useful to clarifythe definitions ofterms which are frequently used (EOE,2014; Briassoulis, 2000; Schindler, 2009).

Accordingly, the term land refers to the delineable area of earth's surface which encompasses attributes of the biosphere immediately above and below the surface of the earth (Briassoulis, 2000; Santa, 2011).Land-cover is described as the physical and biological cover and condition of a ground surface which may include forest, grassland, and agriculture lands (Prakasam, 2010; Mishra et al.2014; Kumar et al., 2015).

Land use is a broader concept and it can be defined from different perspective. Natural scientists define it in terms of syndromes of human activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and biodiversity. Social scientists and land managers define land use more broadly to include social and economic purposes and contexts for and within which lands are managed (or left unmanaged) (EOE,2014; Mishra et al.2014; Kumar et al., 2015). As a result, scientific investigation of the causes and effects of LULCC requires an interdisciplinary approach integrating both natural and social scientific methods, which gave rise to the emergence of the new discipline of land-change science.

Therefore, when users of land decide to employ land and its resources to different purposes, land change will happen (Briassoulis, 2000; Prakasam, 2010). This change in land-use and land-cover is described as land change (Prakasam, 2010; Mishra et al.2014).Land change is a quantitative difference in area of a given type of land-use or land-cover where research study is required (Briassoulis, 2000, Prakasam, 2010).

Land-use/land-cover change has been recognized as a driver of environmental change at all spatial and temporal scale and has emerged as a key environmental issue (Mishra et al.2014). For these reasons, the land change study has become crucial to provide information on land-use and land-cover change to land managers, and decision makers which are useful to support the formulation of land-use policies and decision making processes (Mishra et al.2014; Zhan et al.2014). Towards this objective, the International land change research organization calledLUCC was established with the objective of realizing IHDP and IGBP programs (Pontius,et al.,2006). Accordingly, in 1993, the core research programme of the land change study was initiated (Briassoulis, 2000; Mishra et al.2014).

It has been said that Ethiopia had forest coverage of more than 40% in the last century (Solomon, 2005; Mengistie 2013; Adugnaw, 2014). However, after a couple of decades, deforestation and land degradation impacted and reduced to the current level which is less than 3%. For instance, Adugnaw (2014) and references therein noted that about 150,000 to 200,000ha ofland has been deforested everyyear. Therefore, so much destruction of forests have aggravated soil erosion and resulted in low agricultural productivity, food insecurity and poverty (Solomon, 2005; Adugnaw, 2014).

The catchments have faced similar challenges of deforestation, land degradation, degradation in water quality and quantity and ecological disturbancesas in other places of the country. For instance, Garedew (2010) indicated that the expansion of cultivations and reductions of woodland in his research conducted in central riftvalley, for land use and land cover changes of the years between 1973 and 2000. Similarly, a study conducted in the same area by Bedru (2006) for years from 1973 to 2000showed that the forests were degraded by 26% in the years between 1973 and 1986 and the degradation preceded in the second period (1986-2000). He also indicated that the main loss of the forests was attributed to agricultural intensification. There are also very few regional and basin level studies on land use and land cover by different organizations mostly related to planning for develpoment activities. The two examples commonly quoted by researchers are HALCROW(1992;2008) and WBISPP(2004) for RVLB and, Ziway and Adami Tullu studies respectively.The land use/land cover results ofHALCROW (2008) indicated that the main land use/land covers of the RVLB are cultivation (38%) and shrubland(37%) andcomparing to the land cover/land use mapping of 1992, this showed that the area under cultivation has increased.

According to WBISPP (2004) study in Ziway and Adami Tullu areas, cultivation was increased at larger rate between 1967 and 1972 at the expense of open and dense woodlands (with high grazing pressure). This increase in agricultural land was continued with relatively lower rate in the later period of 1972-2000.

Specific to the study area which included Meki catchment, it was a study that was conducted by Nori et.al.(1999) which highlighted a gradual change from primarily pastoralism to sedentary cultivation over time due to increasing population pressure and decreasing rainfall reliability and a change from the preferential cultivation of ‘sandy’ soil to more clayey, and waterlogged soil. This paper also indicated that in Silte and Guraghe areas population pressure forced people to farm all cultivable land. It has also noted the impacts of villagization in land use processes.

However, these studies could not address land use/land covers of the research catchment (Meki) at the desired level of detail and even it did not cover the Wabe catchment. In addition, inclusions of the effects of the land use/land cover changes directly on hydrologic components was not a part of their objectives. Besides, the relationship between land use/land cover change and driving forces were not identified and explained explicitly and possible future scenario of land use/land cover changeimpacts was not attempted. Hence, this research was designed to fillthese gapsthrough investigating existing problems in the catchments.

5.2 Land Use/Land Cover Classification system

All classes of interest must be carefully selected and defined to successfully classify remotely sensed data into land use/land cover information(Gong and Howarth, 1992). This requires the use of classification system containing taxonomically correct definitions of classes of information, which are organized based on logical criteria. In addition to information class, there is also spectral class that are inherent in the remote sensor data and must be identified and labeled. Therefore, to consider these aspects, certain classification schemes that can readily incorporate land ues/land cover data obtained by interpreting remotely sensed datahave been developed. Besides this classification system, some countries prefer to adapt and define their own classification approaches in accordance with their local conditions.

Therefore, the magnitude and quality of land change can be described in terms of defining category of land classification (Briassoulis, 2000). For this study purpose, five major land classes are adopted from both considerations and redefined in order to suit the input format of the model(Table:5.1).

Table5.1: Land use/land cover classes adopted and modified from (USGS,1976; and,Yohanis, 2014)

Land categories	Descriptions
Forest land	Forest Lands have a tree-crown areal density (crown closure percentage) of 10 percent or more, arestocked with trees capable of producing timber or other wood products, and exert an influence on theclimate or water regime.Forest land includes all forms of forests. This forest land is dominantly occupied by deciduous, evergreen, or mixed forests.
Bare land	Barren Land is land of limited ability to support life and in which less than one-third of the area hasvegetation or other cover. In general, it is an area of thin soil, sand, or rocks. Vegetation, if present, ismore widely spaced and scrubby than that in the Shrub and Brush category of Rangeland.
Agricultural land	Agricultural Land may be defined broadly as land used primarily for production of food and fiber.This land-use land-cover category encompasses areas allocated for production of the perennial and seasonal crops, dispersed and rural settlements.
Rangeland	Rangeland historically has been defined as land where the potential natural vegetation is predominantlygrasses, grasslike plants, forbs, or shrubs and where natural herbivory was an important influence in itspre-civilization state. It is the Land-use land-cover category which is dominantly covered with shrubs, brushes, herbaceous and grasses
Built-up areas	Land feature such as woreda town and other small concentrated villages roofed with corrugated iron sheetand infrastructures like road are categorized under this land class. Built-up Land is comprised of areas of intensive use with much of the land covered bystructures.
Water/wetland	Wetlands are those areas where the water table is at, near, or above the land surface for a significant partof most years. The hydrologic regime is such that aquatic or hydrophytic vegetation usually isestablished, although alluvial and tidal flats may be nonvegetated. Wetlands frequently are associatedwith topographic lows, even in mountainous regions. Examples of wetlands include marshes, mudflats,and swamps situated on the shallow margins of bays, lakes, ponds, streams, and manmade impoundmentssuch as reservoirs.The delineation of water (lake) areas depends on the scale of data presentation and the scale and resolutionCharacteristics of the remote sensor data used for interpretation of land use and land cover.

5.3Accuracy assessment of classified image

After satellite image classification is done, the classified land use and land cover are usually evaluated by comparing with what is actually existing on the ground. This technique is known as accuracy assessment. It is a comparison of the classified map with reference data collected from the study catchments using GPS (Husen, 2009). It is normally performed as a means of quality assurance as the images are prone to errors due to either classification skills or image acquisition techniques(Teshome, 2011). In this case, there are two commonly reportederror types that are expressed in terms of user's and producer's accuracy. User's accuracy refers to the probability that a given pixel will appear on the ground as its class, while producer's accuracy represents the percentage of a given class that is correctly identified on the map. The field work was conducted in order to collect GCPs(Ground Control Points) so as to assess the level of accuracy of the classified images. Accordingly, the classified land use/land cover classes showed the following level of accuracies.

Table 5.2 Accuracy assessement results

ACCURACY TOTALS					
Class name	Reference	Classified	Number correct	Producers accuracy	Users acc
Forest land	15	12	12	80.00%	100.00%
Agricultural land	9	9	8	88.89%	88.89%
Range land	15	13	13	86.67%	100.00%
Bare land	10	13	10	100.00%	76.92%
Built-up areas	1	0	0	---	---
Water body	6	8	6	100.00%	75.00%
Totals	80	80	73		
Overall Classification Accuracy = 91.25%					

5.4 Land Use/Land Cover Classification of Wabe Catchment

The Land use/Land cover types of Wabe catchment (Figure 5.1) clearly showed variations in the last 25 years indicating a certain driving factors and the subsquent impacts on the watershed.

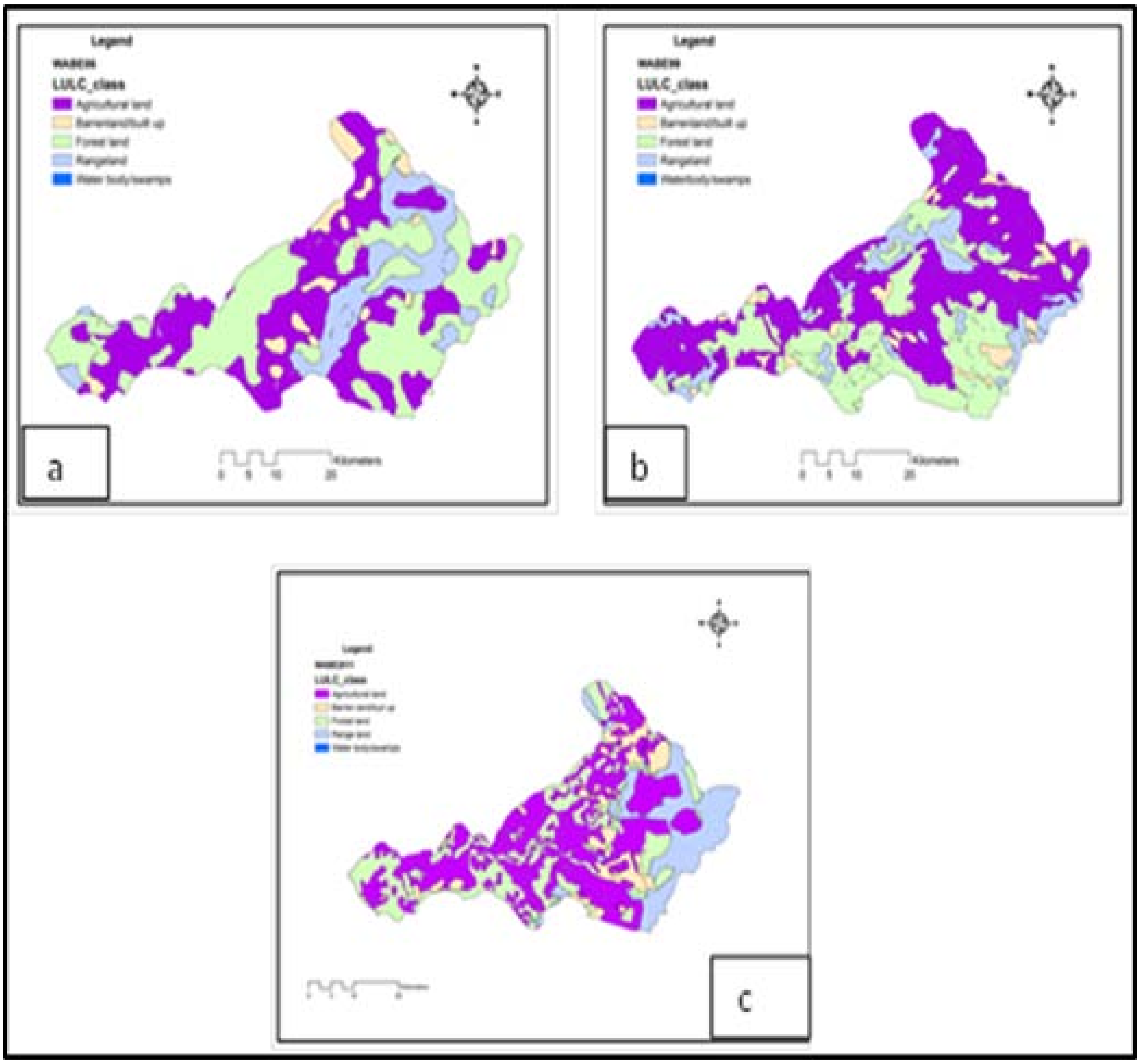


Figure 5.1 Land use/land covers of Wabe catchment for 1986(a) 1999(b), and, 2011(c)

Table5.3Extent of LULC in different study periods (1986, 1999 and 2011)

Area of and use/land cover of study catchments- **Wabe**						
Land use/ cover classes	**1986 Area**		**1999 Area**		**2011Area**	
	Km^2	%	Km^2	%	Km^2	%
Bare land /built up	99.40	6	96.93	6	163.26	10
Agricultural land	655.57	39	879.59	51	843.08	49
Water body/swamp	negligible	negligible	negligible	negligible	negligible	Negligible
Forest land	697.48	40	550.24	32	442.29	25
Range land	275.04	16	193.92	11	273.68	16

Based on the three times (1986, 1999 and 2011) satellite images of the study area, five land use/ land cover classes were identified. These includeforest land, agricultural land, range land, water body/swamps, and bare land /built up. In Wabe catchment the class water body/swamp hardly exists. Normally, these classes of the land use/Land cover types were obtained after reclassifying the 'standard'(first level) land use/land cover classes that rely on the USGS land use and land cover classification system. This modification was prefered to the usual classes in order to align them with the input requirements of the model and to attain the objectives set.

The 1986 image classification results showed that the forest land coverage (40%) was the dominant land cover while the barren land/ built up area (6%) was the least coverage of the catchment. The remaining parts of the Wabe catchment was composed of agricultural land (38%) and rangeland (16%). From 1999 image classification, the agricultural land covered 51% of the study area showing asignificant increment. The Forest land coverage was declined to 32% in the catchment. Rangeland was decreased from 16% to 11% during this time while bare land/ built-up areas remaind unchanged (6%).In land use/ land cover classes of the 2011 image, forest land resulted in further decrease to 25%. The agricultural land was also decreased by 2% from its 1999 coverage. However, the other two classes showed an increaseof 16% for range land and10%for bare land/built-up areas.

Table 5.4 Rate/trends of land use/land cover change differences (1986-2011)

Land use/cover classes	1986 -1999			1999-2011			1986-2011		
	Total changes		annual change	Total changes		annual change	Total changes		annual change
	Km^2	%	%	Km^2	%	%	Km^2	%	%
Bare land /built up	-2.46	-2.4	-0.2	66.32	68	6	63.85	64	3
Agricultural land	224.02	34	2.6	-36.51	-4	-0.32	187.50	29	1
Forest land	-147.23	-21	-2	-107.95	-20	-2	-255.19	-37	-1.5
Range land	-81.12	-29	-2	79.75	29	2	-1.36	-0.5	0

5.5. Land Use/Land Cover Change detection

Land use/land cover change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different times. Essentially, LUCC detection involves the ability to quantify temporal effects using multi-temporal data sets. Often, change detection involves detecting the nature of changes that have occourred, estimating its extents, and analyzing spatial patterns of the changes(Macleod and Congalton, 1998).From the three periods of satellite image classification, it can be observed that significant land use/land cover variations have been identified.

In general, when the changes between 1986 and 1999 are compared, the major changes were in forest and agricultural lands and no change was occoured in water body(swamps). Out of the total changes to land use/ land cover classes, 100% of the forests and range lands were converted to agricultural land. However, in the years between 1999 and 2011, 70% of the forests were converted to rangeland and the remaining 30% went to bare land/built-up areas. Agricultural land was reduced by 2% and it was changed to barren land.

After 1974 land proclamation, many forested lands were cleared to utilize the lands for farming and the situation proceeded until mid-1980s when plantation started and some

Peasant Associations (PAs) formed to protect the forests. In addtion, agricultural intensification, population pressure, both human and livestock, played their own role in impacting the land use/land covers of the area. Within the last 25 years the the poulation of the study area grew at a rate of 2.9%(CSA, 2007 census).

Besides, the common type of crop cultivated in the area influenced the dynamics of land use and land cover of the catchment. Since *enset*grows in the area, in this case, *enset* areas are known to be pressed very much by population density. In 1990s, the government allowed large harvest of forests for local activities and some were transported to the central government. Again, this situation challenged the communities and PAs and they became incapable of keeping the forests from degradations in the following years. As it was expected,deforestation resumed after the year 1990 in different parts of the locality until they experienced the 2004/2005 drought that devastated lives and property. According to local government office, there wererecords of forest fire that affected the eastern sides of Guraghe ridge in 2007/2008. The loss of some springs also occurred under this circumstance.In response to these challenges, some plantations and enclosures have been implemented in few places of the study area.

Since the already occupied lands have provided a lot for succeeding generations, people who had refused to migrate to urban areas were later forced to look for any other activity for their survival. As it was mentioned in the preceding paragraph, the demand for livestock has been increasing as an alternative means of livelihood among the rural population. Hence, open forests and range lands were exposed to overgrazing, especilally in1980s and 1990s which showed additional pressure on environmental resources of the catchments.

5.6 Land Use/Land Cover Classification of Meki Catchment

HACROW(2008) indicated that the most vulnerable areas in land cover change are those subject to deforestation and plantationexpansion.The Land use/Land cover types of Meki catchment clearly showed the variations in the last 25 years indicating a certain drivingfactors and the subsquent impacts on the watershed.

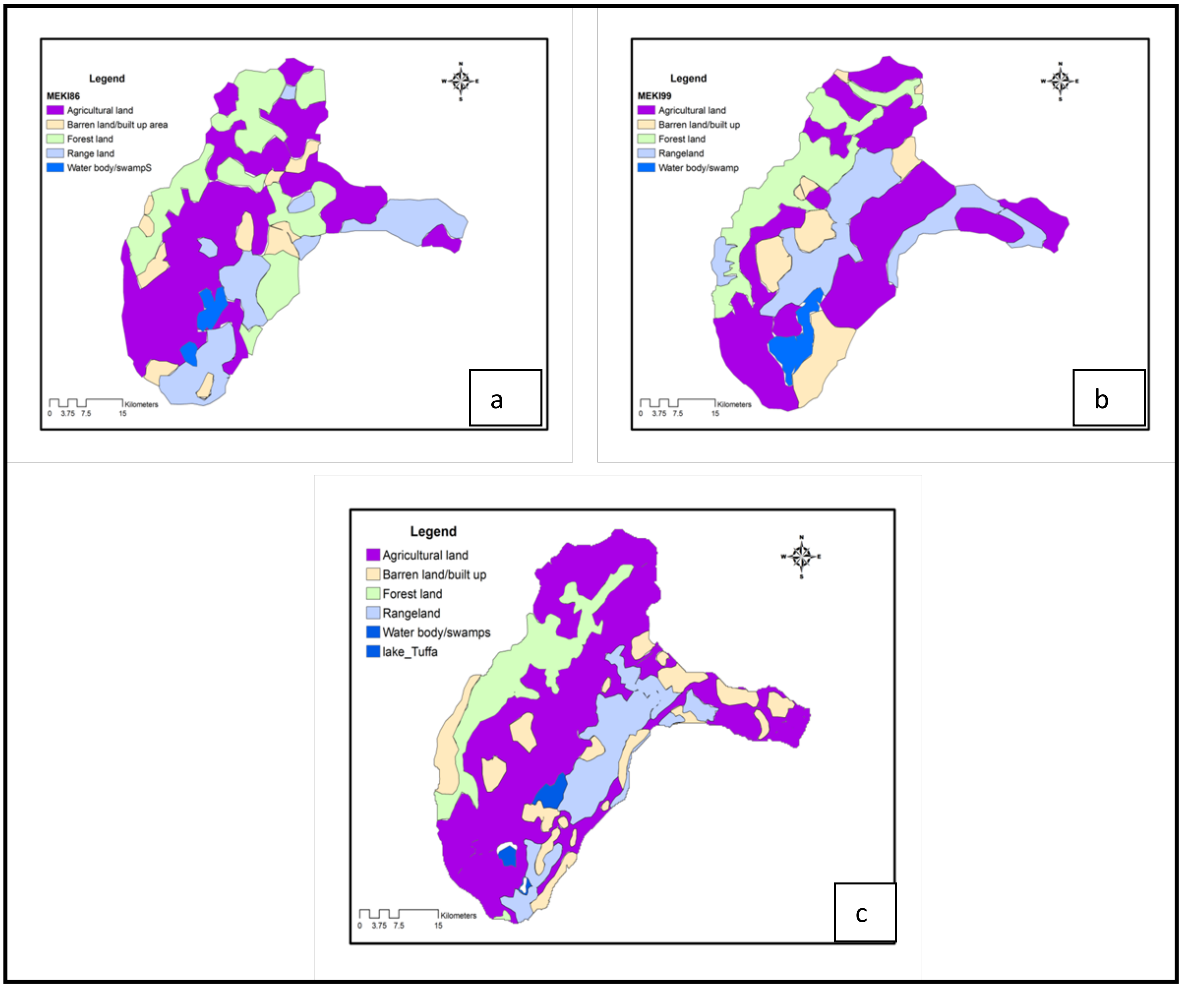


Figure 5.2 Land use/land cover of 1986(a), 1999(b), and 2011(c) of Meki catchment

Table 5.5Extent of LULC in different study periods (1986, 1999 and 2011)

Area and percentage of and use/land cover of study catchments- **Meki**						
Land use/ cover classes	**1986 Area**		**1999 Area**		**2011Area**	
	Km^2	%	Km^2	%	Km^2	%
Bare land /built up	147.50	7	257.19	12	302.0	14
Agricultural land	1029.79	48	1076.00	50	1208.50	56
Water body/swamp	46.02	2	74.97	3	25.47	1
Forest land	550.63	25	345.12	16	309.28	14
Range land	395.03	18	414.70	19	323.96	15

Based on the three times (1986, 1999 and 2011) of satellite images of the study area, five land use/ land cover classes are identified whichinclude forest land, agricultural land, range land, water body/swamps, and bare land /built up. Similar to Wabe catchment, these classes of the land use/and cover types were obtained after reclassifying the 'standard'(first levels) land use/land cover classes that rely on the USGS land use and land cover classification system. This modification was preferred to the usual classes in order to align them with the input requirements of the model and to attain the objectives set.

The 1986 image classification results showed that the agricultural land (48%) was the dominant land cover while the water body/swamps (2%) were the least coverage of the catchment. The remaining parts of the Meki catchment were composed of and forest land coverage (25%) and rangeland (18%).

In land use/land covr classes of 1999 image classification, except the forests, the other classes showed increases in percentages. The forest land coverage was declined to 16% of the catchment. The agricultural land coverage and water body/ swamps grew from 48% to 50% and 2% to 3% respectively. Likewise, rangeland and bare land/ built-up areas increased from 18% to 19% and from 7% to 12% respectively during this time.

In land use/ land cover classes of the 2011 image, forest land resulted in further decrease to 14%. However, the agricultural land was increased by 6% from its 1999 coverage and bare land/built-up areas increased from 12% to 14%. The other two classes generally showed decrease in their percentage and extents in which the range land and water body/swamps declined from 19% to 15% and from 3% to 1% respecctivelly during this time.

5.7 Land Use/Land Cover Changes detection of Meki

From the three periods of satellite image classification, it is possible to observe that significant land use/land cover variations have been identified. In general, when changes between 1986 and 1999 are compared, the major changes were in forest lands and bare lands/built-up and very slight changes was occured in other three classes. Out of the total changes to land use/ land cover classes of the forests, the other four classes took their proportion at the expense of this class. Accordingly, the lion’s share went to bare land/built-up areas, that is 60% of the changes in forest land indicating the coupled roles of deforestation and extension of urban lands into the nearby rural areas. Agricultural land took 2% of the changes while the rangeland and water body each shared 1% of the changes to forest land(Table5.5).

Table 5.6 Rate/trends of land use/land cover change differences (1986-2011)

Land use/cover classes	1986 -1999			1999-2011			1986-2011		
	Total changes		annual change	Total changes		annual change	Total changes		annual change
	Km^2	%	%	Km^2	%	%	Km^2	%	%
Bare land /built up	109.68	74	6	44.82	17	2	154.50	105	4
Agricultural land	46.21	4	0.35	132.49	12	1	178.70	17	0.7
Water body/swamp	28.94	63	5	-49.50	-107	-9	-20.55	-45	-2
Forest land	-205.51	-37	-3	-35.84	-10	-0.9	-241.35	-44	-1.7
Range land	19.67	5	0.4	-90.73	-22	-1.8	-71.06	-18	-0.7

However, in the years between 1999 and 2011, only 2% of the forests were converted to agricultural land. During these times, the wetlands were shrinked from 3% to 1% which showed the stretch of the nearby cultivations to the marginal lands. Out of the 4% changes to the rangeland, half of this percentage was utilized for agricultural purposes while the remaining half was exposed to over grazing and left barren.

The main driving factors for land use/land cover change in this catchment is almost similar to that of Wabe catchment except in the case of the former, the role of natural factors are more prevalent. These factors include intensification of agricultural lands, urbanization, overgrazing and litho-structural settings in the study area. In addtion , the population pressure played its own role as is evidenced that in the last 40 years (CSA, 2008) the population of the country has increased by almost double(Legesse,2010). In the study area, the occurrence of deforstation is not only for expanding agricultural lands, but it has effect in the daily livelihood of the inhabitants. Data from observations have also indicated that there are cutting of trees for making charcoal which is one of the common activities in generating income in the study area.

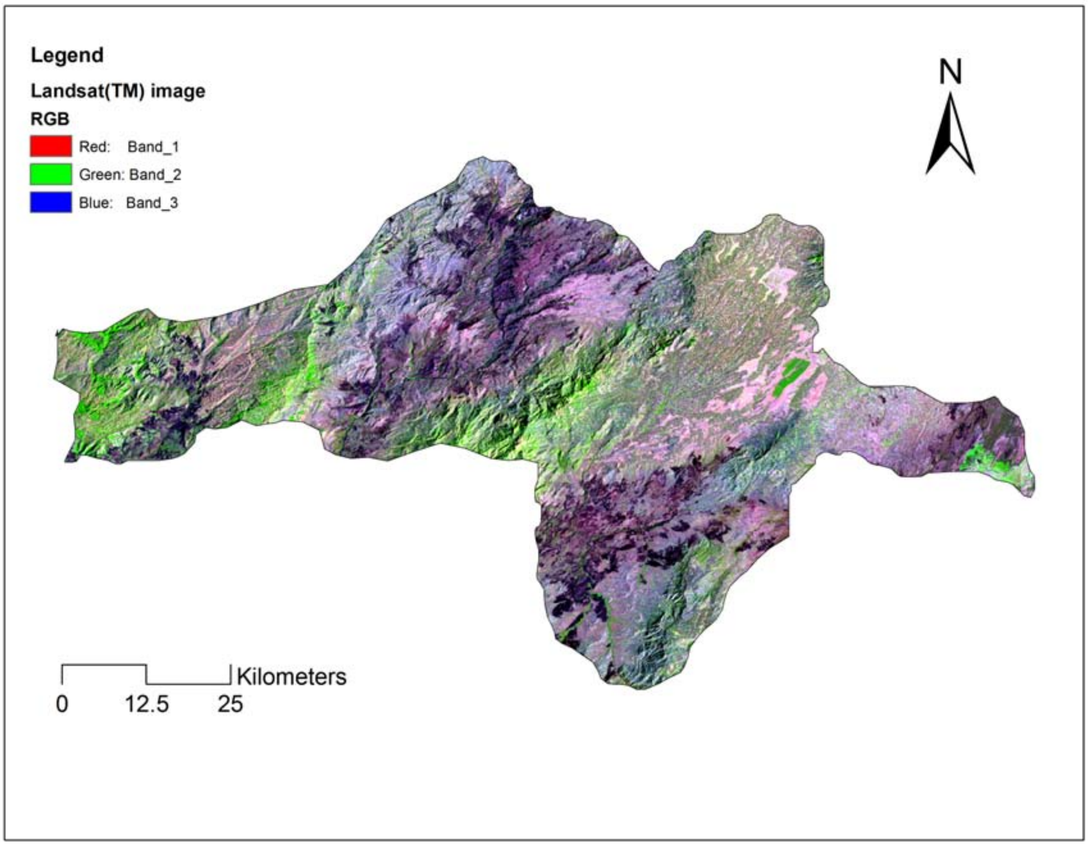


Figure 5.3 Raw Landsat images of 1999 for both catchments (The others are found in appendix)

CHAPTER SIX

HYDROLOGICAL MODELING

The term hydrological model alternatively termed as spatial hydrology, which is the study of the earth's waters and the transport of their constituents using the spatial data structures and functions of a geographic information system. And the development of most hydrological models rely on the newly evolved technology, which opened doors for various modeling techniques that can be used to advance our understandings of water resources assessment and management.

Therefore it is understood that the advancement of Geographic Information Systems (GIS) has become a useful tool for bridging and manifest the spatial properties of water movement through the landscape. And the very essence of GIS is a fundamental set of automated ideas and concepts rooted in over 2500 years of exploration and geographic research and designed to provide answers to questions based on mapped data. In general it is able to integrate and provide data management tools for hydrologic models, as a result the value and application of GIS is now a popular method that allows performance evaluations of multi-objective water management strategies. In this regard, the input data stage is the bottleneck in the development of GIS database and applying its analysis capabilities.

6.1 Input data preparations and organizations

Input data preparation and organization stage involves collection and processing of available and required data for the modeling works. It is a major bottleneck in the process of modeling which requires various tools to transform data from different sources. The fundamental data inputs needed to develop the input database for SWAT model can be categorized as meteorological data, physical data and hydrological data. Required physical data include DEM, slope, soil, and land use/land cover. Hydrological data needed are river discharge and groundwater related data. Required meteorological data include rainfall, temperature, solar radiation, wind and humidity. Particular to this work, the land use/land cover data are the main required data and thus, adressed in detail in Chapter five. Some features of other data are also described in chapter two. Under this section, limited features of the input data are described.

6.1.1 Soil

Soil data input for the model includes both physical and chemical characteristics depending on the objectives of the work. The physical properties govern the movements of water and air in the soil profileand have major impact on the cycling of water within the HRU.Therefore, hydrologic properties of soil were reclassified and reformated to inputing into the model.

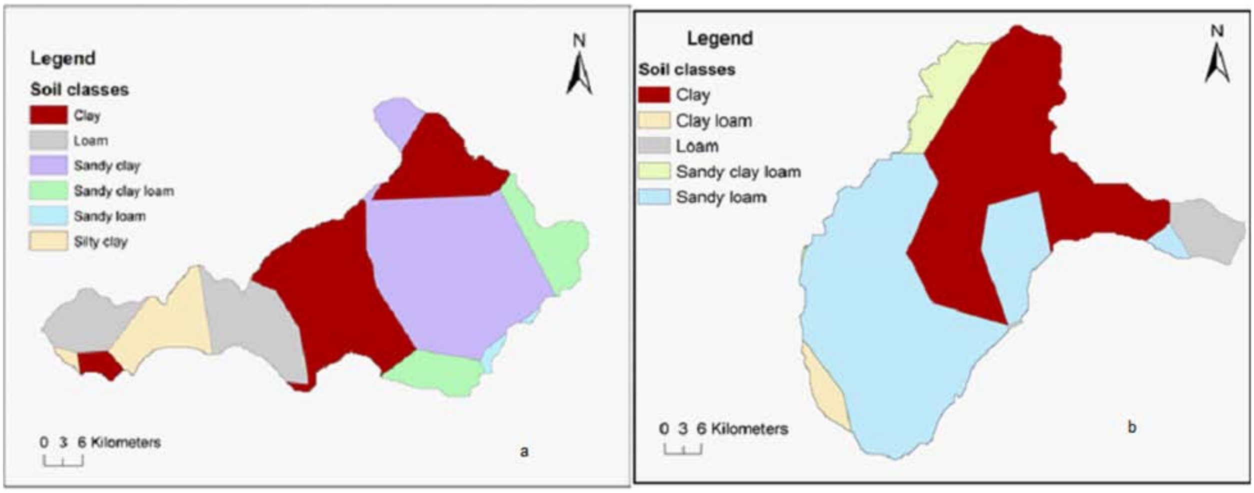


Figure 6.1 Soil classes(Textural) of Wabe(a) and Meki(b) catchments

The soil data was compiled and modified from different sources to get the appropriate soil format for inputting in to the model. Besides the common soil data sources, FAO, HWSD, and USDA, soil data that were collected for local studies like, irrigation practices and other related applications, were also used to organize soil database. These various sources were considered in order to identify and quantify the various soil parameters prior to reorganizing and categorizing into suitable SWAT soil format and classes. The main soil water characteristics(SOL_AWC, SOL_K, and SOL_BD) of the catchments were estimated using SPAW(Soil-Plant-Aair-Water) tool developed by USDA once the texture of the soil type was identified. Figure 6.2shows the soil classes used for inputs and the details of soils used in modeling the catchments are given in Appendix.

6.1.2. DEM/Slope

In modeling using SWAT, DEM (Digital Elevation Model) was used in delineating the watershed and to generate slope which in turn wasused for defining the HRUs together with soil data and land use/land cover classes of the catchments. For both catchments, DEM hasa spatial resolution of 90m that was extracted from SRTM(Shuttle Radar Topography Mission) data.Using GIS spatial analysis capability, slope data was generated and grouped into five classes.

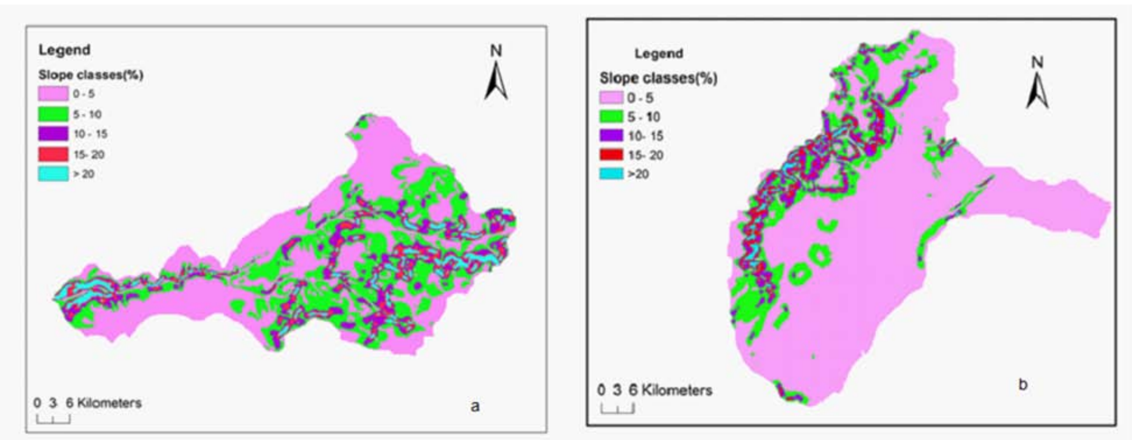


Figure 6.2 slope classes of Wabe(a) and Meki(b) catchments

6.1.3 Weather data

SWAT model requires daily weather data of precipitation, minimum and maximum temprature, solar radiation, relative humidity(dew point) and, wind speed. SWAT includes the WXGEN weather generator model to generate the climatic data or to fill in gaps in measured records.There are two options to obtain these data. They can be read directly from the file that contains the measured data set or the values can be generated using monthly average data summarized over the years. In this case, both stations within and nearby catchments were employed. Where synoptic stations were required (for solar radiations, humidity, and wind speed parameters), statistical techniques were applied between stations of interest and synoptic stationsto figure out the physical conditions associated with the location of the stations. The WXGEN uses the monthly statistical parameters values that were estimated from the representative stations in the catchments. In computing the statistical parameter two commonly used tools were employed. The first tool was dewpointwhich was employed to obtain statistical parameters related to temperature, humidty, and dewpoint. The pcpSTAT, was the second tool that was used to compute precipitation related statistical parameters.

6.1.4 River discharge

Daily river discharge values of Meki, and Wabe rivers for periods between 1986 and 2011 were obtained from the Hydrology Department of the Federal Ministryof Water, Irrigation, and Electricity. These daily river dischargesat the respective gauging stations, near Welkite for Wabe River and at Meki town for Meki Riverwereused for model calibration. In addition, the discharges were used in the computation of the baseflows and river flows(section 2.3). In both catchments it was observed that the peak flows for the rivers often occur between June and September.

6.1.5 Groundwater data

The hydrogeologic characteristics of the catchmens are considered in determining the groundwater related SWAT inputs. Some of these inputs are Groundwater delay(GW_delay), Baseflow alpha factor (Alpha_BF), initial depth of water in shallow aquifer(SHALLST), and Groundwater ‘revap’ coefficient(GW_REVAP). Groundwater delay refers to the time for waterpassing the root zone and getting into shallow aquifer and this is characterized through groundwater delayfactor. It depends on depth to water table and hydraulic characteristics of geologic formations. Alpha_BF is the baseflow recession constant which is the direct index of groundwater response to changes in recharge. Water may move from shallow aquifer in to the overlying unsaturated zone. Water is removed from the shallow aquifer either by evaporation from capillary frienge or by deep-rooted plants. In SWAT this process of upward movement from the shallow aquifer is termed ‘’revap’’ to avoid confusion with soil evaporation and transpiration. Because the type of plants cover will affect the importance of ‘’revap’’ in the waterbalance, the parameters governing revap can be varied by land ues/land cover of the watershed. Thevalues for these parameters were determined by varying between their minimum and maximum values based on the hydrogeologic characteristics of the chatchments. If the optimum value is attained, depending on the level of calibration, the mean of this optimum value is appliedbefore re-runing the simulation. It was observed that changing the values of these parameters was more significant on simulated baseflows.

6.2Hydrological watershed modeling

6.2.1 Hydrologic models andmodeling

A hydrological model can be defined as a simplification or abstraction of a natural system, such as water flows and their components, over a portion of terrain or a section of the vadose zone. Hydrological models can be physicalprocesses or conceptual(Bergstrom,1995). Physically based models describe and represent a natural system mathematically. From a mathematical point of view, models can be empirical or theoretical, and can further be classified as stochastic or deterministic (Brooks et al.,1997).

Additionally,there are lumped and distributed models depending on the discretization scheme in the description of the basin characteristics (for example, spatial variability of the parameters or variables of input and/or output) (Meijerink et al., 1994). For the application of spatially distributed models, the basin is regularly partitioned into a number of hydrological response units, subwatersheds or representative hillslopes (Mendoza et.al.2002).Most of the time, hydrological systems have been represented in watershed models and therefore, understanding these models is required in order to apply them properly(Borah,2008). Traditionally, hydrologic models have considered watershed to be homogeneous (Kilgore, 1997). Hence, weighted average or mean values are used as input for these ″lumped”models. The major drawback in lumped models is the incapability to account for spatialvariability. As computers have become more powerful and less expensive, many waterresources studies have been conducted using distributed parameter models. Thesemodels offer the possibility of a significant improvement over lumped models due to theability to integrate spatial variability of hydrological processes.

Different types of hydrological models have been developed and applied over the pastdecades. These models have similarities in their attempt to incorporate the heterogeneityof the watershed such as the spatial distribution of various inputs and boundary conditions such as topography, vegetation, land use, soil characteristics, rainfall andevaporation, and produce spatially detailed outputs such as soil moisture fields, watertable positions, groundwater fluxes and surface saturation patterns (Troch et al., 2003).In those models, spatial variations are estimated by using spatial variation of precipitation, catchment parameters and hydrologic responses. Temporal variations of hydrologicresponses are modeled by introducing threshold values for different processes to occuror not.

Representation of the catchments by individual subbasins or grids of individual elementsare used to integrate the spatial variability of the aforementioned parameters with themodel. Subsurface zones or vertical layers of soil for each grid element represent verticalvariability. However, these models are yet to become common planning or decisiontools. The majority of watershed models simulated watershed responses without or withinadequate consideration of water quality (Arnold, 1998). On the other hand, someauthors (Jain et al., 1992, Troch et al., 2003) stated that the substantial data requirementfor the available models is one of their biggest shortcomings.

Effective watershed management and ecological restoration require a thoroughunderstanding of hydrologic processes in the watersheds. Spatial and temporal variations in soil, vegetation and land use practices make a hydrologic cycle a complex system. Therefore, mathematicalmodels and geospatial analyses tools are needed for studyinghydrologic processes and hydrologic responses to land use and climatic changes (Singhand Woolhiser, 2002).

6.2.2SWAT model

SWAT(Soil and Water Assessment Tool) is a continuous hydrological model that aims to describe the various physical processescontrolling the transformation of precipitation to runoff, evapotranspiration (ET),surface runoff, infiltration, percolation to shallow and deep aquifers, and channel routing. It is useful for analyzing long-term hydrological changes and watershed management practices. (Arnold et al. (1998),and Neitsch et al. (2002). These processes mayvary spatially as well as temporally and are simulated in four subsystems: surface soil, intermediate zone, shallow and deep aquifers, and open channels. Stream flow in a mainchannel is determined by three sources- surface runoff, lateral flow and base flow fromthe shallow aquifers. SWAT comprisesall the three major components of watershed model. These are hydrology, sediment,andchemicals. It is highly applied predomonantly in agricultural watersheds (Bohar,2008). Further, the model is efficient in computing terms with the ability to perform long simulations. In SWATdistributed hydrological model, the impacts of spatial variationsin topography, land use, soil and other watershedcharacteristics on the hydrology areconsidered in subdivisions. There are two level-scales for the latter: (1) a basin is dividedinto a number of subbasins based on drainage areas of the tributaries, and (2) eachsubbasin is further divided into a number of hydrologic response units (HRUs), definedby sections of similar land cover and/or soil type.

Different works have been published by various researchers that include reasons behind applications of SWAT models in addition to the usual model selection criteria. For example, Chekol et.al, (2007) and Adamu (2013) described why SWAT model is selected in that it has the ability to characterize complex watershed representations to explicitly account for spatial variability of soils, rainfall distribution, and vegetation heterogeneity and to show the effects of different land management practices on surface runoff and sediment yield. Besides, its freely and readily availability, and relatively less demanding on input are another benifits of the model.One of the reasons why SWAT is seleccted for this studyis that it provides thenecessary information for the treatment of the catchments into subcatchments (subbasins) which have their own indicators and interrelationship among them. For a study such as the present one, this capability of SWAThelps to analyze surface runoff, baseflow, ET and groundwater recharge from different land use/land cover and soil types. It can also be used to analyze the effects of various land management practices on land degradations. The hydrological processes included in the model are evapotranspiration, surface runoff, infiltration, percolation, shallow and deep aquifers flow, and channel routing (Arnold et al., 2010). SWAT operates on daily time step and uses input data such as physiographical (elevation, land use and soil properties), meteorological and, hydrological data. The SWAT outputs are often calibrated and validated against observed hydrological and water quality variables(Arnold and Allen, 1996). Once the model is calibrated, it is used to predict the stream flows under different land use/land cover scenarios. This in turn, can help to identify land surface recharge from river seepages and analyze how recharges to groundwater vary with changes in land use/land cover. In SWAT, once the watershed of interest is divided into subbasins, they are then furthersubdivided into HRUs that consist of homogeneous land use, management, and soilcharacteristics. These elements give the model the strength to better represent theproperties of land uses and/or soils of each subbasin that have significant effect onhydrology. There are two options available to discretize the sub-basin into simulationelements: (1) a single hydrological response unit (HRU) based on dominant land use andsoil classes within a subbasin, or (2) multiple HRUs for each subbasin considering the percentageof the land use and the soil class within the subbasin. One may decidewhether or not to use multiple hydrologic response units (HRUs) in the modelingapplication. If multiple HRUs are not employed, the interface will use the dominant landuse and soil characteristic for the entire watershed. To model multiple HRUs, one mustdetermine a threshold level which will take into account the heterogeneity of the land usesand soil in each sub-basin.

Land uses that cover a percentage of the sub-basin area lessthan the threshold level are eliminated and the area of the land uses is reapportioned sothat 100 percent of the land area in the sub-basin is included in the simulation.

For this study, both options were attemptedand the first option was selected after analyzing and comparing the size of the HRU with dominant land use andsoil classes within a subbasin. In most subbasins, when applyingthe default thresholdsvalues of 10% for both soils and land use/land covers in the second option, which means, if a 10% soil area is defined in HRU distribution, only soils thatoccupy more than 10% of a sub-watershed area are considered in HRU distributions, the results showed insignificant differences with the results from the first option. Therefore, for simplicity, a single HRU for each subbasin option, that is 17 HRUs for 17 subbasins before reclassifying the subbasins into five subbasins was considered.Full hydrologic balance of each HRU includes accumulation and evaporation of theplants, determination of effective rainfall, water exchange between surface runoff andsoil layer, water penetration into deeper layers, evapotranspiration, sub-surface flow andunderground flow and water accumulation. Flow generation, sediment yield, and nonpoint-source loadings from each HRU in a sub watershed are summed, and the resultingloads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Thevarious hydrological processes that move precipitation to streamflow, discussed above, are either described by differential equations governing the hydraulic/hydrological lawswithin the various compartments of the hydrological cycle or, for the sake of simplicity, bysemi-empirical algebraic equations with some tunable parameters (Arnold et al., 1998).No matter what type of problem being studied by SWAT, water balance is the driving forcebehind everything that happens in the watershed. In order to achieve precise forecastof circulation of the pesticides, sediments or nutrients, hydrologic cycle is simulated bythe model which integrates overall water circulation in the catchment area. Hydrologicsimulations in the catchment area can be divided into two groups.

In the soil phase ofthe hydrologic cycle the processes on the surface and in the sub-surface soil occur, aswell as the circulation of sediments, nutrients and pesticides through the water flows inall sub-catchments. In the second phase, the circulation of water and sediment throughthe river network up to the exit profile are observed.The hydrologic component ofSWATpartitions precipitation into four control volumes:(1) the surface, (2) the soil profile or root zone, (3) the shallow aquifer, and (4) the deepaquifer. The fundamental hydrology of a watershed in SWAT is based on the followingwater balance equation.

$$SW_t = SW_0 + \sum_{i=0}^{t}\left(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}\right) \qquad 1$$

where $SW_t$is the final soil water content (mm water), SW_0 is the initial soil water contenton day *i* (mm water), *t* is the time (days),$R_{day}$is the amount of precipitation on day *i* (mmwater), $Q_{surf}$is the amount of surface runoff on day *i* (mm water), $E_a$is the amount ofevapotranspiration on day *i* (mm water), $W_{seep}$is the amount of water entering the vadose zone from the soil profile on day *i* (mm water), and $Q_{gw}$is the amount of return flow onday *i* (mm water).The subdivision of the watershed enables the model to reflect differences inevapotranspiration for various crops and soils. Runoffis predicted separately for eachHRU and routed to obtain the total runoff for the watershed. This increases accuracy andgives a much better physical description of the water balance (Arnold et al., 1999).

To estimate surfacerunoff two methods are available. These are the SCScurve number procedure USDA Soil Conservation Serviceand the Green & Ampt infiltration method. In thisstudy, the SCS curve number method was used to estimatesurface runoff. Hargreaves method was used for estimationof potential evapotranspiration (PET). The SCS curvenumber is described by equation 2.

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \qquad \mathbf{2}$$

In which, $Q_{surf}$is the accumulated runoff or rainfall excess (mm), $R_{day}$is the rainfall depth for the day (mm), S isthe retention parameter (mm). The retention parameter isdefined by equation3.

$$S = 25.4\left(\frac{100}{CN} - 10\right) \qquad \mathbf{3}$$

The SCS curve number is a function of the soil's permeability, landuse and antecedent soilwater conditions. SCSdefines three antecedent moisture conditions: 1 – dry (wiltingpoint), 2 – average moisture, and 3 – wet (field capacity).

The moisture condition1 curve number is the lowest valuethat the daily curve number can assume in dry conditions.The curve numbers for moisture conditions 2 and 3 are calculatedfrom equations 4 and 5.

$$CN_1 = CN_2 - \frac{20 \cdot (100 - CN_2)}{(100 - CN_2 + \exp[2.533 - 0.0636 \cdot (100 - CN_2)])}$$

4

$$CN_3 = CN_2 \cdot \exp\left[0.00673 \cdot (100 - CN_2)\right] \quad 5$$

In which CN1 is the moisture condition1curve number,CN2 is the moisture condition2 curvenumbers, and CN3 isthe moisture condition 3 curve number.Typical curve numbers for moisture condition 2 are listedin various tables which are appropriate to slope less than 5%. But in the study catchments there are areas with slopesgreater than 5%. To adjust the curve number for higherslopes the following equation is used (equation 6).

$$CN_{2S} = \frac{(CN_3 - CN_2)}{3} \cdot \left[1 - 2 \cdot \exp(-13.86 \cdot slp)\right] + CN_2 \quad 6$$

In which CN_{2S} is the moisture condition 2 curve numberadjusted for slope, $CN3$ is themoisturecondition 3 curvenumbers for the default 5% slope, $CN2$ is the moisture condition2curvenumbers for the default 5% slope, and *slp* is theaverage percent slope of the sub-basin.

The peak runoff rate, the maximum runoff rate that occurs with a given rainfall event, is an indicator of the erosive power of a storm. It is used to predict sediment loss. SWAT calculates peak runoff rate with a modified rational method which is given as:

$$q_{\text{peak}} = \frac{C.i.Area}{3.6} \qquad 7$$

Where, q_{peak} is the peak runoff rate (m3/s), C is the runoff coefficient, i is the rainfall intensity (mm/h), Area is the subbasin area (km2) and 3.6 is a unit conversion factor from (mm/h)(km2) to m3/s.

The SWAT model employs the Modfied Universal Soil Loss Equation (MUSLE) developed by Williams and Brendt (1977) to compute sediment yield for each sub-basin. MUSLE is a modified version of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978). The MUSLE is given as:

$$\text{sed} = 11.8.(Q_{\text{surf}} \cdot q_{\text{peak}} \cdot \text{area}_{\text{hru}})^{0.86} \cdot K_{\text{USLE}} \cdot C_{\text{USLE}} \cdot P_{\text{USLE}} \cdot \text{LS}_{\text{USLE}} \cdot \text{CFRG} \qquad 8$$

where, sed is the sediment yield on a given day (t), Q_{sur} is the surface runoff volume (mm/ha), q_{peak} is the peak runoff rate (m3/s), $area_{hru}$ is the area of the HRU (ha), K_{USLE} is the USLE soil erodibility factor, C_{USLE} is the USLE cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor and CFRG is the coarse fragment factor.

The SWAT model allows for simultaneous computations on each sub-basin and routes the water, sediment and nutrients from the sub-basin outlets to the basin outlet. The routing model consists of two components—deposition and degradation, which operate simultaneously. The amount of sediment finally reaching the basin's outlet, S_{OUT}, is given as:

$$S_{\text{OUT}} = S_{\text{IN}} - S_{\text{D}} + D_{\text{T}} \qquad 9$$

where, S_{IN} is the sediment entering the reach, S_D is the sediment deposited and D_T is total degradation. The total degradation is the sum of re-entrainment and bed degradation components, and it is given as:

$$D_T = (D_r + D_B)(1 - D_R) \qquad 10$$

Where, Dr is the sediment re-entrained, D_B is the bed material degradation component and D_R is the sediment delivery ratio. Detailed theoretical documentation for the model is given by Neitsch et al. (2005).

6.2.3SWAT model performance and evaluation

Sensitivity analysis describes how model output varies when the given input variables arevaried. In particular,it allowsto identify those model parameters that exert the highestinfluence on model calibration or on model predictions. Model sensitivity is definedas the ratio of the change in model output to a change in parameter input. Sensitivityanalysis and calibration are usually difficult with a large number of parameters. Thus, one important aim of parameter sensitivity analysis is to reduce the number of inputparameters, thereby reducing the computation time for the calibration.

As the SWAT model relies on numerous parameters to represent the various hydrological,climatic, soil and plant processes within a watershed, the calibration of the model fora specific study area is a challenging task and accentuated by the fact that many of thesecalibration parameters may be correlated to each other. Therefore, many researchers (For example, Vandenberghe et al., 2002) have proposed that a sensitivity analysis should beperformed before model calibration to identify the most sensitive parameters andjust use these in the subsequent calibration. For instance, Vandenberghe et al. (2001)presented a calibration approach for ESWAT, a modified version of SWAT, which involvestwo steps, i.e.

a sensitivity analysis followed by an automatic calibration withthose parameters that have been identified as having a significant impact on the modeloutput.

Watershed models, like SWAT, contain many parameters which can be classifiedinto two groups: physical and process parameters. Aphysical parameter representsphysically measurable properties of the watershed whereas process parametersrepresent properties of the watershed which are not directly measurable (Sorooshian andGupta (1995). Hence, in order to utilize any predictive watershed model for estimating theeffectiveness of future potential management practices, one needs to select values forthe model parameters so that the model closely simulates the behavior of the study site.

The objective of calibration is the estimation of values for those model parameters, whichcannot be assessed directly from field data. Thus, calibration can be viewed assome kind of parameter estimation designed to reduce the uncertainty in the estimations of process parameters, but also of poorly defined physical parameters.Refsgaard and Storm (1996) differentiated three types of calibration procedures. The first is,trial-and-error, manual parameter adjustment, second, automatic, numerical parameteroptimization by minimization of the misfit objective function or, and third, a combination of thetwo, whereby manual calibration alone is very tedious, time consuming, and requiressome experience of the user. For this reason automated calibration methods areincreasingly being used, although Gan (1988) recommended that a combination of themodel calibration procedures as the best approach.

The watershed model SWAT can also be better option to perform automatic calibrationof its model parameters. The technique implemented in SWAT is based on the ShuffledComplex Evolution algorithm developed at the University of Arizona (SCE-UA). SCE-UAis a global search algorithm that minimizes a single objective function, i.e. the misfitfunction of the sum of the squared errors between the observed and modeled quantity for up to 16 model parameters (Duan et al., 1992). SCE-UA has been generally found tobe a robust and efficient and has been applied with success to SWAT for the estimationof hydrologic parameters, as well as hydrologic and waterquality parameters (Eckhardt and Arnold (2001); Van Griensven et al., (2002)).

For the evaluation of the calibration (and validation) performance of the model, twostatistical parameters, namely R^2 = the squared correlation coefficient between theobserved and simulated output, which in SWAT is usually the streamflow, and NS = theNash-Sutcliffe efficiency parameters, are used. Values of $R^2 > 0.6$ and $NS > 0.5$ forthe calibration of the daily and monthly simulated streamflow are usually considered asadequate for an acceptable calibration (Santhi et al. (2001). However, considering those constraints related to any of the calibration methods, EAWAG developed SWAT-CUP for facilitating the calibration and validation processes in SWAT model. SWAT-CUP 2012 was the product of a Swiss Federal Institute of Aquatic Science and Technology. Theprogram links SUFI2, PSO, GLUE, ParaSol, and MCMC procedures to SWAT. It enablessensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models. Out of the above procedures, SUFI2 (sequential uncertainity fitting) was applied for the calibration and validation of the model parameters.

In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such asuncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measureddata. The degree to which all uncertainties are accounted for is quantified by a measurereferred to as the *P-factor*, which is the percentage of measured data bracketed by the 95%prediction uncertainty (95PPU).Another measure quantifying the strength of a calibration/uncertainty analysis is the *R-factor*, which is the average thickness of the 95PPU band divided by the standard deviationof the measured data. These performance measures are often considered in addition to the previously mentioned methods for goodness-of-fit measures of model predictions during calibration and validation periods.

6.3 Results and discussions

The two catchments were modeled separately whereby the rift side, Meki catchment,was defined by the outlet gauging station at Meki town and the one which drains to Omo-Gibe river, Wabe catchment,was defined by the outlet at Welkite town. The calibrarion and validationwas done using these two outlets. In order to address the spatial and temporal effects,watershed and sub-watershed(subbasin) scales for spatial variability as well as annual and monthly scales for temporal variability, were considered.

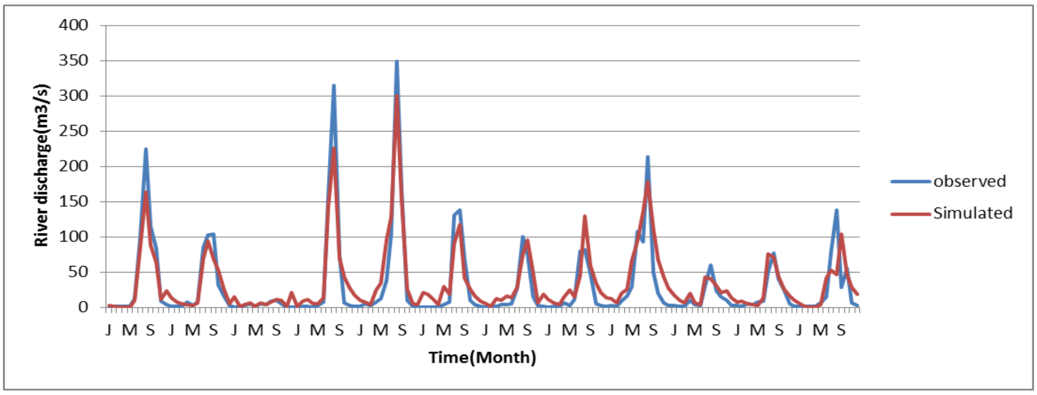
6.3.1 Wabe Catchment

The catchment was delineated into 17 subbasins (before reclassified into five subbasins) based on model suggested flow accumulation treshold of 3525 ha, topography, main streams, and meteorological stations. They were further divided into 124 HRUs. Each HRU can be defined by either using the dominant land use, soil type, and slope or by using the multiple hydrologic response units.

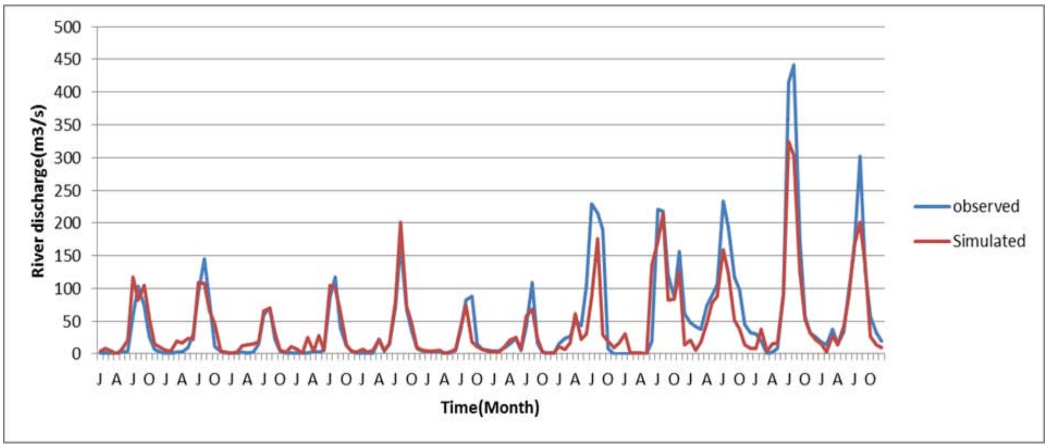
After assessing the level of significance to use either of the options and considering the simplified approach of handling and presenting the analysis results, the number of subbasins and HRUs were redefined and reclassified. Accordingly, the catchment was divided into five subbasins and 17 HRUs following the dominant approach of HRU definitions. The simulatedflow and sediment load at Wabe gauging station was compared with theobserved flows.The most sensetive parameters in decreasing order of sesitivity include curve number (CN2), available water capacity(SOL_AWC), Alpha base flow (ALPHA_BF), and groundwater delay (GW_delay).Accordingly, simulations wereconducted and provided good results of performance measures of acceptable ranges(Table 6.1).

Table 6.1Model performance summary for Calibration and Validation period

	Period	R^2	Ens
Calibration	1988-1999	0.73	0.64
Validation	2000-2011	0.71	0.66



a.



b.

Figure 6.3: Calibration (a) and validation (b) results of average monthly simulated and observed flows for Wabe catchment

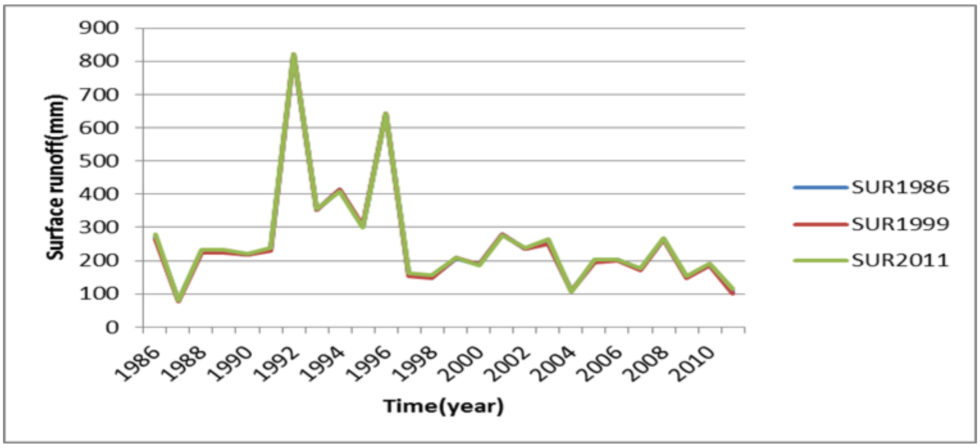


Figure 6.4 Surface runoff of Wabe catchment and its variations from 1986-2011

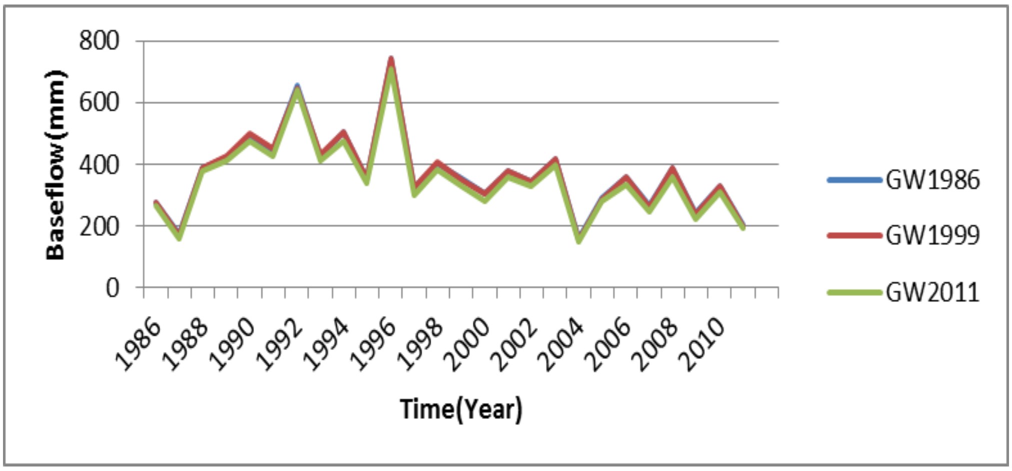


Figure 6.5 Groundwater flow (baseflow) of Wabe catchment and its variations from 1986-2011

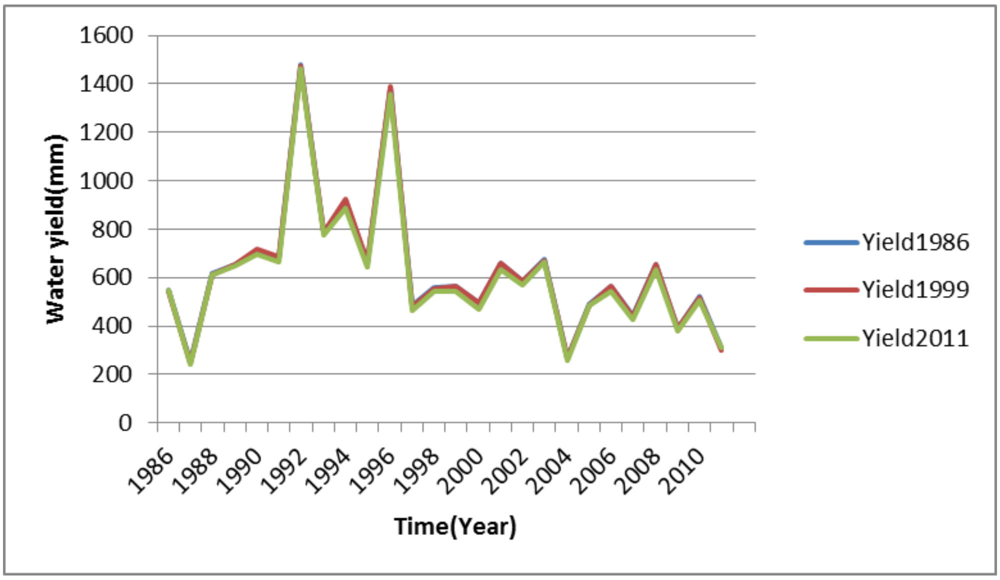


Figure 6.6 Annual mean yields of Wabe catchment and its variations from1986-2011

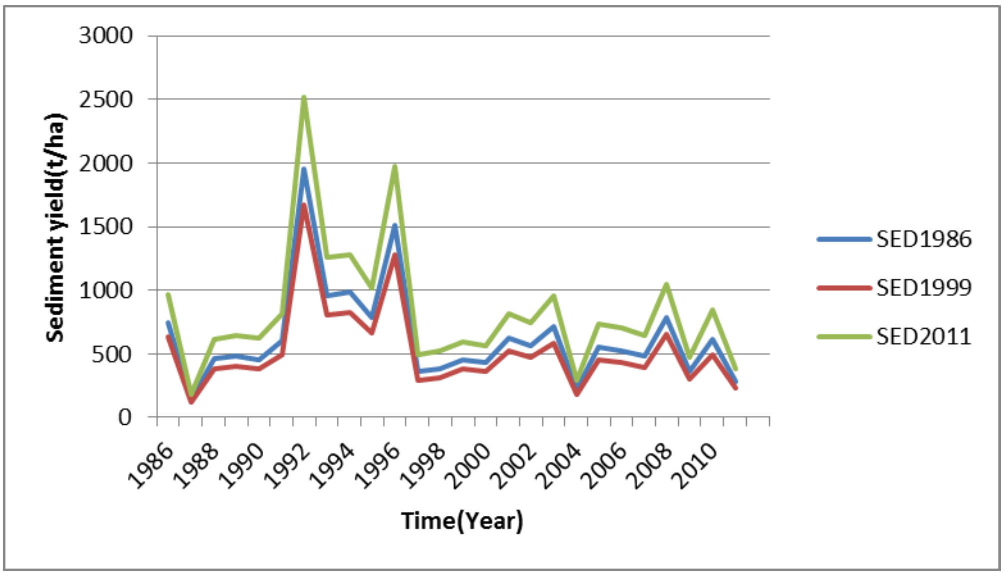


Figure 6.7 Annualmean sediment yield (ton/ha) of Wabe catchment and its variations from1986-2011

The water balance components of this catchment are computed and presented in table 6.2. It was observed that the mean watershed values of these components vary with the changes in catchment soil water storage. The main water loss from the catchment is as a result of ET and shared about 50% of the precipitation in this period.

Table 6.2 shows the water balance ratios in the two periods of Wabe catchment

Parameters	**1986-1999**	**1999-2011**
Stream flow/precipitation	0.465	0.44
Base flow/total flow	0.55	0.565
Surface Runoff/total flow	0.45	0.435
Recharge/precipitation	0.285	0.27
ET/precipitation	0.505	0.5

6.3.2Meki catchment

The catchment was delineated into 30 subbasins (before reclassified into five subbasins) based on model suggested flow accumulation treshold of 3525 ha, topography, main streams, and meteorological stations. They were further divided in to 220 HRUS. Each HRU can be defined by either using the dominant land use, soil type, and slope or by using the multiple hydrologic response units. After assessing the level of significance to use either of the options and considering the simplified approach of handling and presenting the analysis results, the number of subbasins and HRUs were redefined and reclassified. Accordingly, the catchment was divided into five subbasins and 30 HRUs following the dominant approach of HRU definitions. The simulated flow and sediment load at Meki gauging station was compared with theobserved flow.Prior to performing the calibration and validationtask, the most sensitive parameters were tested and identified. These parameters, in order of decreasing sensitivity include Alpha base flow(ALPHA_BF), Groundwater delay (GW_delay) and Curve Number (CN2), and Available Water Capacity(SOL_AWC). For this catchment, the former two parameters are the parameters of interest as they signify the dominant roles of the hydrogeological and geological conditions of this area.

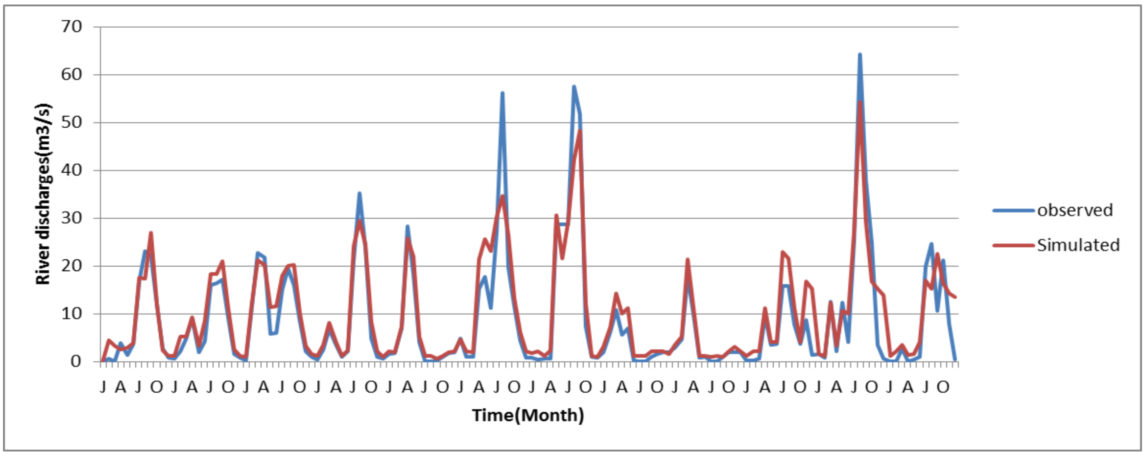
Simulations were conducted on a monthly and annual basis to compare the outputs with the observed discharges. The simulation results and observed data from 1988 to 1991 and from 2008 to 2011 were considered for calibration and validation repectively. In addition, the period from 1986 to 1988 was utilized for warming-up purpose.According to SWAT model developers (Santhiet al.,2001; Neitsch et al., 2005; and Arnold et.al, 2009), the acceptable performance measures for R^2>0.6 and ENs>0.5 was recommended.

It was observed that the calibration and validation results were examined and provided model performance measures of acceptable ranges(Table6.3). But, these measures for Meki catchment (Table 6.3) was not as good as the values for Wabe catchment due to some reasons.The first reason is that the hydrology of Meki catchment is observed to become highly dependent on the hydrogeologic characteristics of this area and the rift valley setting. This was indicated by the high values of sensitivity results related to groundwater parameters for Meki catchment. It was also seen that during calibration process, little changes in the values of Alpha Baseflow(ALPHA_BF), and groundwater delay (GW_delay)parameters for Meki catchment showed large changes to the pattern of the graph(Figure 6.9 a and b).

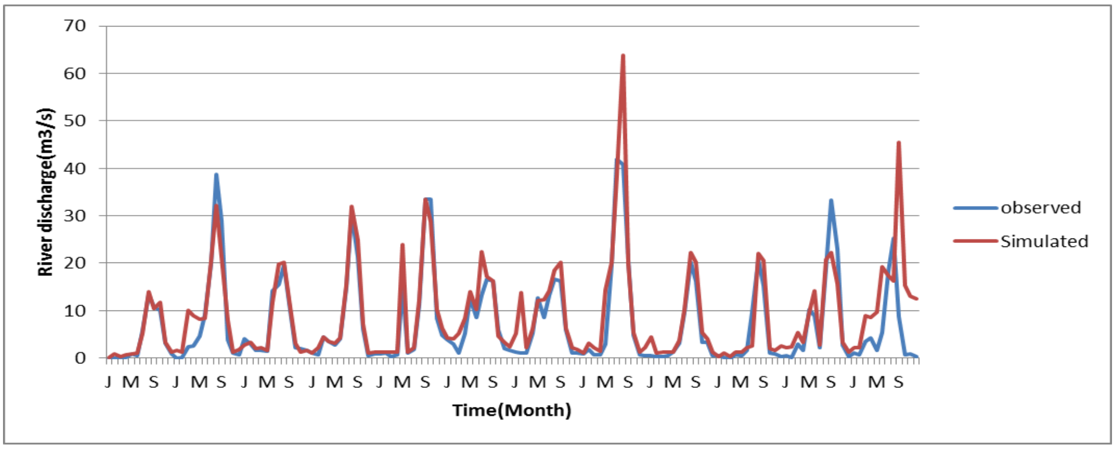
Table 6.3: Model performance summary for Calibration and Validation period for Meki

	Period	R^2	Ens
Calibration	1988-1999	0.61	0.52
Validation	2000-2011	0.62	0.53

In addition, the roles of geologic structures in this catchment wasnot explicitly addressed by the model itself as it only considers the cracks associated with soil layers. Moreover, there are discussions in the scientific communitiesabout the challenges and constraints of CN driven surface runoff generations(Garen and Moore,2005).Even so, in the case of Wabe the highest sensitivity value was for curve number(CN2) which controls the runoff generations. Therefore, the SWAT model generated results for Meki catchmentare not at least in a good agreement with results obtained for Wabe catchment. Similarly, lower values of performance measures for this catchment, but, acceptable values (ENS=0.54) was also obtained by Abraham et.al.,2007.Although applying CN for surface runoff generation has certain constraints which is observed in some places, its impact was insignificant in results obtained for Wabe catchment(Table 6.1). This result is in a good agreement with results obtained by other researchers in the country (For instance, Tibebe,(2011); and Chekol,(2007). Hence, this showed that the SWAT model can be applied comfortably for predicting the future flows in Wabe catchment, but, with those limitations for the case of Meki catchment.



a.



b.

Figure 6.8: Calibration (a) and validation (b) results of average monthly simulated and observed flows of Meki catchment

The surface runoff, baseflow, water yield and sediment yields were simulated and the results were summarized on the basis of monthly and annual values. In order to attain these results, an intensive calibrations were conducted. The outputs of these components are presented in Figures 6.9 to 6.11. The three components show the general trends of an increase from 1986 to 1996 and a decrease until 2011.

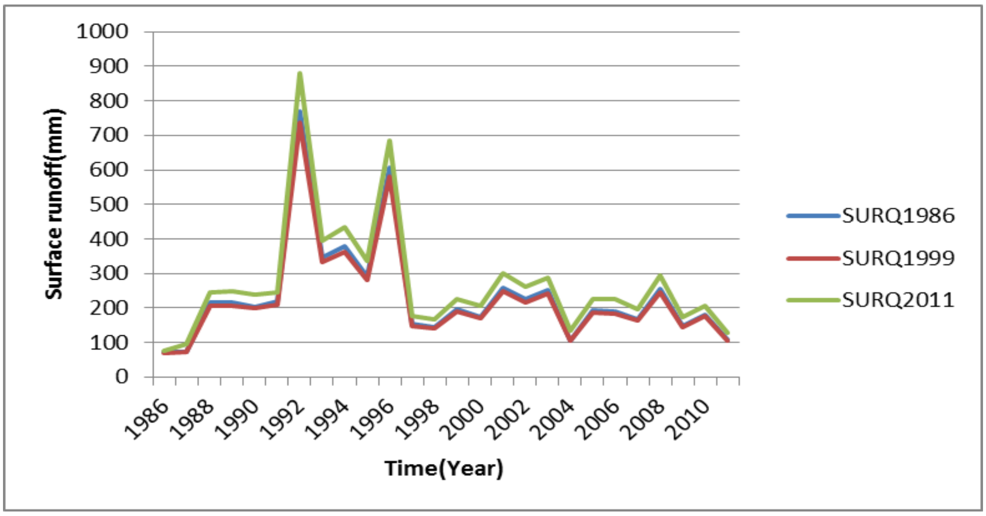


Figure 6.9 Surface runoff of Meki catchment and its variations from 1986-2011

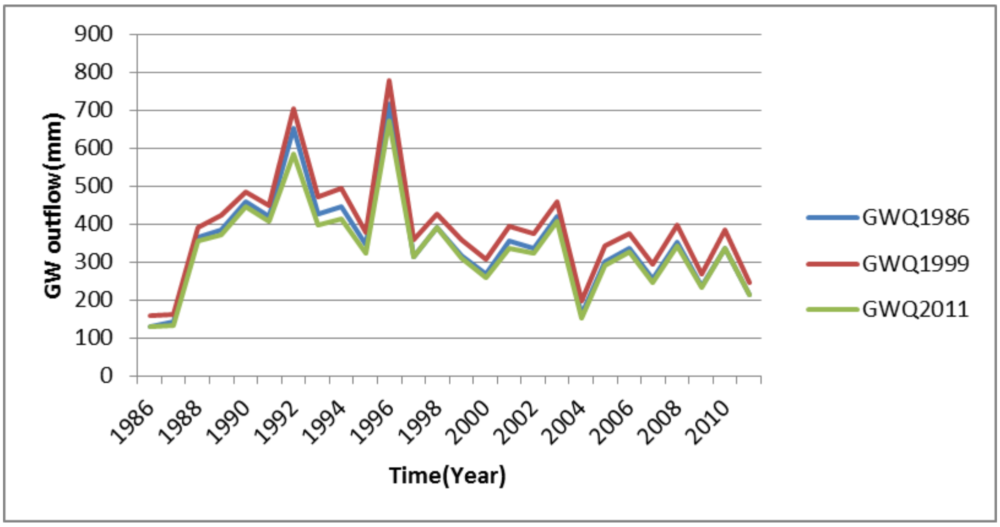


Figure 6.10 Groundwater flow(baseflow) of Meki catchment and its variations from 1986-2011

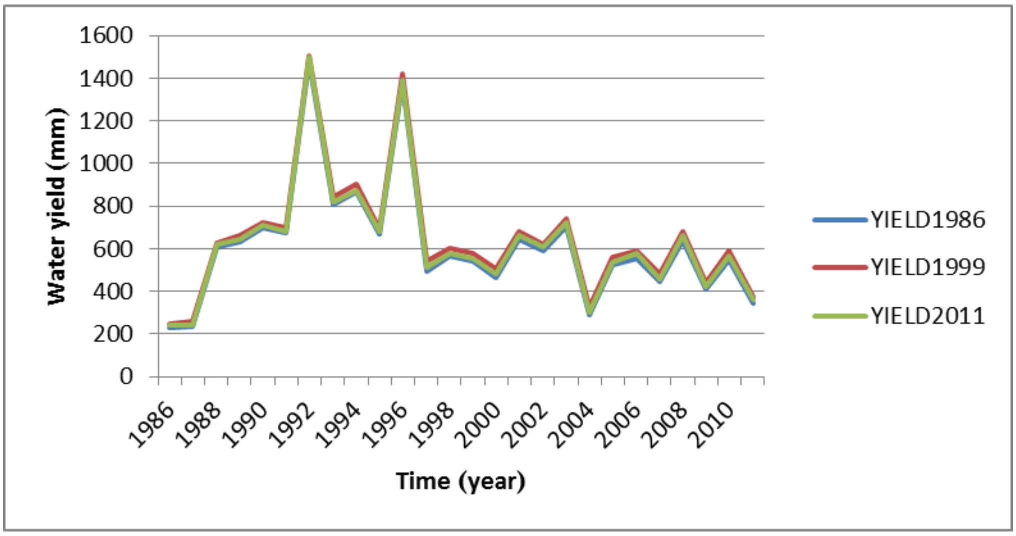


Figure 6.11 Annual mean yields of Meki catchment and its variations from1986-2011

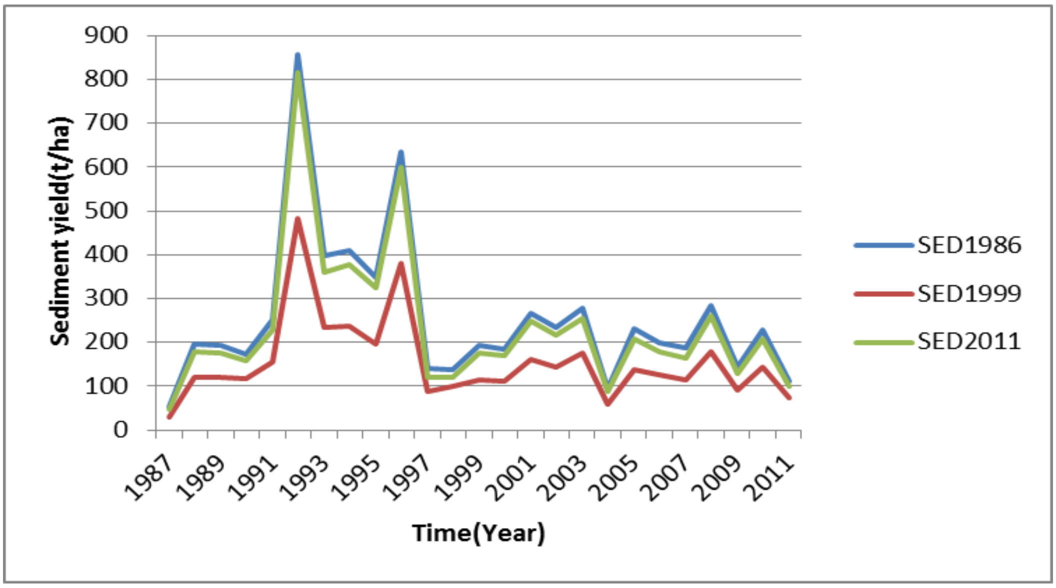


Figure 6.12 Annual mean sediment yield (ton/ha) of Meki catchment and its variations from1986-2011

Water balance is the main driving force in any of the applications of SWAT model in the watershed. Therefore, the model also computed the common water balance components(see Table 6.4) in addition to the above components. It can be observed that the mean watershed values of these components vary with the changes in catchment soil-water storage. The main water loss from the catchment is as a result of ET and in that it sharessignificant amount of the precipitation in both periods.

Table 6.4 shows the water balance ratio in the two periods

Parameters	**1986-1999**	**1999-2011**
Stream flow/precipitation	0.28	0.34
Base flow/total flow	0.45	0.36
Surface Runoff/total flow	0.59	0.62
Recharge/precipitation	0.17	0.15
ET/precipitation	0.66	0.77

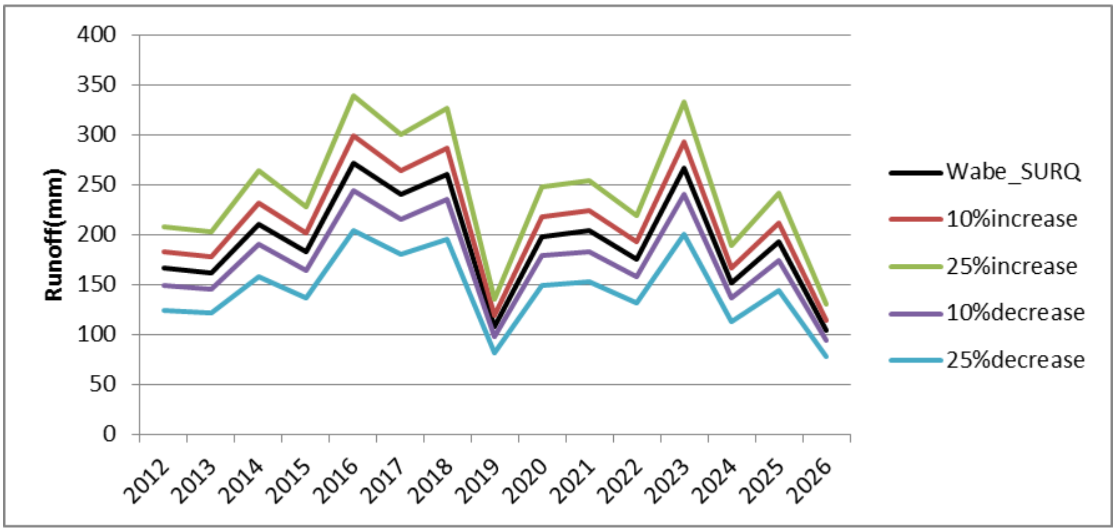
6.4 Predicting flows

SWAT model allows to simulate forecast scenario once the input files that contain the statistical data needed to generate daily climate data on the subbasins are obtained. Inforecast simulation, two periods are defined such as the forecast period and non-forecast period. To run forecast simulation, preparing a forecast weather(.cst) file is required. When the forecast period is simulated, the monthly weather generator parameters for precipitation and temperature are replaced with parameter values stored in the forecast input file(.cst). Therefore, to get these parameters(statistical derivatives of precipitation and temperature), different methods of climate forecasting need to be employed. These methods vary from simple climatology method to the complex and latest numerical weather predictions(forecast models).

The Climatology method is a simple way of producing a forecast which involves averaging weather statistics gathered for years to make the forecast. For example, if the climatology method is used to predict the weather for Meki on July 4, it is required to go through all the weather data that has been recorded on every July 4 and take an average. Thus, to make a forecast for temperature and precipitation, then this recorded weather data will be used to compute the average for temperature and precipitation. The climatology method works well when the weather pattern becomes similar to what was expected for the chosen time of year. Therefore for this work ,the historical climate data of years from 1986 to 2011 was examined and applied with assumptions that this pattern wil repeate in the future.

In addition to the climatic data, the land use/land cover data is re-classified based on the scenario that if the existing annual average rate(sections 5.3 and 5.4) of changes will continue, what will be the hydrological responses of the catchments between the years 2012and 2026. Accordingly, for Wabe catchment, deforestation will increase by 30%, however, cultivation and barren land/built-up areas will rise by 17% and 43% respectively. Similarly, in Meki catchment, forests and range land will decline to 9% and 13% respectively. However, cultivation and barren land/built-up areas will increaseto 62% and 22% respectively.

Similarly, keeping the above land use changes constant, for 10% and 25% increases in rainfall, the runoff will increase from 193mm to 212mm and 241mm andfrom 175mm to192mm and 219mm for Wabe and Meki cachments respectively. For 10% and 25% decreases, the runoff will decrease from 193mm to 174mm and to 145mm and from175mm to 158mm and 131mm for Wabe and Meki cachments respectively(Figures 6.13 and 6.14).



a.

b.

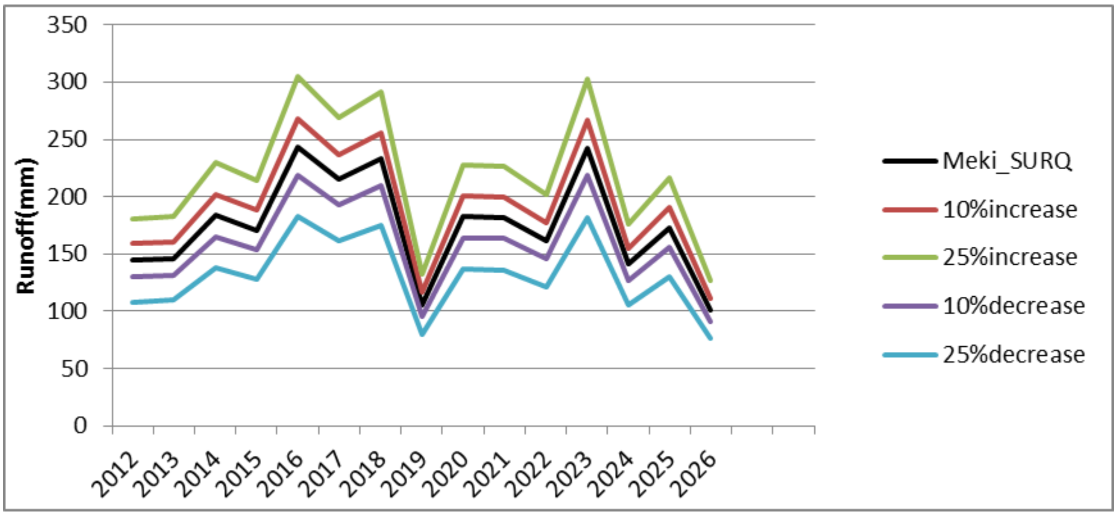


Figure6.13 Predicted mean flows: Wabe runoff(a), Meki runoff(b) for 2012-2026

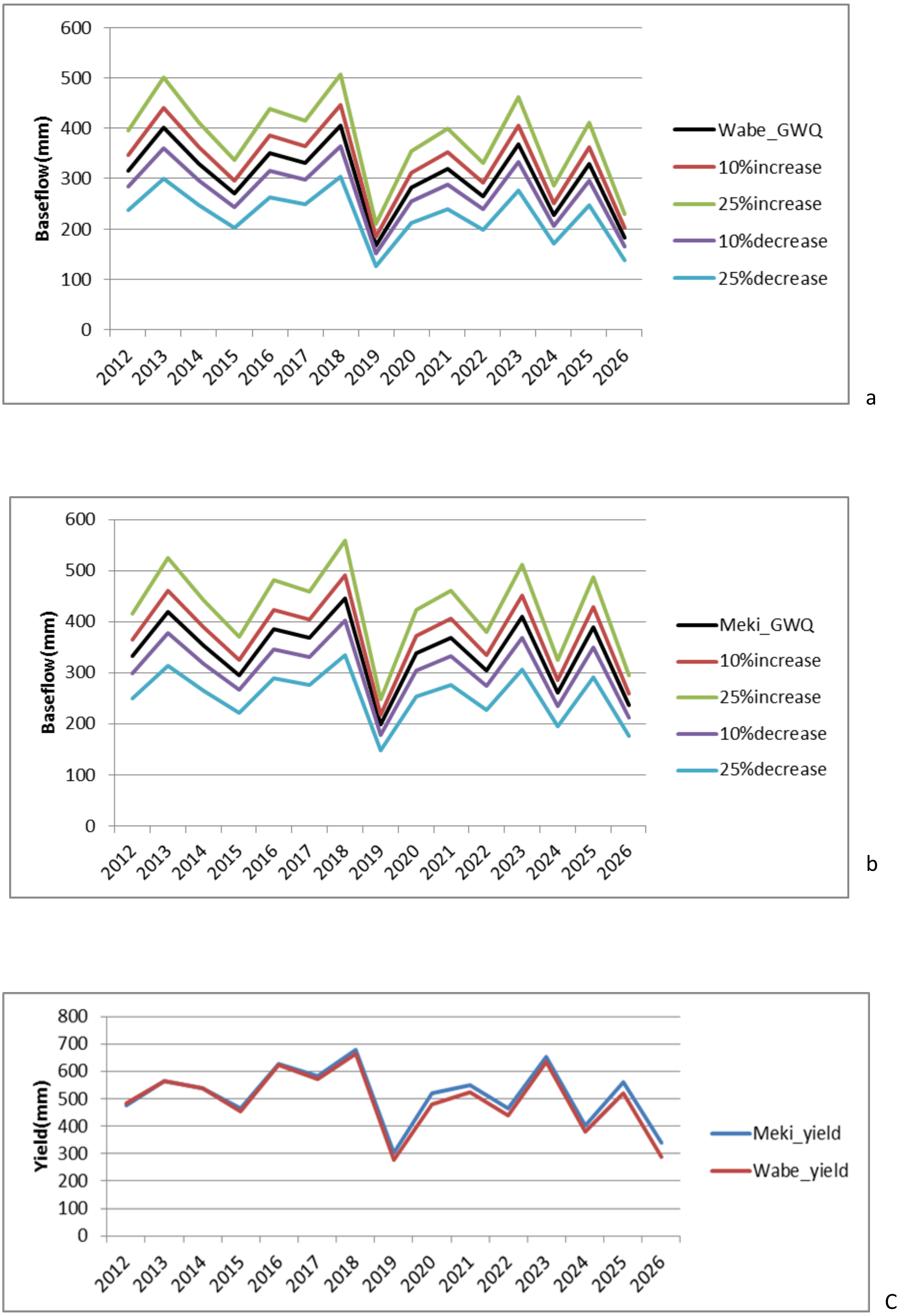


Figure6.14 Predicted mean flows: Wabe baseflows (a)Meki baseflows (b) and average yield(c) for 2012-2026

As a result of these changes, the effects are expressed on hydrologic components of the catchments(Figures6.13). Consequently, theaverage surface runoff decreases from 259mm to 195mm for Wabe catchment and decreases from 188mm to 177mm for Meki catchment. This differences in the declining ofsurface runoff of Wabe and Meki catchments can be associated to the general decline in rainfall factors thanthe expansion of cultivation by 17% and 11% for Wabe and Meki catchments respectively. The baseflows also decrease from 352mm to 303mm in Wabe, but increases from 144mm to 339mm in Meki catchment. The water yields of the future is expected to increase to 546mm for Meki, but decrease to 501mm for Wabe catchment. The monthly water yield for Wabe shows a decreasing trend whereas that of Meki catchment shows insignificant changes from the reference (Figure 6.14). Therefore, the future conditions of hydrological components of the catchments are dependent both on land use/and land cover changes and climatic factors.

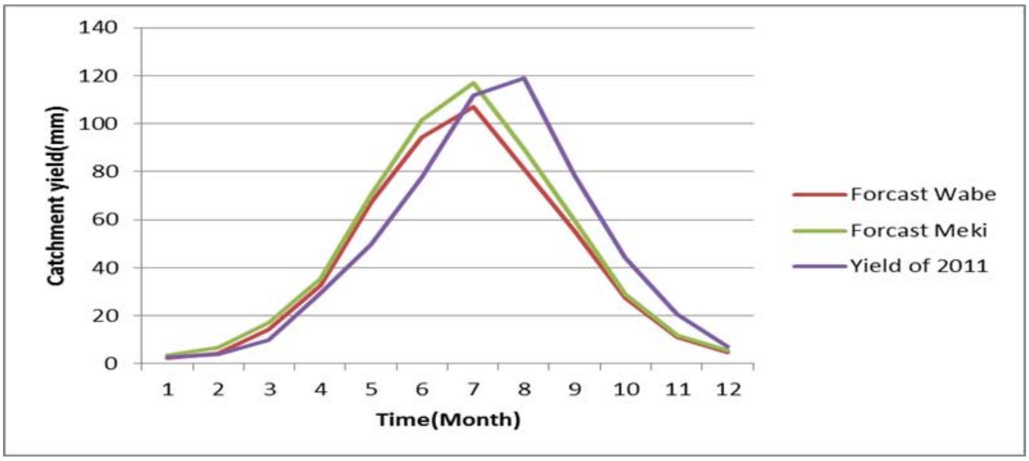


Figure 6. 14 Comparision of simulated and predicted monthly water yields for Wabe and Meki catchments

CHAPTER SEVEN

7. The effects of LULCC on hydrologic components and sedimentation

The effects of land use/land coverchange on hydrologic factors are manifested at different spatial andtemporal scales. The effects of land use and land cover change on water yields and sediment yields of the study area at different levels of conceptualization with respect to space and time will be discussedbased on the simulation results. To clearly observe the impacts, Surface Runoff (SURQ), and Groundwater flow (GWQ), which are the main components of the catchment water yields,are mostly considered.

7.1. Catchment scale: Wabe

The forest lands decreased from 40% in 1986 to 32% in 1999 and further to 25% in2011. Most of the forests were cleared to expand farming lands. This was implied by the increase in agricultural lands from 38% in 1986 to 51% in 1999 although they were decreased to 49% in 2011. The range land was decreased by 5% in the first period (1986-1999) whereas increased by the same percent in the second period (1999-2011).

These changes could have impacts on soil and water, biodiversity and microclimate conditions of the catchment(Lambin *et al*., 2003). Particular to hydrologic aspects, the land use and land cover type can affect both the infiltration and runoff amount depending mostly onthe decline in rainfalls (Hougton, 1995; Abebe, 2005).

The surfacerunoff of this catchment was decreasedby 2mm from its value in 1986, but increased by 5mm in 2011 from its value of 1999 whereasthe recharges to the aquifers remained constant between 1986 and 1999, but declined by 5% in 2011 from its value in the first period(Figure 6.4).

The groundwater outflow(baseflow) also followed similar trend with recharges.The baseflow showed insignificant change between 1986 and 1999, but decreased by 5% in 2011 from its value of the 1986 and 1999(Figure 6.5). Table 7.2shows the summary of simulation results for some hydrologic components for both catchments. It was indicated in the table that the ET was increased from 628.38mm in 1986 to 644.71 in 2011. Conversely, soil water contents reduced from 99.57mm in 1986 to 96.20mm in 2011. Therefore, thissmall decreases in runoff during the first period, was related to increases in evaporations from the catchments owing to deforstations with almost hardly any variations in temperatures of this period. However, in the second period, the impacts from bothincreased bare lands and intensified cultivations were prevalent in the increased surface runoffs regardless of the effects from increased ET at this time.The increases in bare lands and agricultural lands could cause the surface runoff to raise by modifying the land surfacesafter certain times of deforstations. In turn, this land surface modifications along with increases in surface runoffs was also manifested in the sediment yields of the catchments.

The catchment water yield was decreased by 15mm from 1986 to 2011 and it followed similar trend with baseflow. This indicates that the yield of the catchment is more dependent on the baseflow than on the surface runoffs. The baseflow and surface runoff contributed 56% and 44% to catchment water yield respectively. The impacts of deforstations in 1990s (forest harvests)on the recharges was highly manifested in the later period when the recharge was reduced by 20mm in 2011. This condition was also supported by the reduction in soil water contents as a result of limited infiltrations.This amount of reduction in recharges would have substantial effects both onwater supply to local communities and amount of water avilability in the streams during the dry period.In addition to this effects on the hydrologic components, the reduction inforest coverage of the catchment could have impacts on the local rainfalls in the catchments.

As it was observed in the results of the modelon the catchment scale analysis,some of the components showed insignificant variations, especially in the first period while others were affected seriously by land use/land cover changes. Considering the spatial and temporal variability of these hydrologic components and the effects of land use/land cover changes, the more visible impactshave been adressed by dealing with these conditions on sub-catchment/subbasin scale which are relatively of higher spatial resolution.

7.2. Subbasin scale for Wabe Catchment

The Wabe catchment was subdivided into five subbasinsbased on the watershed characteristics(Figure 2.1). Normally, the hydrologic processes are simulated at HRU level which has unique land use, soil, and slope combinations. These HRUs are then combined to get and describe the hydrologic components of each subbasins.

Table 7.1Basic physical characteristics of Wabe subbasins

Subbasin Name	**Area(ha)**	**DominantLanduse/land cover in 1986/1999/2011**	**Dominant soil**	**Dominant slope**
Subbasin1	14,760	Forest land / Agricultural land/ Agricultural land	SL	0-5
Subbasin2	66,764	Agricultural land/ Agricultural land/Range and Agricultural land	C	5-10
Subbasin3	14,040	Agricultural land/Agricultural land/Agricultural land	SL	0-5
Subbasin4	45,452	Agricultural land/Forest/Agricultural/ Agricultural land	C	5-10
Subbasin5	31,604	Agricultural land/Agricultural land/Forest	SL	0-5

7.2.1 Subbasin1

This subbasin is characterized dominantly by sandy loam soil, and slopes that range from 0 to 5%. The forest land coveragewas dominant in 1986, but it was changed into agricultural land in both years, 1999 and 2011. Its areal coverage is the smallest of all the subbasins, and it is located in the Northwestern part of the catchment. The subbasin is drained by Demekash river which is one of the tributaries of Legedima river that feeds Wabe river.

Hydrogeologically, it is mostly characterized by ignimbrites and basaltic aquifers of Nazereth group and Tarmaber formations repectively. In this subbasin, hardly any geological structure is observed. This subbasin is partlylocated in the transitional and partly in the recharge zones of the catchment that gets its water from the foothills of *Weliso* areas, in the Northwestern part of the study catchment. The recharge accounted for about 28% of the precipitations between 1986 and 2011. The hydraulic characteristics of this subbasin showed that it has low transmissivity and hydraulic conductivity.

The baseflow contributions ofthe subbasin showed insignificant variations from 1986 to 2011, and smaller than the average baseflows of the subbasins.Similar to the baseflow, the surface runoff and water yields of the subbasin also showed hardly any variations and their values are 223mm and 577mm respectively.This invariability could be attributed to its small size, and the dominant *Enset*,drought resistant plant, cultivations in most parts of the subbasin. The effects of the size of the subbasin is clearly visible in the relatively small values of runoffs collected from the subbasin, although the land use was conducive for generations of larger amounts of runoffs especially in the second period. Therefore, hydrologic characteristics of this subbasin has been governed more by cummulative effects of physiographic and hydrogeologic conditions that characterize the area.

7.2.2 Subbasin2

The subbasin was dominated by forests land and range lands in thefirst perod and thisclass changed much to agricultural lands in the second period. However, some plantations were also made in addition to the existance of remnant range lands in the second period. Its dominant slope ranges from 5-10% and it has clay soilsin most of its areas. It has the biggest areal coverage in the catchment. In addition to cultivation at this level of slope, the subbasin is drained by large perennial rivers like Cheika, Gogni, and Welene. The latter two have their source from Guraghe ridge and they form the former.

The main lithologic units of the subbasin are ignimbrites and basalts which found in both transitional and recharge zones of the catchment. Hence, its recharge represents28% to 36% of the precipitations between 1986 and 2011. Typically, the subbasin is populated by a number of springs that have high discharges. The hydraulic characteristics of this subbasin showed that it has low to intermediate hydraulic conductivity and transmissivity. In addition to this, relative to the other subbasins, it is cut by few geological structures that seem to convey recharged water from the foot of the ridge towards Southwest of the catchment. Hence, both the lithologies and structures play a great role in characterizing the groundwater conditions of this subbasin.

Surface runoff of this subbasin was by far the largest of all the subbasins from1986 to 2011. Its amount varies from 278mm to 292mm which constituted 20% to 32% of the precipitations during this time. However, this value showed little decrease between 1999 and 2011. It is less likely that the expanded agricultural lands during the second period caused thelarge amount of surface runoffs in the subbasin.

In contrast to the surface runoff, the baseflow contribution to the streams was least as compared to the other subbasins between 1986 and 2011. Normally, the baseflow in 1986 was relatively larger than that of 1999 and 2011. Although,the amount of baseflow was smaller, the discharges of the rivers, particularly Cheika and Gogni,did not vary that much during the dry season. The conversion of most forest lands into cultivations in the second period was the main reason for 17% reduction in recharges to aquifer between 1986 and 1999 despite its limited recovery in the second period. In addition to these factors, the soil water contents of the subbasin is the largest next to subbasin4. This signifies that the thick clay soils of the subbasin impacted water recharging to groudwater which in turn affected the amount of baseflow contributions to streams. This condition was also witnessed during field visit, whereby high discharge springs emerging from beneath thick soils of the subbasin observed at different places.

In general, the hydrologic behaviour of this subbasin could be explained by the cummulative effects of the dominant clay soils, the hydrogeologic characteristics and the land use/land cover changes (agriculture and range land) of this subbasin.

7.2.3 Subbasin3

This subbasin is dominantly characterized by sandyloam soils, slope that range from 0 to 5% and agricultural lands in both periods. Its areal coverage is the smallest of all the subbasins and located in the central part of the catchment. The subbasin is drained by Legedima perennial river which empties into Wabe river along with Kereb river.

Hydrogeologically, it is dominantly covered with ignimbrite aquifers of Nazeret group formations. In this subbasin, hardly any geological structure is observed. It is found in both discharge and transitional zones of the catchment that gets its water from the upstream areas of the catchment. The recharges of this subbasin has the highest percentage (56%) of the precipitations in 1986 and this share was declined to 40% in the later times.The hydraulic characteristics of this subbasin showed that it has low to intermediate transmissivity and hydraulic conductivity.

Though baseflow contributions to the streams in this subbasin was the highest in 1986 (692mm), it declined by 49% in both 1999 and 2011. Whereas, the surface runoff was the least (62mm) of all subbasins in 1986, but it increased by the value of 161mm in both 1999 and 2011. The water yield of this subbasin followed the trend of the baseflow in that it was 759mm in 1986 and decreased to 565mm both in 1999 and 2011. It is easily observed that the subbasin yield was highly affected by the baseflow fluctuations. The possible evidence that corrobotares the highest values of recharge and baseflow in the first period could be associated with lateral flows to the subbasin from adjacent catchment. This might be so, because the soilwater contents of the subbasin was relatively smaller than the other two subbasins and couldnot provide clue as to their increament. The increase in the surface runoffs in the second period could be as a result of conducive land use and land coverage, extensive cultivations.Therefore, hydrologic characteristics of this subbasin could be explained by the integrated effects of physiographic, (hydro)geologic and the land use/land cover changes of the area.

7.2.4 Subbasin4

The subbasin was characterized predominantly by agricultural land and forests (natural and plantations)in 1986 and in the following years the land use/land cover were modified to encompass both cultivable lands and appreciable amounts of plantations.Even at some places in the subbasin, the overcultivated lands and deforested areas were observed to be converted to plantations. It has slope values that range from 5-10% and dominant clay soil type.Its areal coverage is the largest next to subbasin2 in the catchment. One of the biggest rivers in this catchment, Kereb, is found in this subbasin.

Hydrogeologically, it is mainly characterized by ignimbrite aquifers of Nazereth group formations. This subbasin is so vast that it includes discharge, transitional and recharge zones of the catchment.Its recharge zone contributed huge amount of water to the aquifer and its percentage in the precipitation ranges from 29% to 52% in both periods.Some springs and boreholes associated with geological structures that align almost with the regional faults are prevalent in the subbasin. The hydraulic characteristics of this subbasin showed that it hasintermediate to highhydraulic conductivity and transmissivity. The high values could also be related to the higherdensity of these structures indicating both the lithologies and geologic structures play a considerablerole in characterizing the groundwater conditions of this subbasin. The large discharges of this river, in addition to cultivation and hydrogeological characteristics of this subbasin have significant effects on the high yields that it let to the Wabe catchment.

The baseflowcontribution to the stream increased from 357mm in 1986 to 535mm in 1999 but decreased by 30% from this value in 2011.Similar trend was observed in recharges which increased in the first period and decreased later.The surface runoff decreased from 268 in 1986 to 205mm in 1999, but increased to 256mm in 2011. Thesechanges to baseflow and runoff were due to shiftland use/land cover. In the first period, the agricultural lands were not that much extended and even some shift was made towardsthe range lands. Hence, the decline in runoff could be ascribed to the extension of forests into overcultivated lands. In contrast, the recharges increased as the land surface was modified and made easy for the waters to get infiltrated. This was observed in the increased soil water contents from 107mm to 111mm in 1986 and 1999 respectively. However, in the second period, the extension of the forests was particularly related to the plantations(cheifly*Eucalyptus trees*) in 1990s. Presumably, the large and deep roots of these trees could have sucked much amount of the infiltrated waters from the root zone and beyond before reaching the water table. Theamount of recharging water to the shallow aquifer decreased, and this in turnnegatively affected the amount of groundwater outflow to the nearby river. In the second period, the bare lands and the small increase in agriculture in a dispersed mannerwere observed and clearly caused increase in therunoffs of the subbasin in this period. Therefore, based on the above results, the hydrologic characteristics of this subbasin is primarily affected by land use/land cover change besides significant influences from the hydrogeologic nature of the subbasin.

7.2.5 Subbasin5

This subbasin is predominantly characterized by sandy loam soils, and slope that ranges from 0 to 5%. Its areal coverage is close to the mean of the subbasins. It is located in the west part of the catchment where the Wabe river joins Omo-Gibe river. The subbasin is drained by Wabe river which is fed by Legedima and Kereb rivers. The dominant land use/land cover types are forest and agriculture where in the second period some of the overcultivated areas were replaced by plantations. In contrast, some farming lands were extended and thereby engulfed marginal deforested areas.

Hydrogeologically, it is covered with basaltic and ignimbrites aquifers of Jimma volcanics and Nazereth group formations respectively. In this subbasin, hardly any geological structure is observed. Its location isin the discharge zones of the catchment that gets its water from the upstream areas and local precipitations. The hydraulic characteristics of this subbasin varies from low to intermediate values for transmissivity and hydraulic conductivity.

The baseflow contributions of groundwater in this subbasin is the least compared to values of other subbasin except in 2011. These valuesare 338mm both in 1986 and 1999increased to 686mm in 2011. The recharges also showed similar trend that it accounts for 30% to 75% of the precipitations in the first and second periods respectively. The high values in the second period could be related to inflows from the adjacent Walga catchment (north of Wabe catchment) that drains *Woliso* areas. This effect was also assumed to be visible in surface runoffs of this subbasin. According to rainfalls recorded in *Weliso* and *Welkite* stations, the records from *Woliso* station was on average 243mm higher than the one recorded on *Welkite* station in the last five years of the second period (2007-2011).

Concerning surface runoff, no significant change was observed in runoff values (221mm) of 1986 and 1999, but this value was reduced to 61mm in 2011. However, little change was observed in the soil water contents of this subbasin in the second period which increased from 62mm to 66mm. In addition to this condition, the decreases in runoffs of the second period could also be associated withmuch decline in the rainfall and modifications in land use, replacing natural forests with plantations, and cultivation, in this period. This subbasin outlets its water yield into Omo-Gibe river, in the area which is characterized by semi-arid(*Gibe bereha*) climatic conditions unlike most of the upstream subbasins. The water yields exhibited the trends of the recharges and baseflow, where its value increased from 568mm in the first period to 761mm in the second period. In connection with the unexpected effects of the adjacent catchment, this situation was also seen in subbasins 1 and 3, apart from this subbasin. Therefore, additional research needs to be conducted to acertain the relationship between these adjacent catchments so as to come up with sound conclution.

In this subbasin, the land use/land cover changes,size and the elongated shape of the subbasin along with the decreasing rainfallcaused these hydrologic factors to vary unexpectedly.

7.3. Sedimentation and Soil erosion in Wabe catchment

Soil erosion is a worldwide environmental problem that degrades soil productivity and water quality, causes sedimentation of reservoirs and increases the probability of floods (D.Oyung& J.Bartholic, 2001). Most of the countries in the tropics have no appropriate and accurate soil erosionprediction model although the Soil Loss Estimation Model for Southern Africa (SLEMSA) and theUniversal Soil Loss Equation (USLE) are used in some of the countries (M.K. Mulengera, 1999). SWAT employs MUSLE (Williams,1975) to compute erosion caused by rainfalls and runoffs. This is a modified version of USLE developed by Wischmeire and Smith(1965,1978). USLE predicts average annual gross erosion as a function of rainfall energy. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This improves the sediment yield prediction, as the runoff is a function of antecedent moisture conditions and rainfall energy.

Wabe river contributes substantially to the siltations and sedimentation of the Omo-Gibe basin and thereby it has been highly argued that it couldaffectdams constructed in downstream(Figure 6.6). Thus, the assessement of soil erosion rate and sediment yields of these rivers(Meki and Wabe) in relation to changes in land use/land cover is essential for implementing proper management practices.

From the analysis of LULCC of the 1986-2011, the average annual sediment yield of the catchment was estimated by the model and indicated that it was decreased from 37.25 t/ha in scenario 1986 to 31.17 t/ha in 1999, but, increased to 49t/ha in 2011. On this scale, the sediment yield generated was highly susceptible to little changes in surface runoff. For instance, for 1.5mm change in runoff between 1986 and 1999, the sediment yield was declined by about 6t/ha. Similarly, for 4.7mm increase in runoff between 1999 and 2011, the sediment yield was raisedby 18t/ha. These changes were attributed to the land use and land cover changes that would affect the runoffs of the catchment in this both period.

In the same way, sediment yields generated from different subbasins of the catchment vary based on the main physical characteristics of the subbasins and changes to surface runoffs of the particular subbasin. Accordingly, the annual average of the sediment yields of the five subbasins was 31.42t/ha. Hence, based on this average value, the sediment yields generated from subbasin1(14t/ha) and subbasin3 (22t/ha), largely due to their sizes, are much smaller than the average value while subbasins2 (44t/ha), subbasin4 (40t/ha), and subbasin5 (37t/ha) produced values much larger than the average value of the subbasins. The sediment yields from subbasin2 indicated an increase from 34 t/ha in 1986 to 50 t/ha in 2011.However, yields from subbasin4 reducedfrom 51t/ha in 1986 to 0.3t/ha in 1999, but it increased to 68t/ha in 2011. The sediment yields from downstream, subbasin5,increased from 55t/ha in 1986 to 56t/ha in 1999, but decreased to o.1t/ha in 2011 which showed the direct impacts of surface runoffs that followed similar trend. In subbasin4, the expansion of plantations was carried out at the expense of some range lands for some years after 1984/85 drought. This situation caused the sediment to decline that much. Obviously, the decreased runoff in this period was the major factor for these effects. The increased agricultural lands that are drained by high discharge rivers, in both subbasin2 and subbasin4 caused an increase in sediment yields of the subbasins in the later period. In addition to the land use/land cover conditions, in both subbasins, relatively higher yields were observed due to the dominant clay soil type which has poorer infiltration capacity and relatively higher soil erodibility than other soils in the catchment. These variations in sediment yields of the subbasins at different times show that land degradations affectedland forms mainly as a result of land use/land cover changes. In this catchment, the main land use type contributing to sediment yields were intensified cultivation, and deforestation as well as little impacts of barren lands. Thus, the effects of land use/land cover changes on the rate of erosion and sedimentation is more prevalent in subbasins having different values of surface runoffs.

Table7.2Simulated reults of the catchments using land use/land covers of 1986, 1999 and 2011

	Wabe catchment			Meki catchment		
Parameters	**1986**	**1999**	**2011**	**1986**	**1999**	**2011**
Water yield(mm)	629.15	627.54	614.33	397.31	226.32	399.32
Groundwater flow(mm)	370.2	370.24	352.19	215.74	71.02	144.72
Surface runoff(mm)	255.59	254.08	258.71	163.68	157.69	188.03
Recharge(mm)	401.87	401.96	382.1	232.49	76.38	155.44
ET(mm)	628.38	630.04	644.71	630.59	595.16	611.4
Sediment(t/ha)	37.25	31.16	49.06	51.47	31.19	47.29

7.4. Catchment scale:Meki

Assessing the land use/land cover changes of the past 25 years in Meki catchment showed that the forested lands reduced by 11%, rangelands by 3% and water body by 1% between 1986 and 2011. However, the agricultural lands and barren lands/built-up areas increased by 8% and 7% repectively in these years. Unexpectedly, the forests were shrinked by 9% in the first period(1986-1999), whereas, they were reduced only by 2% in the second period(1999-2011). Regardless of the decline in forest coverage, the surface runoff of the catchment was decreased in the former period and increased in the latter period (Table 7.2). This indicates that deforestation maynot always be contributing to the increases in runoffs as it depends on thepercentage of slope at which deforestation happened. Rather, itshowed that deforstation seemed to increase the amount of water available in the soil. Thus, the water would have sufficient time to recharge into the shallow aquifer so as to raise the baseflows. This could also be associated with the reduction in water taken by plant roots which in turn caused an increase in soil water contents from 95mm in 1986 to 99mm in1999.

According to information from local agricultural offices, there were soil and water conservation interventions which were effective in the early stage. However, in some parts, these interventions affected the environment adversely in the later stages. Typical examples are the large gullies that wereincised around *Butajira* and *Kibet* after few years of implementing Gabions and other physical structures which were not supported by plantations.

In the years between 1986 and 1999, the agricultural lands were expanded only by 2%, but in the years between 1999 and 2011, they were expanded by 6% which inducedincrease in runoffs in the latter period. Similarly, in this period, the sediment yields were also increased as a result of enhancement in the surface runoffs and malfunctioning of the implemented land management practices.

In the years between 1999 and 2011, the agricultural lands were raised by 6%, mostly at the expense of range lands. Both forest and wetlands were declined by 2%, however, the bare land/built up area was further expanded by 2% in this period. As a consequence of these changes, the annual average surface runoff was decreased by 4% from 1986 to1999,but increased by 19% between 1999 and 2011(Table 7.2). Similarily, the annual mean of baseflow was decreased by 67% between 1986 and1999, but increased by 102% between 1999 and 2011(Table 7.2).Likewise, the changes to water yield of the catchment showed a decrease of171mm from 1986 to 1999, but an increase of 2mm in 2011 from its value of 1986.With the general decrease in the rainfall of the catchment, in the second period, the larger portion of the rainfall was taken by surface runoffs than infiltrations into the soil profile. This could be related to the cumulative effects of the reductions in the vegetation coverage of the area and expnsions of cultivation which usually reworked the top soil. On the other hand, the recharge determined for the catchment decreased from 232mm in 1986 to 76mm in 1999, butincreased to 155mm in 2011. Its percentage in precipitation varies between 9% and 25%. Therefore, the average recharge for this catchment was 154.77 mm and this can be compared with recharge estimated using various methods by different researchers and instituitions. For instance,AG consult,Consulting Hydrogeologists & Engineers,using different methods for this catchment estimated average recharge of 119.71mm (Dereje Birhanu, 2011).Ayenew(2005) noted that the recharge in the Ziway-Shalla basin of the rift valley varies from 10mm to 100mm from rift floor to the highlands. Similarily, EWTC (2008) estimated recharge for Meki catchment using water balance method, and WEAP model and obtained 130mm and 100mm respectively.

The water yields from this catchment is more dependent on the groundwater outflows (baseflows) from the catchments. In both periods the water yield was in line with the trends of the groundwater component. The surface runoff and groundwater outflows contributed 39% and 56% to the catchment water yields respectively. Normally, this contributions varies from one subcatchment(subbasin) to another based on the physical characteristics of these subcatchments(subbasin). Hence, the details of the hydrologic conditions of the subbasins will be discussed in the following section.

7.5. Subbasin scale for Meki Catchment

The Meki catchment is subdivided into five subbasins based on the watershed characteristics. Normally, the hydrologic processes are simulated at HRU level which has unique land use, soil, and slope combination. These HRUs are then combined to get and describe the hydrologic components of each subbasins.

Table 7.3 Basic physical characteristics of Meki subbasins

Subbasin Name	Area(Ha)	Dominant Landuse/land covers in 1986/1999/2011	Dominant soil	Dominant slope
Subbasin1	58404	Forest and agricultural land/ agricultural land, forest, range land/ agricultural land and forest	SL & C	5-10,0-5, >20
Subbasin2	10836	Agricultural land andforest/Forest,agricultural land,bare and range/Forest and Agricultural land	SL	0-5 &>20
Subbasin3	58488	Agri,Forest,Range&Water/Agri,Range,Forest&Bare,Water/Agri,Forest,Range&Water	SL	0-5,5-10 &>20
Subbasin4	36228	Agri,Range,Water&Bare/Agri,Bare&Water/ Agri,Range&Water	C	0-5
Subbasin5	46405	Agri,Range,Forest&Bare/ /Agri&Range/Range,Agri&Bare	S &SL	0-5

7.5.1 Subbasin1

This subbasin is characterized by sandy loam and clay soils. The last 25 years (1986-2011), much of the forestand range land covers were changed to farming land and hence,at present,most of the subbasin areas are used for agricultural activities. Physiographically, it is dominated by the highland and escarpments, and it has slope classes of 0-5, 5-10, and greater than 20 percent. It is a common parctice to observe cultivation in most of the areas with this much slope, especially the middle class which could have a potential of aggravating land degradations. The higher slopes are due to the location of the subbasin which is found adjecent to the Guraghe ridge. Its areal coverage is among the largest subbasins in this catchment and found in the northern part of Meki catchment. This subbasin is drained by Atamuja river which emanates from the ridge and passes through Bui and Kela towns before joining the main Meki river in the central part of the catchment.

Hydrogeologically, this subbasin is mostly characterized by varieties of ignimbrites from both Nazereth group and Dino formations. In this subbasin, few geological structures that follow the regional and local trends are observed.

This is found in one of the main recharge zones of the catchment as it receives high amount of rainfall. Water from the escarpments and its foothills flows towards the central parts of the catchment. The transmissivity and hydraulic conductivity of this subbasin varies from low to intermediate.

The baseflow contributions of this subbasin increased from 312mm in 1986 to 420mm in 1999. This value then decreased to 274mm in 2011 as cultivation was the dominant land cover in this time. The surface runoff was rasied from 257mm in 1986 to 286mm in 1999. However, it declined to 261mm in 2011.This increase in surface runoff at this particular subbasin could be associated with the large size of the subbasin at relatively high slope which provided suitable environment to generate the runoff even from small changes in rainfall during this time. The impact of these factors was integrated with the effects from reduced forest and increased bare land/built up areas in this period.

Regardless of the smaller value of runoff than baseflow, the subbasin contributed high yield to the catchment due to large amount of both surface runoff and baseflow. However, the trends of water yield which decreased from 1986 to 2011 in this subbasin was not similar to both surface runoff and baseflow. This could be attributed to the effects of the geological structures that transect the subbasin. In addition to this, there are irrigation activities in *Bui*and K*ella* areas that are taking significant amount of water from the subbasin. Therefore, hydrologic characteristics of this subbasin has been governed by cummulative effects of physiographic, hydrogeologic and land use/land cover.

7.5.2 Subbasin2

This subbasin is characterized dominantly by sandy loam soil. In years between 1986 and 2011, much of the forests were converted to range land cover and cultivation and hence,at present,most part of the subbasin is are covered with agricultural activities.

Physiographically, it is dominated by highland and escarpments, and it has two slope classes of 0-5%, and those greater than 20%. The slope class that varies from 0-5% was largely occoupied by cultivation in this subbasin and especially the irrigation activities around Butajira areas are evidence for intensified agricultural works in the subbasin. The higher slopes are parts of the ridge and escarpment. Its areal coverage is the smallest and elongated from the wetern to the central part of Meki catchment. This subbasin is drained by Irenzaf river which emanates from the ridge and feeds *Inseno-Kela* plain before it emties into Weja river in the central part of this catchment.

Hydrogeologically, this subbasin is mostly characterized by lithologic units of ignimbrites, varieties of basalt and lacustrine and alluvial deposits of Tarmaber formations, Nazereth group and Dino formations. The subbasin is cut by geological structures that trends in the similar direction to that of regional and local rift faults. Its western side is part of the recharge zones while its eastern part extends to the foot of the escarpment. This part of the catchment is also characterized by high rainfall amount. The general values of transmissivity and hydraulic conductivity of this subbasin varies from low to intermediate. However, the parts which are close to the faults show relatively higher values of hydraulic conductivity. The groundwater flow direction from this subbasin is also expected to follow the general flow directions which is towards the East of the catchment.

The baseflow contributions of this subbasin increased from 300mm in 1986 to 696mm in 1999. This value then decreased to 258mm in 2011 as cultivation was the dominant land cover in this time. The surface runoff was declined from 212mm in 1986 to 62mm in 1999. However, it increased to 256mm in 2011. The decrease in the surface runoff during this period was ascribed to plantations that was carried out after the 1985/86 severe drought that hit many parts of the country. It was carried out even at the expnse of overcultivatedlands and this led to small reduction in agricultural lands. In addition to these factors, comparing the amount of rainfalls in *Bui* and *Butajira* areas of the main runoff producing months of July and August, the values recorded in Bui areas are much larger than those in Butajira area. The later increases in surface runoff was related to the raised agricultural lands at the expense of bare lands and grazing lands and even extended to some parts of the previous plantations.

The subbasin water yield increased from 1986 to 1999 but decreased from 1999 to 2011 following similar trend with groundwater outflow. Its values in 1999 was the highest of all subbasins. This could be as a consequence of the larger values of groundwater contributions as compared to surface runoff. This much value, 808mm, of subbasin yield was more than expected. Thus, the excess amount could be related to lateral gain from the adjacent subbasin or the quantity that was cotributed from return flows of the irrigation activities. The recharges in this subbasin was increased from 324mm in 1986 to 738mm in 1999 but decreased from this amount to 279mm in 2011. Therefore, hydrologic characteristics of this subbasin is controlled by the cummulative effects of physiographic, climate, hydrogeologic and land use/land cover.

7.5.3 Subbasin3

This subbasin is characterized by sandy loam soil. The last 25 years , vast area of forest, range land cover, and wetlands were changed mainly to cultivation and bare lands/built up areas. At present, most parts of the subbasin are used for agricultural activities. Physiographically, it is dominated by highland, escarpment, and parts of Kuntane-Inseno plain that is occoupied by water body and swamps (wetland). It has slope classes of 0-5, 5-10, and greater than 20 percents. It is a common practice to observe cultivation in most of the areas which are fed by irrigation from springs and borehole water sources. Utilizing areas with this much slope for agricultural and related activities could have adverse effects especially in relation to land degradation.Typical gullies observed in this subbasin might have been associated with these practices. Its areal coverage makes it the largest subbasin in this catchment and found in the southern central part of the Meki catchment. It is located between western escarpment and Tora-Koshe ridge. This subbasin is drained by Eresho and Kibet rivers which emanate from the Guraghe ridge and feed the swamps in the plain.

The subbasin is coverd by the main four lithologic units in this study catchment. The Western part is dominated by Nazereth group and Tarmaber formations while its central and Eastern parts are covered by Dino formations and lacustrine and alluvial deposits. Hydrogeologically, the main aquifers in this subbasin are varieties of ignimbrites, scoracious and vesicular basalts, as well as sand and gravel deposits. In this subbasin, the geological structures are commonly observed in association with boreholes that yield large discharge and mostly used for irrigation purposes. Its western side is part of the recharge zones while its Eastern part which consists of the Tora-Koshe ridge, could be another source of localized recharge. This part of the catchment is characterized by rainfall amounts which is close to the mean values. The general values of transmissivity and hydraulic conductivity of this subbasin varies from intermediate to high values. Hence, the parts which are close to the faults show relatively higher values of hydraulic conductivity especially, areas between *Butajira* and *Kibet* and Northwest of *Inseno* town. The groundwater flow direction from this subbasin is also expected to follow the general flow direction which is towards the East of the catchment.

The baseflow contribution of this subbasin increased from 283mm in 1986 to 445mm in 1999. This value then decreased to 266mm in 2011 as the cultivation were the dominant land cover in this time. The surface runoff was rasied from 235mm in 1986 to 277mm in 1999 and to 296mm in 2011. This increase in surface runoff at this subbasin could be related to the integrated effects of factors such as, large size of the subbasin, the low lying topography of the subbasin and the extensively cultivated lands of the subbasin.

The subbasin yield increased from 628mm in 1986 to 684mm in 1999, and further increased to 711mm in 2011 following similar trend with surface runoff. In this case, the value of the 2011 was much larger than the sum of the two components. This might indicate lateral flows from adjacent subbasin, probably subbasin4. This much excess amount could also be attributed to the quantity that was contributed from return flows of the irrigation activities. The recharge in this subbasin was increased from 305mm in 1986 to 342mm in 1999 but decreased from this amount to 291mm in 2011. Therefore, hydrologic characteristics of this subbasin is controlled by the cummulative effects of physiographic, hydrogeologic and land use/land covers.

7.5.4 Subbasin4

This subbasin is characterized dominantly by clay soil. The last 25 years (1986-2011), much of the range land cover, and wetlands were changed mainly to cultivation and bare lands/built up areas. At present, most part of the subbasin has been ceded to agricultural activities. Physiographically, it is dominated by the Kuntane-Inseno plains that is occoupied with water body and swamps (wetland). It has slope classes of 0-5%. It is a common parctice to observe cultivation in most of the areas especially its western part and recently the areas which were occoupied by swamps. Some gullies are observed in the subbasin, particlarly areas close to Tora-Koshe ridge. Its areal coverage is close to mean of the subbasins of Meki catchment and found in the Southern part of the catchment. It is typically located between Western escarpment and Tora-Koshe ridge. This subbasin is drained by Weja river and small lake. The river rises in the southern part of the catchment and emties into the lake before it joins Meki river.

The major lithologic units are lacustrine and alluvial deposits and Dino formation. Hydrogeologically, the main aquifers include scoria, sand and gravel, ignimbrites andfractured basalts. Its western part consists of the recharge zone and the groundwater flows down into marshy area before it turns towards Ziway lake. Similar to the above subbasins, the Butajira fault transects the subbasin and it is associated to relatively high values of hydraulic conductivities. Apart from areas close to the structures, this subbasin is characterized by intermediate values of hydraulic conductivities.

The baseflow contribution of this subbasin increased from 292mm in 1986 to 570mm in 1999. This value then decreased to 262mm in 2011. The surface runoff was reduced from 223mm in 1986 to 169mm in 1999 but it gained a little and reached 236mm in 2011. The shrink in swamps as a result of decline in rainfalls, enchroachment to the wetlands for cultivation, and the clay type nature of the soil have causeddecline on surface runoffs in the first period. The increase in surface runoff at the lateral period could be due to intensified cultivation of most lands in addition to other factors such as, large size of the subbasin, and its low lying topography.

The subbasin yield decreased from 582mm in 1986 to 493mm in 1999, and further decreased to 476mm in 2011 showing the cumulative effects of both surface runoff and baseflow. In this case, the little decrease in the later period is more related to the declines in the rainfalls. The recharges in this subbasin increased from 315mm in 1986 to 540mm in 1999, but later decreased to 285mm in 2011. Therefore, hydrologic characteristics of this subbasin is determined by the cummulative effects of physiographic, hydrogeologic and land use/land covers.

7.5.5 Subbasin5

This subbasin is characterized dominantly by sandy and sandy loam soil. The last 25 years, much of the forest and range land cover were converted mainly to cultivations and bare lands/built up areas. At present, the subbasin is mainly used foragricultural activities, settlement and range lands. Physiographically, it is dominated by the low-lying land which is part of rift floor. It has the dominant slope classes of 0-5%. Its areal coverage is close to mean of the subbasins of Meki catchment and found in the Eastern part of the catchment which includes some parts of Gademotta caldera and Ziway plain. This subbasin is drained by the main Meki river which emptiesinto Ziway lake.

The prevailing lithologic units in the subbasin are Dino formations and lacustrine and alluvial depoits. Hydrogeologically, it is covered with alluvial sediment, pyroclastic deposit and ignimbrite (tuffs) aquifers at varying depth. In this subbasin, few geological structure is observed. This subbasin is found in the discharge zones of the catchment that gets its water from the upstream areas and local precipitation of the catchment. The hydraulic characteristics of this subbasin generally showed that it has low to intermediate transmissivity and hydraulic conductivity.

The baseflow contribution of this subbasin increased from 423mm in 1986 to 505mm in 1999. This value then decreased to 414mm in 2011.The decreases in 1999-2011 period could be more associated with the decline in rainfalls in this period and intensified irrigation activities that rely on both surface and groundwaters.The surface runoff was reduced from 212mm in 1986 to 205mm in 1999 but it gained a little to 307mm in 2011. The increase in surface runoff at the lateral period could be due to intensified cultivation, increases in settlement, in addition to other factors such as, large size of the subbasin, and its low lying topography.

The subbasin water yield decreased from 599mm in 1986 to 595mm in 1999 was very insignificant. However, its increase to 748mm in 2011 showed the impact of human activitie rather than climatic conditions as both the rechrge and soil moisture content increased in this period. During dry season , farmers use water from the subsurface once the river discharge diminishes. They dig into the unconsolidated materials to irrigate thier farm lands. In one hand, these activities might have trapped the baseflow to the streams, and on other hand, the return flows might have added some waters to the subbasin. The recharges in this subbasin decreased from 453mm in 1986 to 359mm in 1999, but increased from this value to 448mm in 2011. Therefore, hydrologic characteristics of this subbasin is more affected by land use/land cover changes than climatic factors. Hence, proper watershed management needs to be implemented.

7.6. Sedimentation and erosion in Meki catchment

Similar to that of Wabe catchment, sedimentation has also caused a serious pronlem in this catchment as the existing land degradations could be associated with the amounts of sediment yields generating from the catchment. The temporal variation of average sediment yield in the catchment is given in Figure 6.13. From the analysis of LULCC of the 1986-2011, the average sediment yield of the catchment was estimated by the model and indicated that was decreased from 51.47 t/ha in 1986 to 31.19 t/ha in 1999, but increased to 47.29t/ha in 2011. On the catchment scale, the sediment yield generated was highly sensitive to little changes in surface runoff.This in turn, suggests that implementing little proper land management practices can reduce much of the land degradation problems caused by anthropogenic effects. These changes are directly attributed to the land use and land cover changes that caused the runoffs to change in both periods as it was discussed previously.Therefore, it indicates that Meki river contributes substantially to the siltations and sedimentation of the Lake Ziway.

Similar to changes on catchment scale, the amount of sediment generation also varies within the catchment. The subbasin with the highest sediment yields are subbasins 1 and 2 having57t/ha and 63t/ha respectively. These values are much larger than the average (43t/ha) sediment yields of the subbasins. These subbasins are generally characterized by dominant agricultural lands on high slope, clay and sandy loam soil, relatively high water yield, and geologically (structure and lithology) conducive setting for generations of sediments.

Conversely, the least sediment was generated from subbasin5(14t/h) which is the downstream part of the river that drains the lowlying land dominated by cultivation. It has relatively large area, and low to moderate water yield. Subbasin 3 and 4 have sediment yields of 37t/ha and 45t/ha which are close to the mean value. They are subbasins with moderate sediment generation capacities relative to others. Subbasins 3 and 4 have high surface runoffs with water body within, extended cultivations and appreciable amounts of range lands and barren lands. In subbasin3, cultivations on the high slopes and the geological settings of the subbasin may amplify the effects besides the above conditions whereas in case of subbasin4 it is the dominant clay soil that adds more pressure to generation of the sediments.

Similar to the Wabe catchment, land degradation in this catchment, are also evident from different land use/land cover changes. In this catchment, all the five land use/land cover types and the geologyare contributing to sediment yields at different degrees in the subbasins.However,intensified cultivation, deforestation, barren lands/built up areas, and geology of the area are the main factors for the production of the sediments. The Meki river and its tributaries are highly affected by the rift valley settings, and the poor land management practices in the catchmentwould be integrated for existing intense erosion and sedimentations observed in the study catchment. Therefore, based on the amount of sediments generated from the subbasins at different times, and the causing and driving factors, it is possible to generalize that the effects of land use/land cover changes on the rate of erosion and sedimentation is more serious in Meki cathment (18,365 t/ha to 23,099 t/ha)than in Wabe catchment(16,4464 t/ha to 21,686 t/ha)

CHAPTER EIGHT

8. CONCLUSIONS AND RECOMENDATIONS

8.1 Conclusions

The studied Wabi and Meki catchments are located in central Ethiopia and most of the area is within the central Ethiopian plateau adjacent to the central Main Ethiopian Rift. The land use/land covers have been dramatically changed over the last few decades. This study focuses on the effect of land use/cover changes in the hydrology of these cacthments. Different approaches have been used to evaluate the spatial and temoral variability of catchment factors by converging evidences. Aside from hydrometeorological and land use change analysis, sediment yield of the two catchments have been evaluated in a comparative manner. In the analysis of hydrological and catchment sediment yield SWAT model was used.

The multi-temporal analysis of chachment factors indicate that agricultural land and barren land/built-up areas were increased by 10%, and 5% respectively between 1986 and 2011 for Wabe catchment. However, forests were decreased by 15% and range land was unaffected. For Meki catchment, agricultural lands and barren land/built-up areas were increased by 8% and 7% respectively. This shows the high demands of the increased population for additional lands for cultivations and settlements.The hydrogeologic characterization of the catchments was done to understand the groundwater storage conditions of the catchments, and obtain the groundwater related SWAT model inputs. Based on the land use/land cover change analysis and its implications, the capabilities of SWAT model to simulate the hydrological responses to recent land use/land cover changes and itspotential in predicting future river discharge in both Wabe and Meki catchments, the following conclusions has been drawn:

- Thestudy result indicates that the mean annual surface runoff increased in both catchments between 1986 and 2011. This increasewas larger in Meki catchment than in Wabe catchment. The recent reductionand problem of harvesting subsurface waters during dry season especially in the rift floors could be associated with these changes. Moreover, in both periods, the total sediment yield generated from Meki was much higher than Wabe catchment. These changes in sedimentation implied that the higherrate of soil losses severelyaffecting the environment thereby increasing the degrees of land degradation in Meki catchment.

- The baseflows decreased from 1986 to 2011 in both catchments. However the total water yields of the Wabe catchment decreased, on the contrary the yield has increased in the Meki cacthment. The total catchment water yields and baseflows of Wabe aremuch higher than that of Meki catchment. This implies that the higher recharges estimated for Wabe catchment could be the results of the traditional land management practices that have beenimplemented in some parts of the catchment. In both catchments, generally, the baseflow has larger contributions to catchment water yields although this situation has changed recently in Meki catchment; but it remains the same in Wabe catchment.

- In the flow forecasting scenario, the predicted surface runoff and baseflows between 2012 and 2026 show a declining trend in Wabe catchment. However, in Meki catchment, the surface runoff is expected to increase unlike its baseflow assuming that the present land use/land cover remains unchanged and the past patterns of climatic conditions will continue.

- The Guraghe highlands (ridge) and the rift escarpment are the main sources of recharge due to high amount of precipitation, conducive land use and land cover, and physiographic characteristic and hydrogeological (geological) conditions of these areas. In addition to direct recharges, local recharge areas specifically the Northern parts of the catchments were observed contributing significant amount of recharges to the aquifers. In both catchments, the recharges generally declined from 1986 to 2011 substantially. In general better land use management and presence of more forested area favours more recharge in Wabe catchment than in the Meki catchment. The slope is also another important factor in affecting negatively in the recharge of the Meki catchment than the Wabe.

- Attempt was made to establish the sub-regional groundwater flow direction based on limited head observations from wells. Depending on the groundwater contours, the groundwater flow directions are generally from Guraghe highlands (ridge) towards Lake Ziway in case of Meki catchment and mainly from the southern(southeastern) part towards Omo-Gibe river in the case of Wabe catchment. In the Wabe catchment, local migration of groundwater was also observed from Southeastern towards West and Northwestern in addition to flows from Northern part towards Southwest direction. Locally, in Meki catchment, groundwater flows from northern, western, and southeastern part towards the central low-lying areas. In both catchments, a number of highdischarge springs are observed close to the major recharge zones whenever there is condusive geological and geomorphological structures. The groundwater contours have important implications in finding high potential groundwater areas in the lowlands.

- In general, the land use/land cover changes resulted from population pressure which affected the hydrologiccomponents of the catchments and the healthy functioning of the ecosystem by increasing the rate of soil erosion and sedimentation. This study provided important information on how the land use change and land management practices affected the hydrology of the two adjacent cacthments. Aside from the dynamics of the climate in the region land use plays important role in sediment generation and catchment water yields.

- The research underlines the need for using integrated methods of remote sensing, GIS, hydrological modeling, hydrogeological, hydrochemical and isotope techniques in analyzing the surface and groundwater conditions of the two catchments with the intention of recommending proper and better integrated watershed management plans. The study has far reaching implication in soil and water conservation prqctises of highland Ethiopia that adjoins the rift valley and large incised river valleys.

8.2 Recommendations

From the integrated study of the two catchments the following recommendations could be made.

- The integrated approaches that involves the analysis of land use/ land cover changes, and analyzing the effects of these changes on surface water, groundwater and sedimentations of the catchments by applying hydrological models, supports concerned bodies to address issues of ecological restoration within the context of integrated water resource management and watershed management plans.

- The SWAT model does not handel very well the groundwater dynamics. Hence, future studies should use models that handle both surface water and groundwater components along with the various catchments hydrological, geological, geomorphological and land use factors.

- This study has been carried out based on limited hydrometeorological data. Therfore, it is highly recommendced to set better hdro-meterological stations in areas where there is dramatic changes in land cover under cliamet change conditions.

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Appendix

Appendix-1 Weather data

				Mean monthly precipitation(1986-2011)								
Stations	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Bui	45.38	48.27	144.54	167.18	117.28	160.61	211.47	197.68	132.15	62.74	16.92	26.29
Butajira	34.05	66.36	133.67	126.08	110.94	124.14	169.01	159.34	80.51	34.07	10.26	15.58
Tora	25.41	43.69	79.57	120.38	92.13	85.25	132.54	123.32	111.4	50.6	8.36	6.03
Koshe	21.76	50.08	104.94	122.53	99.94	127.25	174.43	168.06	108.12	49.7	15.33	19.08
Meki	18.03	58.93	60.09	67.18	50.46	66.27	166.75	134.17	77.14	29.67	14.96	17.24
Engie	18.7	51.1	67.4	82.4	95.7	144.4	258.3	279.9	153.2	25.1	4.2	12
Kokir	45.38	48.27	144.54	167.18	117.28	160.61	211.47	197.68	132.15	62.74	16.92	26.29
Legedima	21.15	13.48	55.1	104.75	66.56	84.99	146.92	111.28	81.72	32.69	5.98	5.3
Agena	19.8	39.6	85.2	72.1	107.3	155.8	244.9	251.9	146.9	45.2	11.3	10
Welkite	26.2	61.08	90.61	148.81	172.42	242.3	225.76	174.37	90.59	23.3	18.5	18.62

			Mean monthly maximum temperature(1986-2011)									
Stations	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Bui	25.49	26.54	26.98	26.77	26.69	26	23.98	23.5	24.76	25.31	25.76	25.56
Butajira	25.07	26.69	26.75	26.96	26.81	24.93	24.6	21.86	24.2	23.95	24.47	24.48
Tora	26.2	26.12	26.81	27.1	26.96	25.31	25.43	25.57	26.1	26.12	25.64	26.45
Koshe	26.32	25.41	23.64	24.56	25.22	25.24	24.14	23.65	24.55	23.54	24.15	24.34
Meki	26.97	28.32	29.22	28.98	29.57	27.56	25.35	25.61	26.83	27.69	27.28	26.82
Engie	24.12	25.31	25.04	25.14	25.31	24.06	25.55	22.58	26.23	25.21	25.61	26.31
Kokir	25.49	26.54	26.98	26.77	26.69	26	23.98	23.5	24.76	25.31	25.76	25.56
Legedima	26.3	26.25	25.88	26.25	26.64	27.39	27.56	27.56	27.58	28.01	28.11	27.05
Agena	26.3	26.16	25.88	26.25	26.64	27.39	27.56	27.55	27.58	28.11	28.14	27.05
Welkite	26.13	26.25	25.88	26.25	26.64	27.33	27.56	27.56	27.58	28.24	28.34	27.15

				Mean monthly minimum temperature(1986-2011)								
Stations	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Bui	7.99	8.66	10.4	10.66	10.81	9.67	9.55	9.81	9.54	8.27	6.73	6.41
Butajira	11.76	11.78	12.63	13.13	12.58	12.56	12.59	12.39	12.55	12.15	11.58	11.47
Tora	11.2	10.56	10.85	12.1	11.54	10.02	10.13	10.11	11.01	11.25	12.01	12.02
Koshe	11.12	10.2	10.22	9.02	11.31	10.01	10.25	10.11	10.61	11.01	11.25	11.14
Meki	12.7	13.79	15.06	15.56	15.77	15.39	14.98	14.94	14.37	13.07	11.62	11.42
Engie	10.11	10.01	9.31	8.02	10.05	9.24	8.54	8.27	9.41	8.32	6.19	6.17
Kokir	7.99	8.66	10.4	10.66	10.81	9.67	9.55	9.81	9.54	8.27	6.73	6.41
Legedima	13.48	13.46	13.7	13.69	13.95	13.57	13.4	13.44	13.53	13.62	13.75	13.6
Agena	13.48	13.46	13.7	13.69	13.95	13.57	13.4	13.44	13.53	13.62	13.75	13.6
Welkite	13.48	13.46	13.7	13.69	13.95	13.57	13.4	13.44	13.53	13.62	13.75	13.6

Appendix-2 River discharge data of Wabe and Meki rivers(1986-2011)

	Mean monthly Wabe river discharge(m3/s) at Welkite town(1986-2011)											
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	9.39	11.75	17.88	23.61	27.39	45.47	64.92	81.72	80.14	16.86	4.80	3.20
1987	2.42	2.29	8.79	45.45	18.21	33.72	40.86	71.68	33.83	8.51	2.46	1.50
1988	1.48	1.89	1.45	1.23	1.61	12.22	100.06	224.22	114.48	83.84	8.76	4.08
1989	1.57	1.71	1.39	7.99	2.35	7.07	84.60	102.21	104.41	32.50	16.41	3.36
1990	0.23	1.21	3.04	5.46	1.45	5.80	3.44	8.59	10.02	5.10	0.70	0.40
1991	0.19	1.10	2.04	0.88	2.49	7.86	155.99	315.39	73.81	6.69	2.54	1.72
1992	1.69	5.00	3.38	7.23	12.38	37.59	103.55	349.31	169.97	10.04	1.15	0.23
1993	0.32	0.50	0.18	0.71	4.00	8.04	131.06	138.58	70.18	10.23	3.44	2.08
1994	0.23	1.58	1.12	3.94	4.60	5.54	26.74	100.89	76.49	15.46	3.31	1.50
1995	0.67	1.71	1.46	6.69	2.18	10.95	79.02	82.49	47.48	5.82	2.33	1.60
1996	2.74	1.21	9.27	16.45	29.19	107.01	93.34	213.20	49.48	19.35	6.38	2.91
1997	2.40	1.37	2.01	10.28	3.77	3.02	30.43	59.58	23.48	15.13	9.84	2.74
1998	3.18	1.98	5.50	3.47	8.26	9.43	50.15	76.55	40.28	25.12	5.07	1.44
1999	1.88	1.27	2.11	1.55	6.56	14.97	78.51	138.64	28.26	55.70	6.31	2.63
2000	1.42	0.99	0.78	1.51	2.93	4.39	59.12	103.03	73.84	26.35	6.35	3.15
2001	1.53	1.24	2.60	2.15	9.87	30.44	93.93	145.00	79.03	10.59	3.60	1.98
2002	0.29	1.52	2.35	1.70	2.53	14.70	60.45	69.99	22.64	4.09	1.71	1.44
2003	1.23	0.99	1.40	3.89	2.69	5.31	86.47	117.55	41.13	12.19	4.19	1.75
2004	1.78	1.21	1.75	21.95	4.39	14.99	71.55	168.10	68.67	34.32	8.29	4.80
2005	3.83	3.01	4.31	0.42	1.11	5.40	38.08	82.34	88.12	15.97	7.63	5.65
2006	4.32	4.01	9.46	15.90	23.16	5.20	42.20	109.00	16.94	2.17	0.30	0.00
2007	15.12	24.11	26.54	50.66	43.32	104.76	228.84	215.69	189.73	8.12	0.22	0.06
2008	0.00	0.00	0.00	0.00	0.22	18.93	220.57	217.88	119.71	86.38	156.24	61.72
2009	47.14	42.55	37.19	73.41	89.71	106.49	232.61	193.01	117.71	97.14	44.45	32.46
2010	31.11	18.93	0.34	2.86	7.99	90.43	414.64	441.26	176.46	57.30	32.64	25.32
2011	18.17	13.75	37.30	15.30	34.16	98.46	156.70	301.12	127.62	57.06	32.13	19.43

	Mean monthly Meki river discharge(m3/s) at Meki town(1986-2011)											
Year	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
1986	1.39	0.95	4.59	2.86	11.90	14.25	15.31	16.38	11.98	0.97	0.11	0.04
1987	0.00	4.57	15.97	8.56	23.81	9.93	6.74	7.39	5.78	1.79	0.36	0.03
1988	0.04	0.65	0.06	3.95	1.48	3.70	16.86	23.17	22.20	11.92	2.67	0.85
1989	0.55	2.24	4.77	9.14	2.03	4.25	16.08	16.46	17.11	9.06	1.56	0.89
1990	0.31	11.35	22.66	21.79	5.77	5.93	15.12	19.52	16.06	8.45	2.18	1.02
1991	0.50	2.62	6.82	3.57	0.93	2.11	21.29	35.28	23.64	4.84	1.08	0.69
1992												1.09
1993	4.88	1.04	0.96	15.21	17.80	11.19	27.13	56.13	19.72	11.61	4.45	0.90
1994	0.80	0.51	0.55	0.63			28.62	57.58	51.80	7.34	0.96	0.77
1995												
1996									24.51	5.65	2.01	1.29
1997	0.32	0.27	0.57	9.63	3.59	3.61	15.80	15.90	7.77	3.62	8.70	1.34
1998	1.60	0.72	12.46	2.25	12.27	4.11	25.44	64.23	37.95	24.79	3.49	0.66
1999	0.09	0.07	2.83	0.12	0.34	0.95	19.89	24.74	10.63	21.14	7.87	0.42
2000	0.01	0.00	0.00	0.04	0.84	0.46	5.73	13.43	10.76	10.11	3.03	0.95
2001	0.01	0.18	2.41	2.47	4.60	9.08	19.95	38.76	28.91	3.92	1.04	0.60
2002	4.12	2.94	1.55	1.57			15.56	19.55	11.64	2.25	1.95	1.62
2003	0.99	0.59	4.33	3.57	2.78	3.98	14.90	30.65	21.32	6.15	0.45	0.83
2004	0.93	0.99	0.30	0.62	15.10	1.12	1.88	11.25	33.55	33.44	8.29	4.79
2005	3.83	2.96	1.12	5.15	12.60	8.47	13.31	16.68	16.14	5.89	1.97	1.53
2006	1.24	1.10									1.05	1.01
2007	0.83	1.89	0.77	0.75	2.97	19.75	41.82	40.81	20.54	4.83	0.67	0.52
2008	0.42	0.35				3.17	9.59	20.20	16.15	3.26		0.47
2009	0.42	0.07	0.00	0.68	0.48	1.57	9.76	20.76	15.24	0.96	0.83	0.30
2010	0.42	0.17	2.91	1.69	10.24	9.01	2.14	18.85	33.30	23.02	2.79	0.26
2011	0.99	0.65	3.40	4.27	1.61	5.31	18.32	25.30	8.82	0.62	0.83	0.28

Appendix-4 hydraulic properties

Groundwater level				
SampleID	SWL	UTM E	UTM N	GW_level
AW-642	34.55	365444	923342	1667.45
WAMW-12	56.82	376617	902505	1895.18
AW-628	80.6	359617	895285	1892.4
AW-622	20	356564	890804	1817
AW-626	41.18	358593	888310	1872.82
AW-638	47.04	363347	886391	1962.96
AW-264	92.95	393894	886062	2675.438
AW-246	11.74	364905	923161	1682.599
AW-248	2.96	365427	923242	1694.04
AW-249	53.68	365447	922747	1654.448
AW-253	21.83	369104	915815	1813.249
AW-254	11.95	372001	916722	1836.209
AW-431	14.7	377000	942000	1972.01
AW-247	34.55	365433	923338	1661.762
AW-249	53.68	365447	922747	1654.448
AdBh0217	77.9	459928	941554	2093.728
AdBh0222	72.32	426788	887491	2021.039
AdBh0234	8.01	430858	896035	2055.516
AdBh0223	40.7	435268	897823	1954.281
AdBh0224	25.66	439018	898838	1867.548
Tiya Town	114	456837	932873	2204
Adele Kobo	40	453276	901204	1810
Kela	1.86	444918	911937	1884.14
Dugda Goro	185	460865	901754	1740
Refenso	170	457559	908463	1721
Inseno	15.2	441974	890758	1816.8
Inseno Ousme	8.7	440025	890823	1824.3
Shershera Mechm	33.9	439461	904709	1880.1
Dirama Shershera	43.9	436158	901900	1964.1
Kibet town	50	426285	887327	2045
Kibet town	50	426927	887719	2044
Alkeso	162	415084	877224	2139
Yekertef Gibato	180	424695	875670	1874
Woger Ourdubo	160	427800	871600	1760
Dobo Sabola	8.25	436818	892494	1836.75
Debub Goto	35	435517	877276	1825
Semen Goto	0	439069	878182	1940
Udasa	300	442073	875289	1716
Argo Wolilati	182	454319	891741	1746
Ilala Gebiba	172	455912	885586	1614
Ilala Jirano	167	453015	883724	1642

Semen Koshe	158	450074	886127	1726
Koshe 01	180	448478	885096	1704
Koshe Zuria	18	447700	886562	1816
Bidara Faka	160	452613	880214	1651
Shirinto	260	447720	875620	1634
Udasa Washe Faka	151.55	447740	875650	1726.45
Dida Halibo	20	447247	889418	1810
Abosa 01	31	469886	886446	1623
Bekele & Girisa	14.5	479226	898332	1632.5
Bekele & Girisa	9	483074	898580	1639
Weyo	8	472425	890622	1548
Burka Dalocha	33.4	492763	900233	1640.6
Meja Natile	30	496211	897486	1646
Suluke	270	458882	911780	1664
Abine Germama	60	464718	883354	1616
Butajira Town	54.7	432756	897440	2003.3
Adame Tulu	31	467644	868349	1627
Adame Tulu pestic	28	466561	870573	1616
Meki Town	49	480497	900763	1613
Butajira Town	13.4	432084	897957	2042.6
Adame Tulu	30.47	467945	869660	1623.53
Adame Tulu pestic	29	466592	870790	1615
Ziway Town	22.15	468735	875680	1624.85
Ziway Town	28.85	467744	876679	1623.15
Meki Town	29	480694	901824	1632
Butajira Town	22	430941	896250	2048
Gere	53	449101	931543	2520
Amawte Gufutige	25	449315	931983	2540
Semero Michaele	58	459571	927132	2098
Negesa	50	448077	914575	1900
Delelesa	16	443290	912291	1901
Gose Salen	18	447042	906854	1855
Mekicho	3	429210	898363	2090
Mekicho	3.65	428066	898717	2103.35
Inseno	14.5	441913	891311	1822.5
Inseno	14.5	441811	891169	1817.5
Jole	15	440195	905619	1886
Ashute Burako	3	431626	885597	1822
Ashute Burako	3	432220	885690	1820
Shele Washo	4.2	437435	888235	1820.8
Shele Washo	4	437645	890366	1833
Shele Washo	4.5	438398	891339	1828.5
Dobena Inseno	4	438525	892515	1832

Mirab Yekoche	2.5	431103	880724	1834.5
Mirab Yekoche	14.25	430723	880064	1825.75
Mirab Yekoche	25	431974	879460	1816
Misrak Yekoche	24	434096	877393	1827
Debub Goto	25	434916	877533	1822
Mekak Jare Dembe	16	442590	886150	1809
Mekak Jare Dembe	25	443960	885090	1803
Gola Jare Dembek	30	441700	884120	1814
Gola Jare Dembek	30	441090	883120	1816
Waja Jare Dembek	16	444940	887750	1804
Waja Jare Dembek	20	445600	887750	1800
Dida Halibo	17	446061	888355	1810
Dida Halibo	10	446828	886946	1800
Dida Halibo	19.3	448875	890353	1807.7
Dida Halibo	16	447700	890160	1804
Dida Halibo	20	447230	889512	1810
Dida Halibo	20	446693	888753	1803
Hobe Jare Dembel	22	441620	889345	1822
Hobe Jare Dembel	12.2	442203	887428	1819.8
Dida Midore	20	444425	890845	1821
Dida Midore	19	445997	892208	1819
Dida Midore	19.2	445185	889218	1819.8
Dida Midore	20	445711	890834	1813
Dida Midore	23	445831	891566	1815
Dida Midore	23	445587	890527	1812
Dida Midore	15	446858	890325	1817
Kuno Alemena	8	440559	886885	1823
Kuno Kertefa	18	440854	889603	1821
Kuno Kertefa	6	439032	888026	1822
Kuno Kertefa	4.6	438206	887054	1820.4
Kuno Kertefa	12.5	439526	889020	1822.5
Kuno Kertefa	11	439537	889407	1822
Kuno Kertefa	11	439689	889746	1822
Koshe Zuria	16	447780	886782	1813
Washa Shanka	10	432214	869559	1818
Washa Shanka	10	431044	871595	1803
Lamfuro Gebaba	23.5	434454	874460	1826.5
Bekele & Girisa	18	478369	898541	1630
Bekele & Girisa	11	478766	897805	1653
Bekele & Girisa	11	478942	897992	1655
Bekele & Girisa	11	478816	898150	1656
Bekele & Girisa	11	478622	898040	1657
Bekele & Girisa	8	482846	897802	1658
Bekele & Girisa	8	483119	898014	1658

Bekele & Girisa	12	483129	898268	1636
Bekele & Girisa	12	478364	897796	1654
Meja Natile	30	496131	897617	1647
Gogeti	33	443288	909887	1875
Gogeti	18	443712	908129	1880
Gogeti	30	442690	908750	1889
Gogeti	27	441925	908580	1897
Gogeti	15	443068	907198	1878
Gogeti	10	444979	905272	1868
Adele Gose	14	446896	904607	1850
Adele Cheleleke	37	448674	899951	1818
Negesa	5	449214	913791	1919
Adele Gose	30	447562	904659	1833
Adele Cheleleke	44	448953	900604	1812
Jole	8	442310	904952	1865
Jole	12	444039	903498	1848

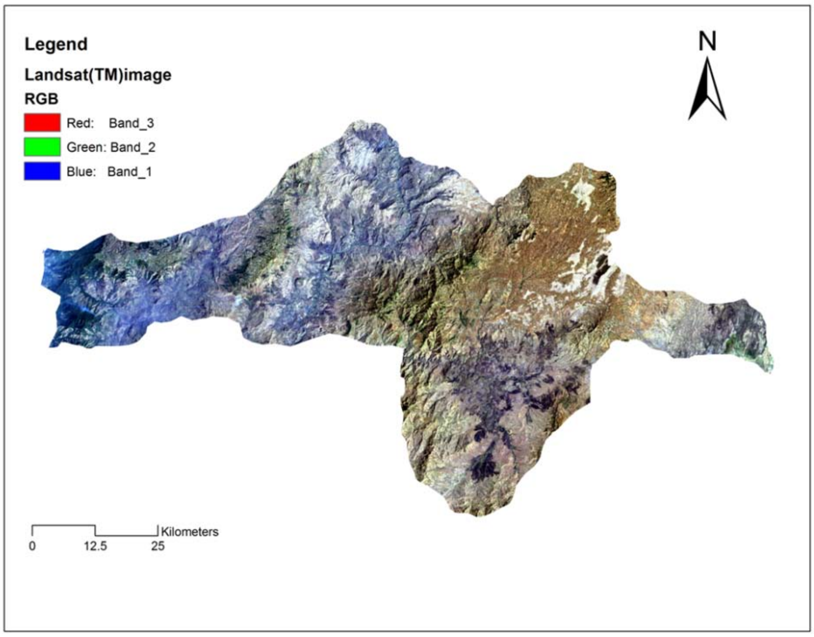

Figure 2011 raw landsat image for both catchments

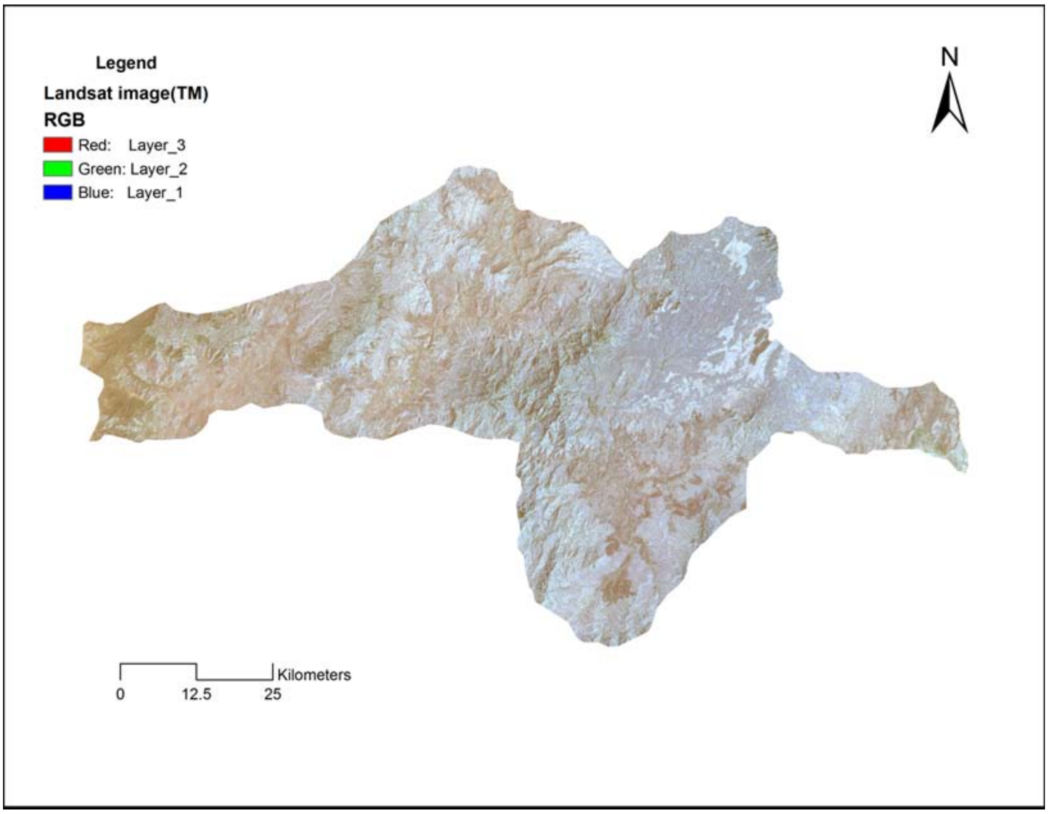

Figure Raw landsat image of 1986 for both catchments

Hydraulic properties (both catchments)					
SampleID	UTME	UTMN	T	K	Q
BH-2	453276	901204	12.71	0.71	
BH-11	426285	887327	37.8	0.9	3.40
BH-16	435517	877276	6	0.25	5.14
BH-17	439069	878182	7	0.29	3.10
BH-18	438154	876204	12.3	0.45	3.40
BH-22	447247	889418	15	0.36	6.00
BH-26	432756	897440	69.26		8.00
BH-28	432084	897957	241.92		10.00
BH-30	430990	896373	95.62	2.66	6.00
BH-31	435852	869258	63.24	2.11	4.00
BH-32	453015	883724	171	7.75	3.20
BH-33	447720	875620	15	0.36	2.56
BH-34	446742	872640	81.55	2.72	3.60
BH-35	432428	886909	8.26	0.35	3.00
BH-37	431086	898842	30	0.96	
BH-41	432501	898201	16	0.67	
BH-42	436926	899049	187.76	20.86	
BH-43	426927	887719	37.8	0.9	7.00
BH-44	432428	886909	8.29	0.35	3.00
BH-47	430838	899162	137	3.81	
AW-642	365444	923342	1.4		0.00
WAMW12	376617	902505	604		25.00
AW-628	359617	895285	25.5		6.67
AW-622	356564	890804	10.79		0.00
AW-626	358593	888310	126		4.00
AW-638	363347	886391	3.19		3.46
AW-264	393894	886062	39.2		5.95
AW-248	365427	923242	221.36		8.40
AW-249	365447	922747	2.96		4.68
AW-253	369104	915815	4.83		2.00
AW-254	372001	916722	13.73		2.40
AW-431	377000	942000	2.84		1.30
AW-246	364905	923161	56.92		7.20
AW-247	365433	923338	0.616		2.40
AdBh0217	459928	941554	8.6		2.50
AdBh0222	426788	887491	378		3.40
AdBh0234	430858	896035	44.83		7.35
AdBh0223	435268	897823	130		3.30
AdBh0224	439018	898838	2.65		5.03

	Mean monthly rainfall(mm)for Meki catchment(1986-2011)											
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	0.14	110.96	41.44	135.64	115.56	197.14	143.26	103.5	147.3	37.14	0.68	4.16
1987		67.6	193.12	89.24	219.4	75.24	85.82	150.84	90.8	27.3		
1988	9.52	58	11.96	108.48	41.34	113.84	190.1	157.86	152.12	81.9		
1989	3.12	79.9	137.54	105.74	42.54	159.2	192.3	188.1	127.88	40.18	9.08	27.52
1990	2.3	260.82	66.54	126.18	64.8	77.62	164.84	119.54	134.82	71.7	48.9	28.32
1991	12.24	89.12	151.94	10.24	19.12	115.15	185.14	201.2	77.72	6.8	0.46	20.28
1992	39.42	70.76	18.96	123.94	76.44	138.3	242.74	279.72	101.3	61.64	47.64	8.1
1993	24.14	78.38	21.5	203.575	138.625	86.19	207.905	182.345	106.965	96.38	0.08	0.4
1994	0.12	4.08	55.46	46.92	57.06	175.42	214.74	120.26	96.46	0.6	9.74	0.54
1995	0	41.9	89.32	247.48	92.94	62.72	145.84	109.56	100.26	14.56	0	49.36
1996	116.74	3.36	203.02	89.92	178.53	218.44	203.08	251.44	103.48	7.48	10.44	4.3
1997	60.5		86.18	169.44	39.8	159.76	138.42	139.14	71.06	114.82	21.62	1.7
1998	63.82	58.48	105.34	70.22	122.72	54.64	183.18	201.22	96	74.22		
1999	0.84		74.68	6.26	46.44	107.36	197.5	132.04	90.6	174.68		
2000			0.22	72.72	110.04	87.66	134.8	134.18	139.9	71.94	85.44	50.82
2001	5.2	46.68	166	37.26	159.94	123.48	173.08	154.6	113.78	16.62	2.96	10.8
2002	26.32	26.78	70.74	82.08	55.14	80.56	109.6	146.24	133.46	0.4	0	21.86
2003	25.8	23.01	83.3	124.74	45.66	95.88	194.08	134.88	100.66	13.58	2.5	44.445
2004	60.02	35.52	139.18	21.14	73.34	134.18	135.34	75.74	63.42	10.34	8.82	0.92
2005	18.12	119.08	66.82	215.62	51.96	167.68	253.98	141.52	77.26	15.72	0	58.38
2006	1.26	48.86	149.58	166.32	107.12	118.42	212.68	137.695	106	37.24	0.08	6.215
2007	4.32	101.8	42.32	71.88	146.94	155.84	186.42	108.9	82.54	14.44	0.7	1.68
2008	0.15	0.34		16.32	83.44	143.07	188.94	183.54	112.415	23.74	116.3	11.75
2009	19.9	7.12	63.92	50.82	70.71	58.4	181.42	98.46	56.26	85.46	22.62	35.67
2010	1.44	80	131.52	137.56	135.86	117.54	122	175.34	101.14	14.88	5.96	7.82
2011	24.58	6.32	72.44	56.9	141.52	165.46	120.38	65.96	72.34		4.08	

	Mean monthly rainfall(mm) for Wabe catchment(1986-2011)											
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986		62.1	62.8	106.3	107.7	420.6	234.3	125.2	172.7	27.4	3.4	7.8
1987		52.1	77.3	112.1	72.6	178.8	107.9	203.3	76.3	60.5		
1988	22.4	59	24.4		60.8	160.9	309.7	235.3	231	116.6		
1989	1.9	11.3	113.7	82.3	120.8	129	303.3	274.2	149.4	77.9	45.4	59.3
1990	11.5	156	52.7	73.9	79.9	187.4	238.7	301.6	205.7	25.2	12.9	0
1991	0	113.5	99.7	7.3	168.4	326.6	247.3	224.3	118.7	7		36.7
1992	16.8	129.8	29.9	247.3	195.3	358.2	326.9	717.1	109.2	55.9	115.6	4.1
1993	31.9	141.2	80.1	248.7	211.3	301.8	265.9	155.5	4.1			
1994	0	8.7	227.9	181.9	209	183.1	369.3	139.8	230.9	3.4	25	
1995	0	27.1	40.3	319.9	75.9	128.1	260.6	385.9	28.1	18.3		55.6
1996	105.4	12.1	233	174.9	243.8	349.3	379.8	450	118.6	13.3	25.3	4.1
1997	74.5	0	99.6	206	116.8	196.3	163.3	152.8	121.9	84.4	15.7	8.5
1998	24.5	131.9	20.5	88.7	104.5	315.2	272.9	161.6	44.9			4.2
1999				43.9	180	240.1	199.1	123.3	300.8	23.1		
2000			16.6	89.8	125.5	259.5	270.7	161.7	113.3	31.2	4.2	6.2
2001	10.9	48.7	26.4	101.2	139.6	323.8	249.1	248.3	109.9	9.7	5.5	47
2002		72.4	68.7	90.8	283.6	210.6	285.3	144.7	7.8	0	31.7	22.3
2003	1.4	93.4	155.4	157.9	325.5	265.4	195	82.6	10.1	9.3	10.3	45.9
2004	79.9	82.8	137.1	160.8	186.8	165	55.8	0	11.7	17.1	32.5	4.4
2005	66.8	72.9	98.6	217.2	235.1	233.1	110.1	12	31.8	0	10	80.3
2006	79	83.2	113.8	117.5	251	240.9	182.9	52.3	35.5	4.7	42.3	58.3
2007	34.9	52.8	122.5	169.8	237.2	203.6	149.2	30.6				8.4
2008	0.6	83	137.4	292.6	249.5	245.3	141.6	3.2	119.5		4.7	58.2
2009	7.2	29.6	58.1	156.1	233.6	164.9	129.9	117.1	1	18.9	37.7	76.1
2010	39	100.6	150.8	266.5	138	222	136.5	27	35		11.8	
2011	55.2	25.4	130.5	153	138.6	222	136.5	27	35			

	Mean monthly River discharge(m3/s) at Meki town(1986-2011)											
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	1.39	0.95	4.59	2.86	11.90	14.25	15.31	16.38	11.98	0.97	0.11	0.04
1987	0.00	4.57	15.97	8.56	23.81	9.93	6.74	7.39	5.78	1.79	0.36	0.03
1988	0.04	0.65	0.06	3.95	1.48	3.70	16.86	23.17	22.20	11.92	2.67	0.85
1989	0.55	2.24	4.77	9.14	2.03	4.25	16.08	16.46	17.11	9.06	1.56	0.89
1990	0.31	11.35	22.66	21.79	5.77	5.93	15.12	19.52	16.06	8.45	2.18	1.02
1991	0.50	2.62	6.82	3.57	0.93	2.11	21.29	35.28	23.64	4.84	1.08	0.69
1992												1.09
1993	4.88	1.04	0.96	15.21	17.80	11.19	27.13	56.13	19.72	11.61	4.45	0.90
1994	0.80	0.51	0.55	0.63			28.62	57.58	51.80	7.34	0.96	0.77
1995												
1996									24.51	5.65	2.01	1.29
1997	0.32	0.27	0.57	9.63	3.59	3.61	15.80	15.90	7.77	3.62	8.70	1.34
1998	1.60	0.72	12.46	2.25	12.27	4.11	25.44	64.23	37.95	24.79	3.49	0.66
1999	0.09	0.07	2.83	0.12	0.34	0.95	19.89	24.74	10.63	21.14	7.87	0.42
2000	0.01	0.00	0.00	0.04	0.84	0.46	5.73	13.43	10.76	10.11	3.03	0.95
2001	0.01	0.18	2.41	2.47	4.60	9.08	19.95	38.76	28.91	3.92	1.04	0.60
2002	4.12	2.94	1.55	1.57			15.56	19.55	11.64	2.25	1.95	1.62
2003	0.99	0.59	4.33	3.57	2.78	3.98	14.90	30.65	21.32	6.15	0.45	0.83
2004	0.93	0.99	0.30	0.62	15.10	1.12	1.88	11.25	33.55	33.44	8.29	4.79
2005	3.83	2.96	1.12	5.15	12.60	8.47	13.31	16.68	16.14	5.89	1.97	1.53
2006	1.24	1.10	1.00								1.05	1.01
2007	0.83	1.89	0.77	0.75	2.97	19.75	41.82	40.81	20.54	4.83	0.67	0.52
2008	0.42	0.35				3.17	9.59	20.20	16.15	3.26		0.47
2009	0.42	0.07	0.00	0.68	0.48	1.57	9.76	20.76	15.24	0.96	0.83	0.30
2010	0.42	0.17	2.91	1.69	10.24	9.01	2.14	18.85	33.30	23.02	2.79	0.26
2011	0.99	0.65	3.40	4.27	1.61	5.31	18.32	25.30	8.82	0.62	0.83	0.28

	Mean monthly River discharge(m3/s) at Welkite(1986-2011)											
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	9.39	11.75	17.88	23.61	27.39	45.47	64.92	81.72	80.14	16.86	4.80	3.20
1987	2.42	2.29	8.79	45.45	18.21	33.72	40.86	71.68	33.83	8.51	2.46	1.50
1988	1.48	1.89	1.45	1.23	1.61	12.22	100.06	224.22	114.48	83.84	8.76	4.08
1989	1.57	1.71	1.39	7.99	2.35	7.07	84.60	102.21	104.41	32.50	16.41	3.36
1990	0.23	1.21	3.04	5.46	1.45	5.80	3.44	8.59	10.02	5.10	0.70	0.40
1991	0.19	1.10	2.04	0.88	2.49	7.86	155.99	315.39	73.81	6.69	2.54	1.72
1992	1.69	5.00	3.38	7.23	12.38	37.59	103.55	349.31	169.97	10.04	1.15	0.23
1993	0.32	0.50	0.18	0.71	4.00	8.04	131.06	138.58	70.18	10.23	3.44	2.08
1994	0.23	1.58	1.12	3.94	4.60	5.54	26.74	100.89	76.49	15.46	3.31	1.50
1995	0.67	1.71	1.46	6.69	2.18	10.95	79.02	82.49	47.48	5.82	2.33	1.60
1996	2.74	1.21	9.27	16.45	29.19	107.01	93.34	213.20	49.48	19.35	6.38	2.91
1997	2.40	1.37	2.01	10.28	3.77	3.02	30.43	59.58	23.48	15.13	9.84	2.74
1998	3.18	1.98	5.50	3.47	8.26	9.43	50.15	76.55	40.28	25.12	5.07	1.44
1999	1.88	1.27	2.11	1.55	6.56	14.97	78.51	138.64	28.26	55.70	6.31	2.63
2000	1.42	0.99	0.78	1.51	2.93	4.39	59.12	103.03	73.84	26.35	6.35	3.15
2001	1.53	1.24	2.60	2.15	9.87	30.44	93.93	145.00	79.03	10.59	3.60	1.98
2002	0.29	1.52	2.35	1.70	2.53	14.70	60.45	69.99	22.64	4.09	1.71	1.44
2003	1.23	0.99	1.40	3.89	2.69	5.31	86.47	117.55	41.13	12.19	4.19	1.75
2004	1.78	1.21	1.75	21.95	4.39	14.99	71.55	168.10	68.67	34.32	8.29	4.80
2005	3.83	3.01	4.31	0.42	1.11	5.40	38.08	82.34	88.12	15.97	7.63	5.65
2006	4.32	4.01	9.46	15.90	23.16	5.20	42.20	109.00	16.94	2.17	0.30	0.00
2007	15.12	24.11	26.54	50.66	43.32	104.76	228.84	215.69	189.73	8.12	0.22	0.06
2008	0.00	0.00	0.00	0.00	0.22	18.93	220.57	217.88	119.71	86.38	156.24	61.72
2009	47.14	42.55	37.19	73.41	89.71	106.49	232.61	193.01	117.71	97.14	44.45	32.46
2010	31.11	18.93	0.34	2.86	7.99	90.43	414.64	441.26	176.46	57.30	32.64	25.32
2011	18.17	13.75	37.30	15.30	34.16	98.46	156.70	301.12	127.62	57.06	32.13	19.43