

**LAND COVER CHANGE IMPACTS ON THE HYDROLOGIC
VARIABILITY, PEAK FLOOD DISCHARGE AND SEDIMENTATION**

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**LAND COVER CHANGE IMPACTS ON THE HYDROLOGIC
VARIABILITY, PEAK FLOOD DISCHARGE AND SEDIMENTATION
IN THE UPPER AWASH BASIN, ETHIOPIA**

by

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Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy
to the



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I dedicate this dissertation to my parents

CERTIFICATE

This is certify that the thesis entitled “**Land Cover Change Impacts on the Hydrologic Variability, Peak Flood Discharge and Sedimentation**” being submitted by **Mr. Alemayehu Abate Shawul** to the **Indian Institute of Technology Delhi**, for the award of the **degree of Doctor of Philosophy** is a record of the original bonafide research work carried by him under my guidance and supervision. The thesis work, in my opinion, has reached the requisite standards fulfilling the requirement for the **Degree of Doctor of Philosophy**.

The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma.

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Alemayehu Abate Shawul

A handwritten signature in blue ink, appearing to read 'Alemayehu', is written over a horizontal line.

ABSTRACT

Quantitative assessment of the impact of land use/land cover (LC) changes and climate variability on the basin water balance, extreme hydrologic events and sedimentations are imperative for efficient policy decisions on sustainable water resources management. Most studies on the effect of LC change mainly focused on the mean streamflow conditions at large basins. However, the relative effects of individual land cover classes on the particular hydrologic components and extreme flow events on the local scale subbasins have received less attention. Thus, the main aim of this study are to assess the impact of land cover change on the hydrological fluxes mainly on the water balance components, flood events and sedimentation at multiple temporal and spatial scales in the Upper Awash Basin. Assessment of climate data quality, presence of monotonic trend, distribution of precipitation, and extreme climate indices were determined. The supervised method of image classification was applied to determine the historical LC changes based on series of Landsat imageries in the past 50 years. The near-future LC change scenarios were developed using the machine-learning approaches in the Land Change Modeler (LCM). The Soil and Water Assessment Tool (SWAT) model was calibrated and validated at main gauged subbasins for runoff and sediment yield simulations. Moreover, to highlight the availability of alternative data sources, the performance of global precipitation databases was also evaluated for hydro-climatic studies. Comprehensive assessment of the relative effect of LC classes on the hydrologic components was performed using integrated approaches of hydrologic modeling and partial least squares regression (PLSR). The influence of past and probable future LC change on the extreme flood magnitude and frequency was examined by fitting the annual maximum daily discharge simulated for different LC change scenarios with probability distribution function. Moreover, the indicator of hydrologic alteration (IHA) was used to quantify the high and low environmental flow conditions for different land management and climate change scenarios.

The mean annual and dry season precipitation values demonstrated higher spatial and temporal variability, whereas, in the wetter seasons, it exhibited low precipitation concentration or regular distribution. The statistical trend test revealed a significantly increasing trend of maximum temperature series; however, the trend of annual and extreme precipitation indices was not significant for the majority of stations. Evidently, the multi-temporal LC change detection revealed significant increments in the areal extent of the cropland and urban areas at the expense of the forests, pasture and shrubland coverage. Similarly, the modeled LC change scenarios of the near future years between 2025 and 2035 exhibited intense expansion of

cropland and urban areas, and substantial loss in the forest and shrubland areas. The SWAT model performed well for simulation of daily and monthly streamflow, and monthly sediment yield at main gauged subbasins. In addition, the performance of global precipitation estimates for hydrologic simulation was found to be encouraging for hydro-climatic studies in data-scarce tropical regions. In relatively smaller watersheds, the suitability of global precipitation was lower due to the limited number of data points resulted from the coarser resolution of the data sources.

The monoplots of PLSR components for LC change impact on the annual basin values exhibited that groundwater is highly correlated with the forest areas and lateral flow is strongly correlated with pasture. While surface runoff is mainly attributed to the change in urban and cropland, and sediment yield is mainly attributed to the cropland area. The Variable Importance for the Projection (VIP) also revealed that the decline of groundwater is mainly due to urban area; whereas, the increase in forest area enhanced groundwater flow. PLSR was found to be an effective statistical tool for assessment of the relative impacts of multiple land use methods on hydrologic variability and sediment yield. In addition to watershed morphometric parameters, hydrologic parameters such as surface runoff, runoff coefficient and water yield were used to infer major sediment source areas. Prioritization of sub-watersheds for best management practices can be effectively performed by integrating GIS, hydrologic modeling and advanced statistical tools. Riparian zone and steep slope reforestation scenario can be seen to significantly reduce the peak flood discharges and sedimentation. In contrast, the urban sprawl and vegetation disturbance scenarios demonstrated escalation of surface runoff, sediment yield and flood magnitudes, and nonetheless significant decline in the baseflows.

The dynamics in the land cover largely increased the frequency and magnitude of extreme flood discharge. The increase in peak runoff is marginally varied for higher return periods such as 200- or 100-year than the 5- or 2-year floods. Moreover, the magnitude and trends of several extreme climate change indices for baseline and future climate scenarios were computed and unlike the extreme precipitation indices, most of the temperature indices demonstrated significantly increasing trends. Overall, the effect of land cover deterioration on the hydrologic processes, extreme hydrologic events and sediment yield is highly pronounced in the smaller subbasins. The hydrologic impact of climate change would be more significant when accompanied by probable future LC change and the coupled influence is more significant on extreme hydrologic events than mean streamflow values. A more systematic understanding was achieved for attributing the recurring environmental changes to hydrological processes in one of the most dynamic tropical river basins.

सार

बेसिन जल संतुलन, चरम जलविद्युत घटनाओं और अवसादन पर भूमि उपयोग / भूमि कवर (एलसी) परिवर्तन और जलवायु परिवर्तनशीलता के प्रभाव का मात्रात्मक मूल्यांकन, स्थायी जल संसाधन प्रबंधन पर कुशल नीतिगत निर्णयों के लिए आवश्यक हैं। लैंडकवर परिवर्तन के प्रभाव पर अधिकांश अध्ययन मुख्य रूप से बड़े बेसिन में औसत प्रवाह की स्थिति पर केंद्रित थे। हालांकि, विशेष रूप से हाइड्रोलॉजिकल घटकों और स्थानीय सबबेसिन पैमाने वाली चरम प्रवाह की घटनाओं पर व्यक्तिगत भूमि कवर वर्गों के सापेक्ष प्रभावों पर कम ध्यान दिया गया है। इस प्रकार, इस अध्ययन का मुख्य उद्देश्य ऊपरी अस्थायी बेसिन में हाइड्रोलॉजिकल फ्लक्स मुख्य रूप से जल संतुलन घटकों, बाढ़ की घटनाओं और लौकिक और स्थानिक अवसादन पर भूमि कवर परिवर्तन के प्रभाव का आकलन करना है। जलवायु डेटा की गुणवत्ता का आकलन, लयबद्धता की उपस्थिति, वर्षा का वितरण, और चरम जलवायु सूचकांक निर्धारित किए गए थे। पिछले 50 वर्षों में लैंडसैट इमैजरीज की श्रृंखला के आधार पर ऐतिहासिक एलसी परिवर्तनों को निर्धारित करने के लिए छवि वर्गीकरण की पर्यवेक्षण पद्धति लागू की गई थी। भूमि परिवर्तन मॉडलर (एलसीएम) में मशीन-लर्निंग दृष्टिकोण का उपयोग करके निकट भविष्य के एलसी परिवर्तन परिदृश्य विकसित किए गए थे। मृदा और जल मूल्यांकन उपकरण (स्वाट) मॉडल को अपवाहित किया गया था और अपवाह और तलछट उपज सिमुलेशन के लिए मुख्य गेज किए गए सबबेसिन पर मान्य किया गया था। इसके अलावा, वैकल्पिक डेटा स्रोतों की उपलब्धता को उजागर करने के लिए, हाइड्रोइमैटिक अध्ययन के लिए वैश्विक वर्षा डेटाबेस के प्रदर्शन का भी मूल्यांकन किया गया था। हाइड्रोलॉजिकल मॉडलिंग और आंशिक रूप से कम से कम वर्गों प्रतिगमन (PLSR) के एकीकृत दृष्टिकोण का उपयोग करके हाइड्रोलॉजिकल घटकों पर लैंडकवर वर्गों के सापेक्ष प्रभाव का व्यापक मूल्यांकन किया गया था। अत्यधिक बाढ़ परिमाण और आवृत्ति पर अतीत और संभावित भविष्य के लैंडकवर परिवर्तन के प्रभाव की जांच संभावना वितरण फंक्शन के साथ विभिन्न एलसी परिवर्तन परिदृश्यों के लिए नकली वार्षिक अधिकतम दैनिक निर्वहन को फिट करके की गई थी। इसके अतिरिक्त, जलविभाजक परिवर्तन (आईएचए) के संकेतक का उपयोग, विभिन्न भूमि प्रबंधन और जलवायु परिवर्तन परिदृश्यों के लिए उच्च और निम्न पर्यावरणीय प्रवाह स्थितियों को निर्धारित करने के लिए किया गया था।

औसत वार्षिक और शुष्क मौसम वर्षा के मूल्यों ने उच्च स्थानिक और लौकिक परिवर्तनशीलता का प्रदर्शन किया, जबकि, गीले मौसम में, यह कम वर्षा एकाग्रता या नियमित वितरण का प्रदर्शन किया। सांख्यिकीय प्रवृत्ति परीक्षण से अधिकतम तापमान श्रृंखला की काफी बढ़ती प्रवृत्ति का पता चला; हालांकि, अधिकांश स्टेशनों के लिए वार्षिक और अत्यधिक वर्षा सूचकांकों का रुझान प्रभावपूर्ण नहीं था। जाहिर

है, बहु-लौकिक लैंडकवर परिवर्तन का पता लगाने से वनों, चरागाह और झाड़ी-झाड़ियों के कवरेज की कीमत पर फसल भूमि और शहरी क्षेत्रों की क्षेत्रीय सीमा में महत्वपूर्ण वृद्धि का पता चला। इसी तरह, 2025 और 2035 के बीच निकट भविष्य के वर्षों के प्रतिरूपित लैंडकवर परिवर्तन ने फसल भूमि और शहरी क्षेत्रों के गहन विस्तार का प्रदर्शन किया, तथा वन और झाड़ी वाले क्षेत्रों में पर्याप्त नुकसान हुआ। स्वाट मॉडल ने मुख्य अनुमानित सबबेसिन में दैनिक एवं मासिक धारा प्रवाह और मासिक तलछट उपज के अनुकरण के लिए अच्छा प्रदर्शन किया। इसके अलावा, हाइड्रोलॉजिक सिमुलेशन के लिए वैश्विक वर्षा अनुमानों का प्रदर्शन डेटा-दुर्लभ उष्णकटिबंधीय क्षेत्रों में हाइड्रो-क्लाइमेटिक अध्ययनों के लिए उत्साहजनक पाया गया। अपेक्षाकृत छोटे जलक्षेत्रों में, वैश्विक वर्षा की उपयुक्तता कम थी क्योंकि डेटा स्रोतों की सीमित संख्या के परिणामस्वरूप डेटा बिंदुओं की सीमित संख्या थी।

वार्षिक बेसिन मूल्यों पर नियंत्रण रेखा परिवर्तन के लिए पीएलएसआर घटकों के मोनोप्लॉट ने दर्शाया कि भूजल अत्यधिक वन क्षेत्रों से संबंधित है और पार्श्व प्रवाह दृढ़ता से चरागाह के साथ सहसंबद्ध है। जबकि सतह अपवाह मुख्य रूप से शहरी और क्रॉपलैंड में परिवर्तन के लिए जिम्मेदार है, और तलछट उपज मुख्य रूप से फसल भूमि क्षेत्र के लिए जिम्मेदार है। वैरिएबल इंपोर्टेंस फॉर द प्रोजेक्शन (वीआईपी) ने यह भी खुलासा किया कि भूजल की गिरावट मुख्य रूप से शहरी क्षेत्र के कारण है; जबकि, वन क्षेत्र में वृद्धि से भूजल प्रवाह में वृद्धि हुई है। पीएलएसआर को जलविज्ञानी परिवर्तनशीलता और अवसादन उपज पर कई भूमि उपयोग विधियों के सापेक्ष प्रभावों के आकलन के लिए प्रभावी सांख्यिकीय उपकरण पाया गया। वाटरशेड मॉर्फोमेट्रिक मापदंडों के अलावा, प्रमुख अपक्षय स्रोत क्षेत्रों में अनुमान लगाने के लिए सतह अपवाह, अपवाह गुणांक और पानी की उपज जैसे हाइड्रोलॉजिक मापदंडों का उपयोग किया गया था। सर्वोत्तम प्रबंधन प्रथाओं के लिए उप-जलक्षेत्रों का प्राथमिकताकरण जीआईएस, हाइड्रोलॉजिकल मॉडलिंग और उन्नत सांख्यिकीय उपकरणों को एकीकृत करके प्रभावी ढंग से किया जा सकता है। रिपेरियन ज़ोन और खड़ी ढलान पुनर्वितरण परिदृश्य को चरम बाढ़ के निर्वहन और अवसादन को कम करने के लिए देखा जा सकता है। इसके विपरीत, शहरी फैलाव और वनस्पति की गड़बड़ी परिदृश्यों ने सतह अपवाह, तलछट उपज और बाढ़ परिमाण में वृद्धि का प्रदर्शन किया, और फिर भी बेसफ्लो में महत्वपूर्ण गिरावट आई।

भूमि कवर में गतिशीलता ने बड़े पैमाने पर अत्यधिक बाढ़ निर्वहन की आवृत्ति और परिमाण में वृद्धि की है। 5 या 2-वर्ष की बाढ़ की तुलना में 200 या 100-वर्ष के रूप में उच्च वापसी अवधि के लिए शिखर अपवाह में मामूली वृद्धि हुई है। इसके अलावा, बेसलाइन और भविष्य के जलवायु परिदृश्यों के लिए कई चरम जलवायु परिवर्तन सूचकांकों के परिमाण और रुझानों की गणना की गई और अत्यधिक

वर्षा सूचकांकों के विपरीत, अधिकांश तापमान सूचकांकों ने काफी बढ़ते रुझान का प्रदर्शन किया। कुल मिलाकर, जलविभाजक प्रक्रियाओं, अति जलजमाव की घटनाओं और तलछट की उपज पर भूमि के आवरण के बिगड़ने का प्रभाव छोटे उप बेसिन में अत्यधिक स्पष्ट है। संभावित भावी नियंत्रण रेखा परिवर्तन के साथ जलवायु परिवर्तन का हाइड्रोलॉजिक प्रभाव अधिक महत्वपूर्ण होगा और औसत धारा प्रवाह मानों की तुलना में युग्मित प्रभाव चरम हाइड्रोलॉजिकल घटनाओं पर अधिक महत्वपूर्ण है। सबसे गतिशील उष्णकटिबंधीय नदी घाटियों में से एक में हाइड्रोलॉजिकल प्रक्रियाओं के लिए आवर्ती पर्यावरण परिवर्तनों को जिम्मेदार ठहराने के लिए एक अधिक व्यवस्थित समझ हासिल की गई थी।

TABLE OF CONTENTS

ACKNOWLEDGMENTS	i
ABSTRACT	iii
TABLE OF CONTENTS	viii
LIST OF FIGURES	xii
LIST OF TABLES	xv
LIST OF ABBREVIATIONS	xvii
CHAPTER ONE	1
GENERAL INTRODUCTION	1
1.1. Background	1
1.2. Statements of Problem	2
1.3. Objectives of the Study	4
1.4. Scope of the Study	4
1.5 Study Area	5
1.6. Model Input and Data Sources	6
1.7. Dissertation Outline	9
CHAPTER TWO	11
Assessment of long-term data quality, trends of precipitation, temperature and hydrologic data, and extreme climate indices	11
2.1 Introduction	11
2.2 Materials and Methods	13
2.2.1 Study area	13
2.2.2 Data availability	14
2.2.3 Statistical test of homogeneity	16
2.2.4 Precipitation concentration index (PCI)	17
2.2.5 Mann-Kendall trend test for precipitation and temperature data	18
2.2.6 Trend and magnitude of extreme precipitation and temperature indices	19
2.2.7 Standardized precipitation index (SPI)	19
2.3 Results and Discussion	20
2.3.1 Temporal data quality analysis	20
2.3.2 Precipitation concentration index (PCI)	23
2.3.3 Mann-Kendall trend test of annual rainfall data	25
2.3.4 Annual maximum daily (AMD) rainfall	27
2.3.5 Trend and magnitude of extreme precipitation events	28

2.3.6 Trends in the maximum and minimum temperature data	32
2.3.7 Standardized precipitation index (SPI) for the selected weather station	35
2.3.8 Flow data at main subbasins of Upper Awash	36
2.3.9 Implications of climate variability and extreme precipitation to water management	37
2.4 Conclusion	39
CHAPTER THREE	40
Spatiotemporal detection of land use/land cover change using integrated approaches of remote sensing and GIS in the Upper Awash Basin	40
3.1 Introduction	40
3.2 Materials and Methods	42
3.2.1 Land Use or/and Land Cover (LULC) Classification	42
3.2.2 Accuracy Assessments	44
3.2.3 Future LULC change scenario modeling	45
3.3 Results and Discussions	47
3.3.1 Classifications of LULC	47
3.3.2 Subbasin level LULC change assessment	52
3.3.3 Accuracy assessment LULC classification	54
3.3.4 Effects of Topography on LULC Changes	56
3.3.5 Modeling the Future LULC Changes	57
3.3.6 Main Drivers of LULC Change in the Upper Awash Basin	59
3.4 Conclusion	61
CHAPTER FOUR	63
Performance of global precipitation products for hydrologic prediction in the main watersheds of Upper Awash Basin	63
4.1 Introduction	63
4.2 Materials and Methods	66
4.2.1 Data requirements and data sources	66
4.2.2 Comparison of the conventional gauged data and global climate data	67
4.2.3. Hydrologic model setup and simulation	68
4.3 Results and Discussions	71
4.3.1 Comparison of precipitation estimates	71
4.3.2 Sensitivity analysis and performances of global climate data for hydrologic prediction	77
4.3.3 Implications of different precipitation data sources on the extreme daily discharges and annual hydrologic components	83

4.4 Conclusions	86
CHAPTER FIVE	87
The response of water balance components and extreme flood discharges to landuse/landcover (LC) change in the Upper Awash Basin	87
5.1 Introduction	87
5.2. Materials and Methods	89
5.2.1 Evaluation of the performance SWAT model for hydrologic simulation	90
5.2.2. Model application for land cover (LC) change scenarios simulation	90
5.2.3. PLSR modeling of LC change impact on water balance components	91
5.2.4. Land cover (LC) change impact on the extreme flood discharges	92
5.3. Results and discussion	94
5.3.1. Hydrologic model calibration and validation	94
5.3.2. Impact of LC change on the hydrologic processes	98
5.3.3. The relative contribution of LC change on water balance components based on PLSR model	106
5.3.4. Impacts of historical LC change on extreme flood peaks	111
5.4. Conclusions	123
CHAPTER SIX	125
Modeling the impact of land cover change on the sediment yield and determination of critical sediment source areas	125
6.1. Introduction	125
6.2. Materials and Methods	127
6.2.1. Sediment data sources	127
6.2.2. SWAT model setup for sediment simulation	128
6.2.3. Identification and prioritization of critical sediment source areas	130
6.3. Results and Discussions	134
6.3.1. Calibration and validation of sediment yield	134
6.3.2. Influence of Land cover change on the sediment yield	137
6.3.4. Prioritizing sediment source areas in the Upper Awash Basin	147
6.4. Conclusions	157
CHAPTER SEVEN	159
Impact of climate change on the extreme climate conditions and hydrologic variability, and the combined impact of LC and climate change	159
7.1. Introduction	160
7.2. Materials and Methods	162

7.2.1. Data sources and data availability	162
7.2.2 Climate change projections	162
7.2.3 Mann-Kendall trend test of annual climate series and extreme climate indices	165
7.2.4 Change in the extreme climate indices	166
7.2.5 Formulation of climate change scenarios for hydrologic impact analysis	166
7.3. Results and Discussions	168
7.3.1. Performance of RCM models for precipitation	168
7.3.2 Projected future climate based on RCM model output	171
7.3.3 Change detection in the projected future precipitation	176
7.3.4 Projected change in the extreme climate indices	181
7.3.5 Probable climate change impact on streamflow and extreme runoff events	187
7.3.6 The combined impact of projected LC change and climate scenarios on streamflow	196
7.4. Conclusions	200
CHAPTER EIGHT	202
CONCLUSIONS AND SCOPE OF FUTURE WORKS	202
8.1. Conclusions	202
8.2. Scope of Future Works	205
REFERENCES	208
APPENDICES	225
Appendix I. Supplementary material on climate data analysis	225
Appendix II. Hydrological components of SWAT model	227
Appendix III. Sediment routing methods and sediment rating curves	229
Appendix IV. Bias Correction Methods of RCM Climate Outputs	233
LIST OF PUBLICATIONS	236
BRIEF BIO-DATA OF THE AUTHOR	238

LIST OF FIGURES

Figure 1.1 Main river basins of Ethiopia, and main subbasins, hydrologic stations, climate stations and DEM of Upper Awash Basin at the headwater of Awash river basin.	6
Figure 1.2 Map of (a) average annual rainfall isohyet, (b) DEM and elevation contour line, (c) FAO soil classes, (d) slope classes in (%), and (e) Thiessen polygons and (f) main gauged subbasins.	9
Figure 2.1 Monthly patterns of rainfall of climate stations in the basin.	21
Figure 2.2 Box plot of annual rainfall data (mm) for stations measured between year 1980 and 2015.	22
Figure 2.3. Annual variability of PCI values of main climate stations.	25
Figure 2.4. Spatial map areal PCI (a) annual PCI, (b) JJA season PCI, (c) MAM season PCI, (d) SON season PCI and (e) DJF season PCI values over Upper Awash Basin.	25
Figure 2.5. AMD rainfall (mm) for different return periods in year (T-100yr, T-50yr, T-20yr, T-10yr and T-5yr) and mean of AMD rainfall values for main climate stations.	28
Figure 2.6. Spatial patterns and trends of extreme indices (a) location of climate stations, (b) sdii, (c) r10, (d) r20, (e) CDD and (f) CWD. NT=no trend; P=positive trend; SP=significant positive trend; N=negative trend and SN=significant negative trend.	30
Figure 2.7. Spatial patterns of mean annual values and trends of precipitation amount/intensity/days indices (a) river reaches, (b) PRTOT, (c) rx1day, (d) rx5day, (e) r95 and (f) r99.	31
Figure 2.8. Monthly maximum and minimum temperature at main stations.	33
Figure 2.9. Spatial map average maximum and minimum temperature (°C) based on IDW interpolation technique, and MK trend test of (a) maximum temperature, and (b) minimum temperature profile.	34
Figure 2.10. Standardized precipitation index (SPI) for selected stations for (a) JJA, (b) SON, (c) DJF and (d) MAM season.	36
Figure 3. 1 Summarized flowchart showing the overall methodology of image classification, LULC change analysis, and future LULC modeling.	47
Figure 3.2. The spatial patterns of LULC change in the Upper Awash Basin (a) LULC 1972, (b) LULC 1984, (c) LULC 2000, (d) LULC 2014, (e) LULC 2025 and (f) LULC 2035.	49
Figure 3.3. Areal coverage (Km ²) and (%) of classified maps of LULC 1972, LULC 1984, LULC 2000, LULC 2014, and predicted future LULC 2025 and 2035.	50
Figure 3.4. LULC changes between consecutive time (a) absolute difference in Km ² , (b) rate of change Km ² /year, and (c) relative change (%) where negative values are decreasing and positive values are increasing.	50
Figure 3.5. Subbasin level LULC change detection, area change (%) for (a) Melka Kuntre, (b) Akaki, (c) Melka Homole, and (d) Mojo subbasins in Upper Awash Basin of years 1972, 1984, 2000 and 2014.	53
Figure 4. 1 Climate data grid points, rain gauge stations, DEM, Upper Basin (UB) and Lower Basin (LB) areas and river reaches in the main subbasins.	66
Figure 4.2. Annual rainfall, monthly rainfall and scatterplot of monthly precipitation (mm) for Upper Basin (UB) and Lower Basin (LB) areas for rain gauge data (Obs) and global precipitation (CFSR-NCEP, CPC-NOAA, and TRMM data).	73

Figure 4.3. Spatial distribution of annual rainfall (RF) over Upper Awash Basin using IDW interpolation technique (a) rain gauge data, (b) CFSR-NCEP data, (c) CPC-NOAA data and (d) TRMM data.	77
Figure 4.4. Hydrograph of monthly measured and simulated discharge using (a) rain gauge precipitation data, (b) CFSR-NCEP data, (c) CPC-NOAA data and (d) TRMM data at (i) Hombole, (ii) Melka Kuntre, (iii) Mojo and (iv) Akaki watersheds.	80
Figure 4.5. Scatter plot of daily best simulated (cms) and observed daily discharge (cms) based on (a) Rain gauge, (b) CFSR-NCEP, (c) CPC-NOAA and (d) TRMM precipitation data at Hombole, Melka Kuntre, Mojo and Akaki watersheds.	82
Figure 4. 6. Flow duration curve for daily observed, simulated discharge based on gauged and gridded precipitation data for (a) Hombole watershed, (b) Melka Kuntre watershed, (c) Akaki watershed, and (d) Mojo watershed.	84
Figure 5.1 Flowchart of LC change detection, hydrologic simulation with the SWAT model, impact of LC change using PLSR and flood response to LC change scenarios.	94
Figure 5.2. Hydrographs of monthly discharge for calibration and validation periods at five main subbasins (a) Hombole, (b) Melka Kuntre, (c) Mojo, (d) Akaki and (e) Teji subbasin.	96
Figure 5. 3. Monthly performance rating during model calibration and validation for runoff simulation at five main watersheds.	97
Figure 5.4. Scatter plot of daily discharge during calibration and validation period at (a) Hombole, (b) Melka Kuntre and (c) Akaki subbasins.	98
Figure 5. 5. Change in annual SurfQ (a), GWQ (b), and LatQ (c) in different LC. The bar graph shows the annual values, and lines show the relative change for the specified period.	101
Figure 5. 6. Annual average areal values of SurfQ and GWQ, and area (%) of land cover classes for LC 1974 and LC 2014 at (a) Hombole, (b) Melka Kuntre, (c) Akaki, and (d) Mojo subbasins.	103
Figure 5.7. Subbasins level change in the CN, AWC, SurfQ, GWQ, actual ET and SedQ between the simulations based on (a) LC 1974 and LC 1984; and (b) LC 2000 and LC 2014 in the Upper Awash Basin.	105
Figure 5.8. Graph of correlation circle of change in the LC classes and water balance components with (t1; t2), X = predictor variables, Y = dependent variables.	109
Figure 5.9. VIP values of the six predictors used in the PLSR model for (a) SurfQ, (b) LatQ (c) GWQ, (d) ET, and (e) WtrQ.	111
Figure 5.10. Change in extreme daily high flow and low flows at Hombole (a), Melka Kuntre (b), Akaki (c), Mojo (d) and Teji (e) subbasins for LC 1974, LC 1984, LC 2000 and LC 2014, and change (%) between LC 1974 and LC 2014.	114
Figure 5. 11. Accumulated 5-day maximum annual discharge for historical LC change inputs at (a) Hombole, (b) Melka Kuntre, (c) Mojo, and (d) Akaki subbasins.	115
Figure 5.12. Responses of extreme flood events to LC changes at (a) Hombole, (b) Melka Kuntre, (c) Mojo and (d) Akaki subbasins.	117
Figure 5.13. Series of annual maximum daily (AMD) flow (cms) and delta change (%) relative to the baseline land cover (LC 2014).	120
Figure 5. 14. Extreme flood responses to LULC change scenarios at the main subbasin.	122
Figure 5.15. Relative change (%) in the extreme flood discharge for different LULC change scenarios at (a) Hombole, (b) Melka Kuntre, (c) Mojo and (d) Teji subbasins.	122
Table 6.1 The definitions and formula for the calculation of basic watershed morphometric parameters.	132
Table 6. 2 Sensitive sediment parameters with the fitted values for respective subbasins.	134

Table 6.3. Statistical model performance measures for sediment yield simulation at Hombole, Melka Kuntre, Mojo and Akaki subbasins for calibration (Cal) and validation (Val) periods.	137
Table 6.4. Correlation matrix of predictor variables and dependent variable (sediment yield t/ha) and PLSR model quality statistics.	147
Table 6.5. Intercorrelation matrix of subbasins levels hydrologic components and sediment yield at Upper Awash Basin.	150
Table 6.6. Intercorrelation matrix of 11 main morphometric parameters and their communalities.	154
Table 6.7. Proportions of total variance explained by different factors (morphometric parameters).	155
Table 6.8. Unrotated component matrix and rotated component matrix of 11 morphometric parameters.	156
Figure 7.1 Flowchart of the climate change and LC change scenarios analysis.	167
Figure 7. 2. Observed maximum temperature (a), modeled historical (b), and observed minimum temperature (c), modeled historical (d) based on bias-corrected RCM output.	170
Figure 7.3. Areal average observed data, bias-corrected and raw historical maximum (a) and minimum temperature (b) data over the Upper Awash Basin.	170
Figure 7.4. Mean monthly precipitation for observed, raw historical climate data and bias-corrected data at Addis Ababa (a), Ginichi (b), Mojo (c) and Tulubolo (d) stations.	171
Figure 7.5. Areal mean (a) and absolute change (b) in (°C) of monthly, seasonal minimum temperature, the 2040s and 2080s.	173
Figure 7.6. Areal mean (a) and absolute change (b) in (°C) of monthly, seasonal maximum temperature, for the 2040s and 2080s in the Upper Awash Basin.	174
Figure 7.7. Areal monthly (a) and seasonal precipitation (b), relative changes (%) (c).	178
Figure 7.8. Spatial change in the projected precipitation average values between (2020 and 2060) in the Upper Awash Basin.	179
Figure 7.9. Annual series of precipitation for RCP 4.5 and RCP 8.5 scenarios in the main station.	181
Figure 7.10. Monthly RX1day (a) and monthly RX5day (b) precipitation.	182
Figure 7.11. Change in extreme precipitation indices for baseline and future scenarios.	184
Figure 7.12. Change in monthly and seasonal water balance components (%).	189
Figure 7.13. Mean monthly plot of streamflow (cms or m ³ /s) and percentage change (%) for baseline and future scenarios at (a) Hombole, (b) Melka Kuntre, (c) Mojo and (d) Akaki basins.	190
Figure 7.14. Extreme hydrologic events for baseline, future scenarios values in (m ³ /s) at Hombole and Mojo subbasins.	192
Figure 7.15. Change in the extreme daily flow for baseline and future climate scenarios.	194
Figure 7.16. Spatial patterns of change in the daily extreme flow for baseline and climate scenarios.	196
Figure 7.17. Mean streamflow under baseline, LC 2040, RCP 4.5, RCP 8.5 scenarios, and future LC with climate combined effects, (a) Hombole, (b) Mojo and (c) Akaki subbasin.	199
Figure 7.18. Change in mean daily streamflow under projected LC 2040 and climate scenarios, (a) Hombole, (b) Mojo and (c) Akaki subbasin.	200

LIST OF TABLES

Table1. 1 . Main soil type and slope classes and area coverage in the Upper Awash Basin.	8
Table 2. 1 The presence of five climatic zones in Ethiopia.	14
Table 2. 2. Inventory of all climate gauging stations and statistics of rainfall data.	15
Table 2. 3. Statistics of daily discharges in the main gauged subbasins of Upper Awash Basin.	16
Table 2. 4. Statistical test of homogeneity for annual rainfall series of main climate stations.	23
Table 2. 5. Mann-Kendall trend statistics of total annual rainfall data series.	26
Table 2.6. Correlation coefficients of annual extreme precipitation indices for baseline precipitation data from 1980 to 2014 at Addis Ababa climate station.	32
Table 2. 7. Probability of annual maximum (AMD) discharge for different return periods.	37
Table 3.1 Inventory of Landsat satellite data used for LULC classification.	43
Table 3.2. Description of main LULC classes considered for classification.	43
Table 3.3. Total LULC change matrix showing land encroachment from-to values in (Km ²) (a) 1972 to 1984, (b) 1984 to 2000 and (c) 2000 to 2014 in Upper Awash Basin.	52
Table 3.4. Confusion matrix generated for accuracy assessment (the diagonals shows pixels classified correctly).	55
Table 3.5. Summary of LULC classification accuracy assessment (%) User's Accuracy (UA), Producer's Accuracy (PA), overall accuracy and Kappa coefficient of classified LULC of the year 1972, 1984, 2000 and 2014.	56
Table 3.6. LULC change corresponding to different land slope (%) classes.	57
Table 3.7. Transition probability predicted based on the Markov Chain model for future LULC change modeling.	59
Table 4.1 General performance ratings for recommended statistics for streamflow on a monthly time step.	71
Table 4.2 Descriptive statistics of observed areal precipitation over the Upper Basin (UB) and Lower Basin (LB) area.	74
Table 4.3. Performance of global precipitation product on the monthly and daily scale in the Upper Basin (UB) and Lower Basin (LB) area of Upper Awash Basin.	75
Table 4.4 Flow parameters, iteration methods, and finally calibrated values for Hombole, Melka Kuntre, Akaki, Mojo, and Teji subbasins.	78
Table 4.5. Statistical measures for monthly and daily simulation of runoff at (a) Hombole, (b) Melka Kuntre, (c) Mojo and (d) Akaki watersheds.	83
Table 4.6. Comparison of the mean annual water balance components (mm) of simulations driven by gauge, CFSR-NCEP, CPC-NOAA, and TRMM data over Upper Awash Basin.	85
Table 5.1. Definitions of LC change scenarios.	91
Table 5.2. Model efficiency criteria on monthly calibration and validation period at main gauged subbasins.	96
Table 5. 3. Annual basin values (mm), area change in LC classes (%) at different time, and change between consecutive periods in the whole basin.	99
Table 5.4. Pearson correlation coefficients between change in LC classes and water balance components used in the PLSR analysis.	107
Table 5.5. PLSR models summary for the LC change and hydrologic components.	107
Table 5.6. VIP and w values for component 1 of the predictor variables for PLSR modeling of water balance components in the Upper Awash Basin.	111

Table 5.7. Trend of rx1day, rx5day and threshold of Q10 for Hombole (250cms), Melka Kuntre (160 cms), Mojo (33 cms), Akaki (32 cms) subbasins.	118
Table 6. 1 Sensitive sediment parameters with the fitted values for respective subbasins.	134
Table 6.2. Statistical model performance measures for sediment yield simulation at Hombole, Melka Kuntre, Mojo and Akaki subbasins for calibration (Cal) and validation (Val) periods.	137
Table 6.3. Correlation matrix of predictor variables and dependent variable (sediment yield t/ha) and PLSR model quality statistics.	147
Table 6.4. Intercorrelation matrix of subbasins levels hydrologic components and sediment yield at Upper Awash Basin.	150
Table 6.6. Intercorrelation matrix of 11 main morphometric parameters and their communalities.	154
Table 6.7. Proportions of total variance explained by different factors (morphometric parameters).	155
Table 6.8. Unrotated component matrix and rotated component matrix of 11 morphometric parameters.	156
Table 7. 1 Overview of CORDEX-Africa RCM models metadata, which was used.	164
Table 7.2. Representative precipitation and temperature stations used for bias-correction.	165
Table 7.3. Statistical efficiency measures for validation of monthly precipitation generated from RCM (RCA4) models with observed station data in the Upper Awash Basin.	169
Table 7.4. Projected change in seasonal minimum temperature (°C).	172
Table 7.5. Future change in seasonal maximum temperature (°C).	174
Table 7.6. Trends of projected future change in minimum temperature between 2020 and 2100.	176
Table 7.7. Trends of projected future maximum temperature between 2020 and 2100.	176
Table 7.8. Future change in seasonal precipitation (%).	178
Table 7.9. Trends of projected future precipitation between 2020 and 2100.	180
Table 7.10. Trends of extreme precipitation indices for baseline and future climate scenarios in the Upper Awash Basin.	185
Table 7.11. Trends of extreme temperature indices for baseline and future climate scenarios in the Upper Awash Basin.	187
Table 7.12. Change in the extreme hydrologic events for baseline data and future scenarios.	193
Table 7.13. Change in the annual basin values (%) simulated with the combined climate and LC change scenarios.	197

LIST OF ABBREVIATIONS

AMD	Annual Maximum Daily
AOGCMs	Atmosphere-Ocean General Circulation Models
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CA	Cellular Automata
CC	Correlation Coefficients
CFSR	Climate Forecast System Reanalysis
CII	Concentration Impact Index
CMIP5	Coupled Model Intercomparison Project phase 5
CORDEX	Coordinated Regional Climate Downscaling Experiment
CPC	Climate Prediction Center
CSA	Central Statistical Authority of Ethiopia
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Authority
ETCCDI	Expert Team on Climate Change Detection and Indices
FAST	Fourier amplitude sensitivity test
FDRE	The Federal Democratic Republic of Ethiopia
GCM	Global Circulation Model
GCPs	Ground Control Points
GHG	Greenhouse gases
GIS	Geographic Information System
HEC-SSP	Hydrologic Engineering Center- Statistical Software Package
IDW	Inverse Distance Weighted
IHA	Indicator of Hydrologic Alteration
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-tropical Convergence Zone
LAMs	Limited area models
LC or LULC	Land use/land cover
LCM	Land Change Modeler
LII	Load Impact Index
LUAII	Load per Unit Area Index
MK	Mann-Kendall trend test
MLP	Multi-Layer Perceptron

MoA	Ministry of Agriculture
MoWIE	Ministry of Water Irrigation and Energy
MUSLE	Modified Universal Soil Loss Equation
NCEP	National Centers for Environmental Prediction
NMSA	National Meteorological Service Agency of Ethiopia
NOAA	National Oceanic and Atmospheric Administration
PCA	Principal Component Analysis
PCI	Precipitation Concentration Index
PLSR	Partial Least Squares Regression
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SCS	Soil Conservation Service
SMHI	Swedish Meteorological and Hydrological Institute
SNHT	Standard Normal Homogeneity Test
SPI	Standardized Precipitation Index
SRES	Special Report on Emissions Scenarios
SRTM	Shuttle Radar Topography Mission
SUFI-2	Sequential Uncertainty Fitting version 2
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT calibration and uncertainty program
TRMM	Tropical Rainfall Measuring Mission
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
USDA	United States Department of Agriculture
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Traverse Mercator
VIP	Variable Importance for the Projection
WCRP	World Climate Research Program
WMO	World Meteorological Organization