COURSE: ENGINEERING HYDROLOGY

Lecture-1 Introduction

Lecturer: Sisay Demeku Derib (PhD),
sisay.demeku@aastu.edu.et
Assistant Professor in Water Resources Engineering,
Addis Ababa Science & Technology University,
College of Engineering, Civil Engineering Department

Image on the cover page:
Grand Ethiopian Renaissance Dam (GERD) under completion
Source: Prime Minster Office, https://commons.wikimedia.org/wiki/File:GERD_3.jpg

1.1 Course Description

The course Engineering Hydrology introduces students to fundamental hydrologic and hydraulic principles essential for understanding the water cycle and water budget. It equips students with the skills to address problems related to various components of the hydrologic cycle, including rainfall, runoff, evapotranspiration, reservoir capacity, extreme events, and statistical analysis for engineering applications. The course also emphasizes techniques for predicting risks and uncertainties through statistical methods, particularly in relation to flood control systems and drought occurrences.

Additionally, the course provides foundational knowledge on hydrologic modeling, catchment characteristics, urban hydrology across different catchment sizes, data interpretation using statistics and probability, handling missing data, and managing ungauged catchments.

1.2 Course Goals and Objectives/Course Learning Outcomes (CLO)

The general goal the course is to gain basic understanding and problem-solving skills of students on Engineering Hydrology.

Course learning outcomes-based objectives of the course are to make the student to be able to:

CLO-1: Apply measurement techniques of the components of the hydrologic cycle, complete a water balance on a watershed and filling of missed Hydrological data;

CLO-2: Examine Rainfall-runoff relationship and use hydrologic data for hydrograph;

CLO-3: Examine the probability of occurrence of a particular hydrologic extreme event (e.g. rainfall, flood, drought, etc.) and determine the design flood for major hydraulic structures;

CLO-4: Analyze the physical processes involved in the movement of water in to, over, and through the soil surface and use important statistical properties of one or more time series;

CLO-5: Design capacity of reservoir from historical inflow records in the stream and assess the magnitude of sediment deposition in the reservoir;

CLO-6: Plan runoff volume and time of distribution of the runoff hydrograph from urbanization effect.

Lecture 1 learning outcomes

At the end of following this lecture, students will be able to:

1. List main experiences from the previous (pre-requisite) courses.
2. Extract the main topics of this course work.
3. Explain the important concepts of hydrologic cycle at global and Ethiopian levels.
4. Establish ways for grouping for project work.

1.3 Contents of the first lecture

1. Pre-course assessment – past experiences and plan for this course.
    a. Experiences of the pre-requisite courses
    b. Present the course outline
2. The hydrologic cycle
    a. Important concepts of hydrologic cycle at global and Ethiopian levels.
    b. The importance of engineering hydrology

1.3.1 pre-requisite courses and the course outline

Engineering Hydrology is given at the third-year course. It has pre-requisite courses to be successfully passed to be admitted in this course. Open Channel Hydraulics is the immediate pre-requisite of Engineering Hydrology. General Physics, Engineering Mechanics I (Statics) and Hydraulics are the successive pre-requisites for Open Channel Hydraulics. Basic sub-topics of these courses have remembered in this lecture. Pre-course student experiences assessment were collected online from registered students before commencing this lecture to have better introduction and preparation of this course by students. students shared their experience and their plan for this course. This pre-course assessment information will be used to manage this course work and evaluate post-course achievement for continuous quality improvement.

This course has organized with seven chapters supported by the first introductory and course reorganizing presentation and the final summary and student mini-project seminars.

Week	Topics
Week 1	**INTRODUCTION** 1 Pre-course assessment – past experiences and plan for this course. • Experiences of the pre-requisite courses • Present the course outline 2 The hydrologic cycle and engineering hydrology • Important concepts of hydrologic cycle at global and Ethiopian levels. • The importance of engineering hydrology
Week 2	**CHAPTER 1: HYDROLOGY AND ITS MEASUREMENT** 1.1 Meteorological data 1.2 Hydrological data 1.3 Principle of data analysis 1.4 Missing data and comparison with the precipitation data
Week 3	**CHAPTER -2 RAINFALL-RUNOFF RELATIONSHIPS** 2.1 Hydrological Models 2.2 Rational Method 2.3 Rainfall intensity and Time of Concentration 2.4 SCS Curve Number and 2.5 Time-Area Methods
Week 4	2.6 Stream Flow Hydrograph 2.6.1 Hydrograph Analysis 2.6.2 Factors Affecting Flood Hydrograph 2.6.3 Effective Rainfall 2.6.4 Separation of Base Flow and Runoff 2.7 The Unit Hydrograph (UH) 2.8 Applications of Unit Hydrograph
Week 5	2.9 Synthetic Unit Hydrographs 2.9.1 Snyder’s Method 2.9.2 Dimensionless Unit Hydrograph 2.10 Hydrology of Ungauged Catchment
Week 6	**HAPTER -3 FLOOD ROUTING** 3.1 General 3.2 Simple Non-Storage Routing 3.3 Storage Routing 3.4 Reservoir or Level Pool Routing

Week 7	3.5 Channel Routing 3.5.1 Muskingum Method of Routing 3.5.2 Application of The Muskingum Method 3.6 Hydraulic Routing
Week 8	**CHAPTER-4 FREQUENCY ANALYSIS** 4.2 Flow Frequency 4.3 Flood Probability 4.4 Methods of Peak flood determination 4.5 Regional Frequency Analysis
Week 9	4.6 Low Flow Analysis 4.6.1 Definitions and Basic Concepts 4.6.2 Low Flow Frequency Analysis 4.6.3 Drought Analysis 4.7 Precipitation Probability 4.8 Risk, Reliability and Safety Factor
Week 10	**CHAPTER-5 STOCHASTIC HYDROLOGY** 5.1 Introduction. 5.2 Time Series 5.3 Analysis of Hydrologic Time Series 5.4 Time Series Synthesis
Week 11	5.5 Some Stochastic Models 5.6 The Uses of Stochastic Models
Week 12	**CHAPTE- 6 RESERVOIR CAPACITY DETERMINATION** 6.1 Mass Curve (Ripple's) Method: 6.2 Design Reservoir Capacity and Sediment Inflow 6.3 Sediment Load Prediction
Week 13	**CHAPTE- 7 URBAN HYDROLOGY** 7.1 Catchment Response Modifications 7.2 Urban Development Planning 7.3 Drainage Design
Week 14	**COURSE SUMMARY**

1.3.2 The hydrologic cycle and engineering hydrology

I. Hydrology

Hydrology is indeed the scientific study of water in all its forms and interactions within the Earth's system. It encompasses various aspects, including:

1. Occurrence: This refers to where water is found on Earth, including oceans, rivers, lakes, groundwater, glaciers, and atmospheric moisture.

2. Circulation: Hydrology examines the water cycle, which includes processes such as evaporation, condensation, precipitation, infiltration, runoff, and transpiration. This cycle describes how water moves through different states and locations in the environment.

3. Distribution: This aspect focuses on how water is distributed across the planet, considering factors like geography, climate, and human activities. It looks at the availability of freshwater resources in relation to demand.

4. Chemical and Physical Properties: Hydrologists study the properties of water, including its temperature, density, salinity, pH, and dissolved substances. These properties influence how water interacts with its environment and living organisms.

5. Reactions with the Environment: This includes understanding how water interacts with soil, rocks, and the atmosphere, as well as its role in weathering, erosion, and sediment transport.

6. Relations to Living Things: Hydrology also investigates how water supports ecosystems and human life. This includes studying aquatic habitats, water quality, and the impact of water availability on agriculture, navigation and health.

Overall, hydrology is a critical field for managing water resources sustainably, addressing environmental challenges, and understanding climate change impacts.

II. Engineering Hydrology

Engineering hydrology is a specialized branch of hydrology that focuses on the application of hydrologic principles and data to the design, operation, and management of water resources engineering projects. Here are the key areas involved in engineering hydrology:

1. Estimation of Water Resources: This involves assessing the availability and distribution of water resources, including surface water (rivers, lakes) and groundwater. Techniques such as hydrological modeling, statistical analysis, and remote sensing are often employed to estimate water availability.

2. Study of Hydrologic Processes: Engineering hydrology examines the fundamental processes that govern the movement, distribution, and quality of water in the environment. This includes understanding precipitation, evaporation, infiltration, runoff, and groundwater flow.

3. Analysis of Extreme Events: A significant focus is placed on studying extreme hydrologic events such as floods and droughts. This includes developing methods to predict their occurrence, understanding their impacts, and formulating strategies for mitigation and management during extreme events.

4. Design and Operation of Water Resources Projects: Engineering hydrology plays a critical role in the design and management of various water-related infrastructure projects, including:

- Irrigation Systems: Designing systems to efficiently deliver water for agricultural purposes.
- Water Supply Systems: Ensuring reliable sources of water for municipal and industrial use.
- Flood Control Measures: Designing levees, floodwalls, and retention basins to manage flood risks.
- Hydropower Projects: Assessing water flow for energy generation.
- Navigation Systems: Ensuring navigable waterways for transportation.

5. Capacity of Storage Structures: Engineering hydrology involves evaluating the capacity of reservoirs and other storage facilities to manage water supply and flood control effectively. This includes determining the optimal size and operation of these structures.

6. Flood Flow Magnitude: Analyzing flood flows is crucial for designing drainage systems, river restoration projects, spill ways, culverts, … that can safely handle excess water during storm events. This involves estimating peak flows and developing flood frequency analysis.

7. Minimum and Peak Flow Analysis: Understanding low-flow conditions is essential for water supply and ecological health, while peak flow analysis is vital for flood risk management.

8. Interaction with Hydraulic Structures: Engineering hydrology studies how flood waves interact with hydraulic structures such as dams, levees, weirs, bridges, and culverts. This interaction is critical for ensuring the safety and functionality of these structures during extreme events.

Overall, engineering hydrology is essential for sustainable water resource management and infrastructure design, helping to address challenges related to water availability, quality, and flood risk in a changing environment.

III. Hydrologic cycle

The hydrologic cycle, also known as the water cycle, is the continuous movement of water within the Earth and atmosphere. It describes how water evaporates, condenses, precipitates, and flows through various reservoirs. The cycle is crucial for maintaining the Earth's ecosystems and regulating climate. Here are the main components of the hydrologic cycle:

1. Evaporation: This is the process by which water changes from a liquid state to a vapor state or from solid to vapor (called sublimation) due to heat from the sun. It primarily occurs from oceans, lakes, rivers, and soil surfaces. Plants also contribute to this process through transpiration.

2. Transpiration: This refers specifically to the release of water vapor from plants into the atmosphere. Together with evaporation from other surfaces, it is often combined into a single term called "evapotranspiration."

3. Condensation: As water vapor rises into the atmosphere, it cools and changes back into liquid water, forming clouds. This process is essential for the formation of precipitation.

4. Precipitation: This occurs when condensed water droplets in clouds become heavy enough to fall back to the Earth in various forms, including rain, snow, sleet, or hail.

5. Infiltration: When precipitation reaches the ground, some of it seeps into the soil and becomes groundwater through a process called infiltration. The rate of infiltration depends on soil characteristics, vegetation cover, and land use.

6. Runoff: Water that does not infiltrate the ground flows over the surface as runoff. This can occur in streams, rivers, and lakes and eventually returns to oceans or other bodies of water.

7. Groundwater Flow: Water that infiltrates the ground can move through soil and rock layers as groundwater. It may eventually discharge into rivers, lakes, or oceans or be extracted through wells for human use.

8. Storages: Water is stored in various reservoirs throughout the cycle:

- Atmosphere: Water vapor exists in the air.
- Surface Water Bodies: Includes oceans, rivers, lakes, and wetlands.
- Groundwater: Water stored in aquifers beneath the Earth's surface.
- Ice and Snow: Water stored in glaciers and snowpacks.

9. Evaporation from Water Bodies: In addition to terrestrial evaporation, water bodies like oceans and lakes also contribute significantly to atmospheric moisture through evaporation.

The hydrologic cycle is a dynamic system influenced by various factors, including climate, topography, vegetation, and human activities. Understanding this cycle is essential for managing water resources and predicting hydrological responses to environmental changes for an engineering decision.

IV. Hydrology and water resources of Ethiopia

Ethiopia's hydrological setup is complex and influenced by the rainfall patterns due to its diverse topography, and the presence of several major river systems. Here’s an overview of the key elements of Ethiopia's hydrology, including drainage basins, surface flows, lakes, that can influence decision on the transboundary water management for different water resources development projects.

1. Topography

Ethiopia's topography is characterized by highlands, plateaus, valleys, and lowlands. The Ethiopian Highlands, often referred to as the "Roof of Africa," are a prominent feature that significantly influences the country's climate and hydrology. The elevation ranges from about 200 meters below sea level in the lowland areas to over 4,500 meters in the highlands.

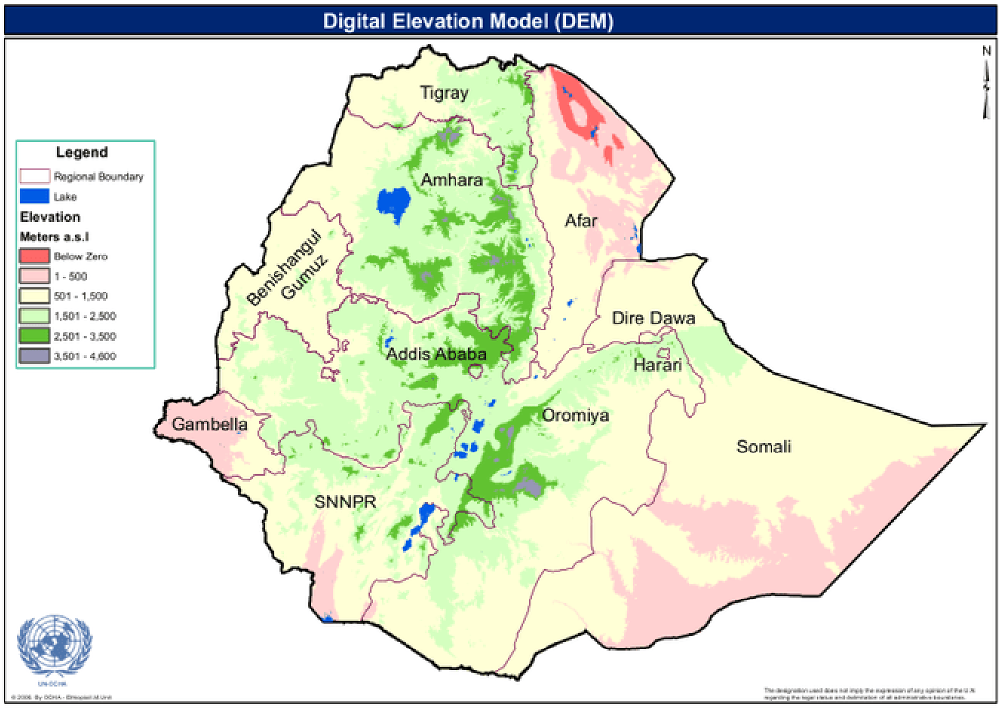

Fig. 1 Elevation map of Ethiopia [Source: UN-OCHA, 2006]

2. Rainfall

Ethiopia experiences a varied climate with distinct wet and dry seasons. The main rainy season (Kiremt) occurs from June to September, while a shorter rainy season (Belg) occurs from February to May in some regions. Rainfall distribution is uneven, with the highlands receiving more precipitation compared to the lowland areas.

- **Annual Rainfall**: Ranges from less than 400 mm in arid regions to over 2,000 mm in some highland areas.
- **Rainfall variability**: The variability in rainfall contributes to different agricultural practices and water resource management strategies. However, it leads to extreme events and failure on agriculture and water supply for proper life of the society

3. Drainage Basins

Ethiopia is home to several major river basins:

- **Ethiopian Blue Nile Basin**: Originates in the Ethiopian Highlands and flows into Sudan, contributing significantly to the Nile River. This basin includes *Abbay, Tekeze, Mereb, Angereb, Shinfa, Dinder, Rehad,* and *Baro Akobo*. It is crucial for both Ethiopian agriculture and downstream countries: South Sudan, Sudan and Egypt.

- **Awash Basin**: Located in central Ethiopia, it is an important basin for irrigation and supports agriculture.
- **Omo River Basin**: Flows southward into Lake Turkana in Kenya and is vital for hydropower, irrigation, recreation, local ecosystems and communities.
- **Shebele-Genale Basin**: Flows into Somalia and is significant for hydroelectric power generation and irrigation.
- **Rift-valley Lakes Basin:** This basin has rivers like *Katar, Meki, Dijo, Bilate* that discharges surface water to *Ziway, Langano, Shalla, Awasa, Abaya* and *Chamo* Rift valley lakes.

Ethiopia has also three dry basins to the east cost of the country. More of the rivers of Ethiopia, except Awash River and Rift-valley Lakes Basin, discharges more than 90% of the surface water neighboring countries that challenges the decision of water resources development in the country.

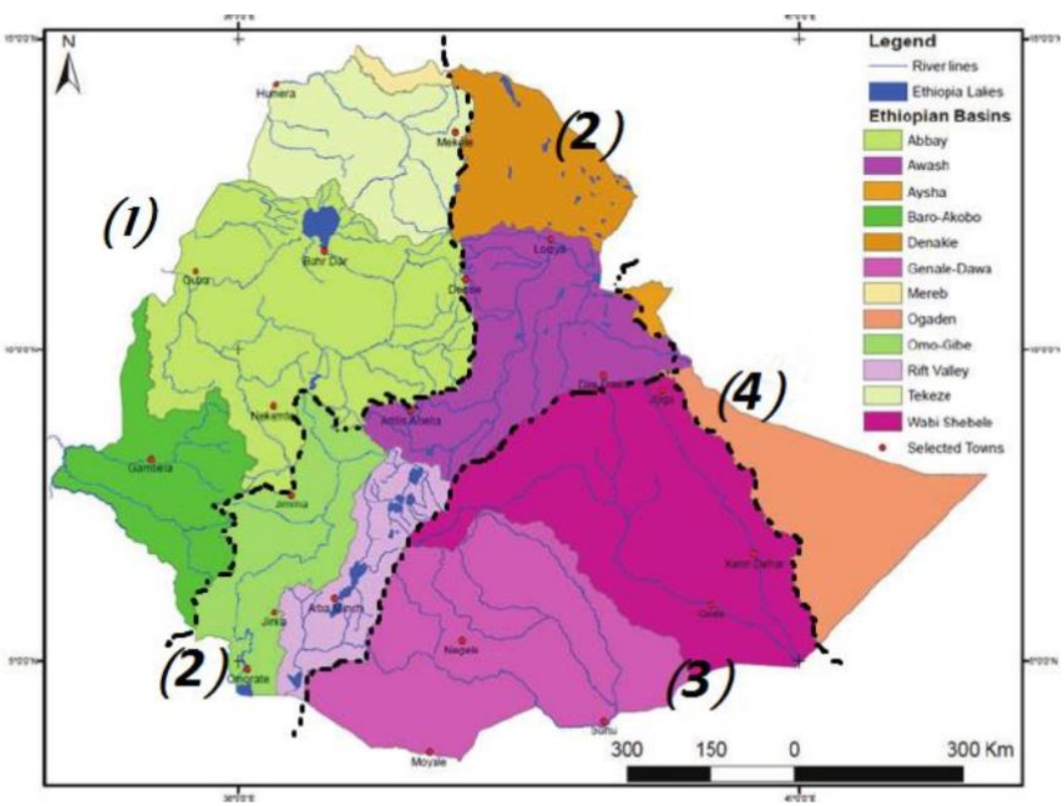

Fig. 2 Drainage Basins of Ethiopia. (1) Ethiopian Blue Nile with Abbay River Basin, (2) Rift Valley, (3) Shebele-Juba, and (4) East Cost

[Source: Modified form of Birhanu, 2014]

4. Transboundary Water Management

Ethiopia shares several river basins with neighboring countries, making transboundary water management critical. It needs understanding of the hydrology of these rivers across the boundary for those areas who possess water resources shared among country, called transboundary rivers. Key aspects of issues along the Nile Basin include:

• Nile Basin Initiative (NBI): A cooperative framework involving Ethiopia, Sudan, Egypt, and other Nile Basin countries aimed at promoting sustainable management of shared water resources. Long negotiation processes for equitable and wise water use have not yet reached at required level. Ethiopia has started to develop its water resources while considering the negotiated water management.

• Grand Ethiopian Renaissance Dam (GERD): is dam for hydropower production on *Abbay* River, the main river contributing to Nile. This hydroelectric project on the Blue Nile River, shown on the cover page of this course material, has raised concerns among downstream countries regarding water flow management and impacts on their water supply.

5. Surface Flows Variations

Ethiopia's rivers are characterized by seasonal flow patterns influenced by rainfall:

- **Seasonal Variation**: Rivers experience high flows during the rainy season and low flows during the dry season.
- **Flooding**: Heavy rains can lead to flooding in various regions, affecting agriculture and infrastructure.

6. Lakes

Ethiopia has several significant lakes, including:

- **Lake Tana**: The largest lake in Ethiopia and the source of the Blue Nile River. It supports fisheries and is an important cultural site.
- **Lake Abaya**: Located in the southern part of the country, it is one of the largest lakes but faces challenges related to pollution and water quality.
- **Rift Valley Lakes**: A series of lakes formed by tectonic activity, including Lakes Ziway, Langano, and Awasa, which are important for biodiversity and tourism.

7. Irrigation, Water Supply and Sanitation

Water supply for agriculture, power and sanitation in Ethiopia face significant challenges that leads the country even behind East and Sub-Saharan Africa due to the above hydrological variabilities and socio-economic factors.

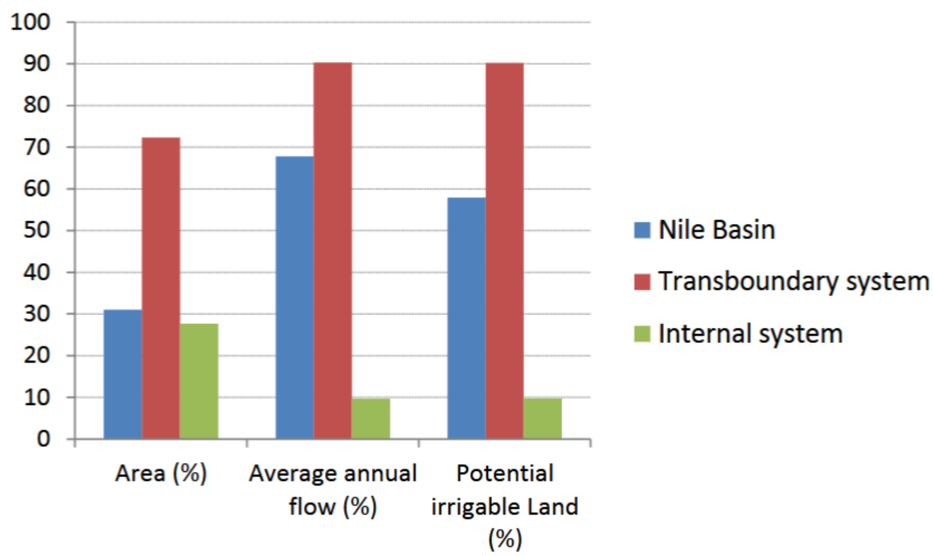

Fig. 3 Distribution potential land and surface flows with resect to transboundary and internal water systems.

[Source: Derib, 2025]

- **Access to Clean Water**: While access has improved in urban areas, rural communities still face difficulties in obtaining safe drinking water.
- **Sanitation Facilities**: Many rural areas lack adequate sanitation facilities, leading to health issues.

- **Government Initiatives**: The government and various NGOs are working towards improving water supply and sanitation through infrastructure development and community engagement.

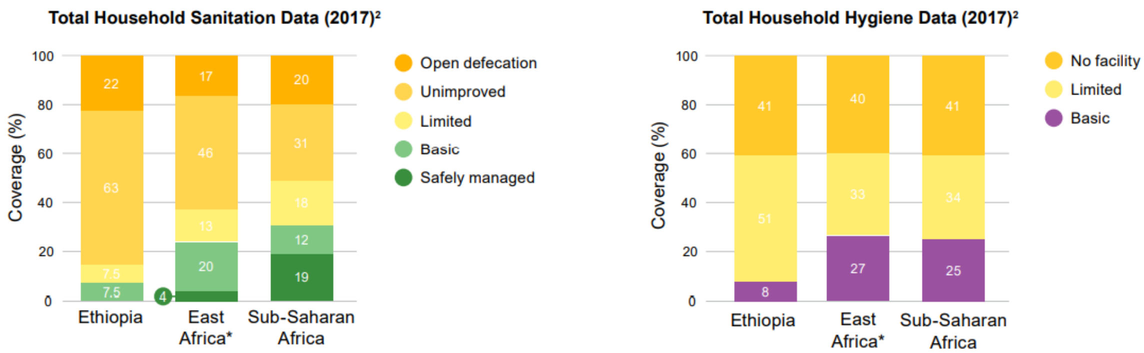

Fig. 4 Sanitation and hygiene status of Ethiopia with respect to East and Sub-Saharan Africa

[**Source**: USAID. "Sanitation Profile: Ethiopia 2020", 2020, https://amcow.ams3.cdn.digitaloceanspaces.com/resources/Sanitation%20Profile_Ethiopia_Final.pdf

Conclusion

Understanding the process of hydrological cycle on a given area is very essential for proper utilization of our scarce water resources. Lack of skilled man power for this understanding and wise utilization is a challenge like Ethiopia with ample water resources. Ethiopia's hydrological setup is shaped by its unique geography and climate. Effective management of water resources is essential for addressing challenges related to agricultural productivity, energy generation, and ensuring access to clean water and sanitation for its growing population. Water flows across political boundaries that calls for cooperated management. Transboundary cooperation will also be vital as Ethiopia continues to develop its water resources while considering the needs of neighboring countries. This course is designed to increase engineering hydrology knowledge and skills of the students together with all the pre-requisite courses. Students shall participate actively to exploits materials, participate online and face-to-face course works and submit assignments on time.

References:

Berhanu, B., Y. Seleshi and A. M. Melesse.2014. Surface Water and Groundwater Resources of Ethiopia: Potentials and Challenges of Water Resources Development,In: Melesse, A., W. Abtew and S.

Setegn (eds.). Nile River Basin: Ecohydrological Challenges, Climate Change and Hydropolitics, Springer, New York.

Derib, S. D. (2015) Balancing water availability and water demand in the Blue Nile: A case study of Gumara watershed in Ethiopia. Ecology and Development Series Bd. 95. PhD Thesis, University of Bonn.

MoWEI, 2015. Second Growth and Transformation National Plan for the Water Supply and Sanitation Sub Sector (2015/16 – 2019/20), Addis Ababa.

UN-OCHA. "Ethiopia: Digital elevation model (DEM)", 2006, https://reliefweb.int/map/ethiopia/ethiopia-digital-elevation-model-dem

USAID. "Sanitation Profile: Ethiopia 2020", 2020, https://amcow.ams3.cdn.digitaloceanspaces.com/resources/Sanitation%20Profile_Ethiopia_Final.pdf