Hydrologic soil group based curve number matrix modeling for Enset-Based land use system in Meki River Watershed, Western Lake Ziway Sub-Basin, Central Rift Valley of Ethiopia

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Abstract

Background

Enset-Based land use system (EBLUS) exhibits good carbon stock and infiltration rate equivalent to forest covered areas, which enhances infiltration and water holding capacity and it can reduce the curve number (CN) of the watersheds but it was not considered in former studies. Therefore, this study is planned to model the hydrologic soil group (HSG) based CN matrix of EBLUS relative to other LUSs with established hydrological characteristics in the Meki river watershed. The soil data is used to determine the HSG of the watershed collected from Ministry of Water, Irrigation and Energy (MOWIE) and verified by Harmonized World Soil Database (HWSD). A Model is developed for CN of EBLUS relative to other LUSs (Alemu’s formula). The model considers both infiltration rate measured using Amozi-meter and carbon stoke of soil weighed as 85% and 15% respectively. HEC-GEO-HMS model is used to consider the CN of EBLUS as a separate LUS to verify the developed CN matrix model to generate CN of the sub-watersheds.

Result

The field measurement results show that an infiltration rate of 12.9675, 11.1875, 10.375, 7.065 and 12.8125 mm hr\(^{-1}\) for Natural Forest, Grassland and plantation, cultivated, built-up and EBLUS respectively. The model is: \[ E = \frac{0.85 \cdot \sum_{i=1}^{n} EI_i + 0.15 \cdot \sum_{i=1}^{n} EC_i}{n} \] and the resulting CN matrix of EBLUS is 39, 51.5, 58.3 and 61.6 for HSG of A, B, C and D respectively.
Conclusion

Significant reduction in mean CN of the watershed that shows the role of EBLUS in managing the water resources and flood is high. Therefore, escalating EBLUS will reduce the CN of the watershed which reduces runoff volume in the watershed and it ensures the sustainability of Lake Ziway by reducing sedimentation.

Key words: Enset, CN, SCS, Infiltration, Carbon stock, HSG, HEC-HMS
1. Introduction

Land use and land cover (LULC) changes affect the processes that provide redistribution of soil material and soil properties (Jerzy, Anna, & Jan, 2014) and it leads to change in soil organic carbon (SOC) and soil quality (Nyssen, Habtamu, Mulugeta, Amanuel, Nigussie, & Mitiku, 2008). Soil infiltration capacities are spatially and temporally dynamic properties due to varying land use management practices (Oliver, Niels, Hogler, & Reinhard, 2006).

Land cover affects the infiltration capacity of the soil (A., B., & J., 2011; Schilling, Jha, Zhang, Gassman, & Wolter, 2008; Mao & Cherkauer, 2009; Elfert & Bormann, 2010; Ghaffari, Keesstra, Ghodousi, & Ahmadi, 2010), surface and subsurface flow regimes (base flow) (A., B., & J., 2011; Tu, 2009), surface roughness (A., B., & J., 2011; Feddema, et al., 2005) and peak runoff (A., B., & J., 2011; Burch, Bath, Moore, & O’Loughlin, 1987) and flood frequency and magnitude (A., B., & J., 2011; Ward, Renssen, Aerts, van Balen, & Vandenberghhe, 2008; Remo, Pinter, & Heine; Benito, Rico, Sanchez-Moya, Sopeña, THorndycraft, & Barriendos, 2010; Qiu, Jia, Zhao, Wang, Bennett, & Zhou, 2010).

Similarly, based on Kebede Wolka et al., (2015), Enset-Based land use systems (EBLUS) can reduce the rain drop impact equivalent to the forest and it exhibited a good carbon stock equivalent to high-vegetation areas (Mesfin, Osamu, Christine, & Kumelachew, 2017; Mbow, Van Noordwijk, Luedeling, Neufeldt, Minang, & Kowero, 2014) that modifies the infiltration and water holding capacity of the soil for a longer period (Barbora & Jaroslava, 2014) which in turn influences the curve number (CN) of Meki river watershed.
The socio-economic (Shiferaw Feleke, 2003), yield and inputs required (Uloro & Mengel, 2014), EBLUS as a food security tool and as a sources of income (Mesfin, Osamu, Christine, & Kumelachew, 2017; Mbow, Van Noordwijk, Luedeling, Neufeldt, Minang, & Kowero, 2014; Tilahun & Robert, 2006; Anita, et al., 1996), the physiological (Admasu Tsegaye 1 and P.C.Struik2, 2003), ecosystem services (Mesfin, Osamu, Christine, & Kumelachew, 2017), agronomy (Admasu, 2007), breeding (James Harrison 1, 2014), pathology (Bridge, 1992), postharvest (Yirmaga, 2013) and soil nutrition (Elias, 2011) aspect of EBLUS are studied.

The Relative impact of EBLUS on surface water has not been established and quantified (Anita, et al., 1996; Uloro & Mengel, 2014) and the impact of EBLUS changes on hydrological processes are not fully understood (A., B., & J., 2011; Wang, Liu, Kubota, & Chen, 2007) and contribution of EBLUS to modify the CN responsible to model peak runoff (Merwade V., 2012) is not studied formerly in the Meki river watershed.

Considering the importance of Meki river watershed and its role in contributing to the sustainability of lake Ziway, detailed watershed modeling and analysis are needed including an assessment of how the change in EBLUS at different scales (e.g., from the hydrologic response unit to the basin scale) influenced the CN in the watershed to understand the underlying mechanisms and to establish theory regarding the effects of EBLUS on CN of Meki river watershed.

Therefore, the aim of this study is to articulate the influence of Enset-Based land use system (EBLUS) on Curve number (CN) and to develop a model for HSG based CN matrix of EBLUS
relative to other land use systems with established hydrological characteristics in Meki river watershed.

2. Methods

2.1. Study area description

Meki river watershed is found in the western part of lake Ziway between 7°45’N to 8°30’N and 38°10’E to 39°00’E as shown in Figure 1 in the Central Rift Valley (CRV) of Ethiopia and the watershed has a mean elevation of 2169m.a.s.l, the mean annual rainfall ranges from 824mm to 1292mm and the mean monthly temperature varies between 15°C and 29°C, the mean relative humidity of 60%, average wind speed of 1.66m/s and average sunshine hour of 7.3 hrs (Alemu Beyene et al, 2020; ENMA, 2017; Oliver et al., 2007).
2.2. Research Framework

Soil organic carbon and Land use are the critical factors to influence the infiltration capacity of the soil (Yimer, 2008; A.O.Ibeje, 2018). The mean steady state infiltration rates of farmlands, bamboo fields and forestland are 1.98 cm/h, 2.44cm/h and 2.43cm/h respectively (A.O.Ibeje, 2018). This shows that the infiltration rate of the soil is under the influence of land use and also the land use change can affect the infiltration capacity of the soil (A.O.Ibeje, 2018).

Enset-Based land use system (EBLUS) considered in the land cover classification process using ERDAS imagine software with maximum likelihood algorithm and used to model the CN matrix.
of Meki river watershed. Therefore, this study articulates the influence of EBLUS on CN of Meki river watershed and model the CN matrix for EBLUS as shown in the Flow diagram presented in Figure 2.

Figure 2: CN matrix model flow diagram

### 2.3. Field measurement and analysis of infiltration capacity of LUS

#### Sample site selection criteria

Measuring and mapping of vegetation zone based infiltration rate of the soil under different land use systems to evaluate their relative hydrological influence are achieved using Amozi-meter in the labor intensive field work. The soil type (soil texture) is one of the bases for sample site selection next to vegetation zone.
Preliminary GPS based site assessment was carried out starting from the highest point of the watershed to Lake Ziway which is characterized by high elevation differences from 1633m.a.s.l at the gauging station of Meki river discharge to 3612m.a.s.l at Zebidar Mountain which can give enough head and opportunity for water resources development options.
In the process of field measurement site selection; Vegetation zone, dominant LUS and Dominant soil types in the study area as shown in Figure 3 are considered as the main factors influencing the infiltration capacity of the soil and the sampling matrix is prepared after the overlay of those maps together so as to choose appropriate locations to organize the proposed field measurement.

**Sampling and Measurement techniques**

In order to get and compare the hydrological characteristics of EBLUS, the following sampling matrix was prepared as shown in Table 1. In the process of sampling, land use class is crucial for the relative comparison of hydrological components (infiltration capacity) with replication.

The study area is classified into eight land cover classes that include forest and natural vegetation LUS, grass LUS, EBLUS, eucalyptus with sparse vegetation LUS, cultivated LUS, built-up and degraded LUS but due to non-availability of data for all eight LUSs and for the ease of sampling, the LUSs are aggregated as Cultivated LUS, Built-up & Degraded LUS, Grass & Plantation LUS, EBLUS and Natural Forest LUS for the sampling purposes. The soil type data is collected from MOWIE GIS section and Vertisol, Cambisol, Luvisol and Leptosol are considered as the dominant four soil types in the watershed. The soil type is verified by harmonized world soil database (HWSD).

The vegetation zones are combined with dominant soil types as vegetation zone 1 with soil type 1 (Z11) up to vegetation zone 3 with soil type 4 (Z34). Vegetation zones are expressed as Afro-alpine as vegetation zone 1, Dry Afro-montane as vegetation zone 2 and Acacia wooded grass
land of rift valley as vegetation zone 3 verified in the field as shown in Figure 4 below and the dominant soil types considered are Vertisol, Cambisol, Luvisol and Leptosol and called to be soil type 1, soil type 2, soil type 3 and soil type 4 respectively as shown in Table 1.

Figure 4: Vegetation zone verification assessment

A = Divide line at western end of the watershed where more than half part of the watershed is visible (Silti zone)

B & F = Western upper part of Meskan woreda (Yewutin & Yetebon respectively)

C = Found around Eastern Meskan woreda and Western Sodo woreda
D = Scene at Chohamba Meskan woreda

E = Conversion from lake to wetland (Lake Ziway)

Table 1: Sampling points based on vegetation zone, Dominant soil type and Dominant LUS

| Combined Vegetation & Dominant Soil type class | Land Cover                          | Cultivated LUS | Builtup & Degraded LUS | Grass & Planted Forest LUS | EBLUS | Natural Forest LUS |
|-----------------------------------------------|-------------------------------------|----------------|------------------------|----------------------------|-------|-------------------|
| Z11   CZ11                                    | BZ11                               | GZ11           | EZ11                   | NZ11                        |       |                   |
| Z12   CZ12                                    | BZ12                               | GZ12           | EZ12                   | NZ12                        |       |                   |
| Z13   CZ13                                    | BZ13                               | GZ13           | EZ13                   | NZ13                        |       |                   |
| Z14   CZ14                                    | BZ14                               | GZ14           | EZ14                   | NZ14                        |       |                   |
| Z21   CZ21                                    | BZ21                               | GZ21           | EZ21                   | NZ21                        |       |                   |
| Z22   CZ22                                    | BZ22                               | GZ22           | EZ22                   | NZ22                        |       |                   |
| Z23   CZ23                                    | BZ23                               | GZ23           | EZ23                   | NZ23                        |       |                   |
| Z24   CZ24                                    | BZ24                               | GZ24           | EZ24                   | NZ24                        |       |                   |
| Z31   CZ31                                    | BZ31                               | GZ31           | EZ31                   | NZ31                        |       |                   |
| Z32   CZ32                                    | BZ32                               | GZ32           | EZ32                   | NZ32                        |       |                   |
| Z33   CZ33                                    | BZ33                               | GZ33           | EZ33                   | NZ33                        |       |                   |
| Z34   CZ34                                    | BZ34                               | GZ34           | EZ34                   | NZ34                        |       |                   |

There are about 60 sampling possibilities, but EBLUS is not common at the acacia wooded part of the watershed for which zones Z31 to Z34 to all LUSs are not applicable in this research.

The resulting sampling points are Z11 up to Z24 (8 combined zones of two vegetation zones and four dominant soil types) for five LUSs which results in 40 sampling points replicated to four fold to make it representative and to reduce human and instrumental errors.

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1 CZ23 refers to Cultivated LUS in vegetation zone two (Dry afro-montane) and soil type three (Luvisol)
The infiltration data collected from those sampling points using Amozi-meter as shown in Figure 5. Hence, 160 samples were collected in the field excluding the lower zone of the watershed since it has no sufficient EBLUS to be considered and the result is analyzed and mapped using ArcGIS 10.1 for their hydrological characteristics of different land use systems compared with EBLUS.

Enset-Based land use system (EBLUS) was not included in all former land use studies and now in this portion more focus is deputed to the infiltration capacity of EBLUS relative to all land use systems in Meki river watershed. Amozi-meter is used to measure the infiltration capacity of soil under each land use system, including EBLUS as shown in Figure 5 and considered to model CN matrix of EBLUS.

Figure 5: Amozi-meter infiltration measurement of EBLUS

The hole dug to the level to which the water is released into the ground through sensor at the tip of the plastic pipe attached to the main tanker of the Amozi-meter. The level of digging the
hole depends on the number of pipes filled to keep the balance pressure which is equivalent to 0.5m deep for one pipe. The main tanker was filled from the top with clean water to protect blockage of flowing pipes of the instrument to the sensor.

The water is released to flow down to the ground and time and depth of flow recorded using a stopwatch and gauge fitted to the instrument respectively based on the procedural manual.

2.4. Review of Carbon stock of Land use systems

Published articles are reviewed to get the carbon stock of different land use systems which accounts EBLUS. According to Mesfin et al, 2017, carbon stock of land uses are measured and reported as shown in Table 2 and considered to develop the CN of EBLUS.

Table 2: Carbon stock of different land use systems (Source: Mesfin et al, 2017)

| Land Cover/Land Use                      | Carbon stock (ton/yr) |
|-----------------------------------------|-----------------------|
| Open Water                              | 0                     |
| Built-up, Medium Intensity LUS          | 132                   |
| Natural Forest LUS                      | 45,714                |
| Grasslands (Pasture) & plantations LUS  | 8350                  |
| Cultivated LUS                          | 19,950                |
| Enset-Based LUS                         | 77,286                |
2.5. Review of HSG based curve number of land use systems

CN matrix is developed for all land use systems except EBLUS as shown in Table 3 that is used to develop a relation among the model the CN matrix for EBLUS relative to other land use systems with predetermined CN.

Table 3: Curve number lookup table (ERA, 2013; Chow, 1988)

| Land Cover/Land Use                  | Hydrologic Soil Group |
|-------------------------------------|-----------------------|
|                                     | A  | B  | C   | D  |
| Open Water                          | 100| 100| 100 | 100|
| Developed, Open Space               | 39 | 61 | 74  | 80 |
| Developed, Low Intensity            | 57 | 72 | 81  | 86 |
| Developed, Medium Intensity         | 77 | 85 | 90  | 92 |
| Developed, High Intensity           | 98 | 98 | 98  | 98 |
| Barren Land, Rock, Sand, Clay       | 63 | 77 | 85  | 88 |
| Deciduous Forest                    | 36 | 60 | 73  | 79 |
| Evergreen Forest                    | 36 | 60 | 73  | 79 |
| Mixed Forest                        | 36 | 60 | 73  | 79 |
| Scrub/Shrub                         | 35 | 56 | 70  | 77 |
| Grasslands, Herbaceous              | 39 | 61 | 74  | 80 |
| Pasture, Hay                        | 49 | 69 | 79  | 84 |
| Cultivated Crops                    | 67 | 78 | 85  | 89 |
| Woody Wetlands                      | 100| 100| 100 | 100|
| Emergent Herbaceous Wetlands        | 100| 100| 100 | 100|

The CN matrix of the dominant land use systems are used in modeling the CN matrix of EBLUS in Meki river watershed.
2.6. **CN Matrix Model development method**

The formerly developed CN matrix for all land use systems (LUSs) except EBLUS, infiltration capacity of the soil under all LUSs including EBLUS and carbon stock of the soil under all LUSs including EBLUS are used to develop a model for CN matrix of EBLUS relative to other LUSs with predetermined CN using Microsoft excel.

2.7. **Preprocessing and CN model verification procedure in HEC-GeoHMS**

Soil conservation service curve number grid is used by many hydrologic models to extract the curve number for watersheds (Fleming & Brauer, 2018; Merwade, 2012) for further analysis of watershed parameters and runoff modeling. To produce the CN grid several activities are expected that include watershed delineation, land use grid preparation, HSG grid preparation, merge the land use and soil data, create CN lookup table and finally creating the CN grid for Meki river watershed.

1.1.1. **Delineation of the watershed from DEM**

Meki river watershed and sub-watersheds are automatically extracted from Digital Elevation Model (DEM) and the DEM is preprocessed to produce the watershed fill, flow direction, flow accumulation, stream definition, stream segmentation, combined stream link, sink link, catchment grid delineation, catchment polygon processing, flow length, slope, Elevation, aspect, contour line, drainage line processing and adjoinment catchment processing, etc are derived using HEC-GeoHMS model of Arc GIS 10.1(Iliasse Khaddor & Adil HafidiAlaoui, 2014).
The project setup is generated using the outlet point at Lake Ziway by providing the data at the preprocessing phase of the project. Basin merge and river merge processes are taken place to increase consistency and convenience of the result output.

According to Fleming and Brauer (2018), in order to perform CN modeling, various types of information are required that includes watershed parameters from DEM, HSG and LUSs and the CN grid is used by many hydrologic models (Merwade, 2012).

### 1.1.2. Land use data preparation for CN grid

Land use map was generated using Land sat image data (30m) supported by Google earth. GPS based field visit is performed to collect data to train ERDAS 2014 to classify the images with maximum likelihood clustering algorithm of supervised classification method (Iliasse and Adil, 2014; Fleming and Brauer 2018) and eight Land use systems are identified as shown in Figure 6 and reclassified into five classes as shown in According to Fleming and Brauer (2018) and Merwade (2012), the Spatial Analyst Tools in Arc Toolbox is used to implement re-classification
Table 4 based on the USGS land cover institute (LCI\(^2\)) and modified to include the recently recognized EBLUS (Fleming and Brauer, 2018; Okirya Martin, Albert Rugumayo and Janka Ovcharovichova, 2012; Merwade, 2012).

Figure 6: Land use system of the area for CN mapping

According to Fleming and Brauer (2018) and Merwade (2012), the Spatial Analyst Tools in Arc Toolbox is used to implement re-classification

\(^{2}\) [http://landcover.usgs.gov/classes.php](http://landcover.usgs.gov/classes.php)
Table 4: Land use reclassification based on USGS land cover institute (LCI) with modification

| Number | Land cover classification | Revised classification |
|--------|---------------------------|------------------------|
| 11     | Water bodies              | 1                      | Water                  |
| 95     | Wetlands with herbaceous plants | 2                      | Built ups              |
| 21     | Developed, Open space LUS | 3                      | Forest& Natural vegetation |
| 22     | Developed, Low and medium intensity LUS | 4 or 5 | Agricultural |
|   | Cultivated land LUS |   | Grass land LUS |   |
|---|---------------------|---|----------------|---|
| 82| Enset               | 6 | EBLUS          |   |

In the reclassification window, confirm the Input raster is LULC_2017_March2019Recl field is Class_Name, and then manually assign the new numbers from Table 4 as shown in Figure 7 and the output raster is saved as LULC_2017_March2019Recl.

Figure 7: Reclassification window with assigned new values

The final steps in processing land use data were converting the reclassified land use grid (raster) into a polygon feature class following the procedure in Conversion Tools of the Arc Toolbox and assign the new value.
1.1.3. Hydrologic soil groups data preparation for CN grid

The hydrological soil data are collected from Ethiopia Ministry of Water, Irrigation and Energy (MOWE, 2013) as shown in Figure 8 and verified by HWSD viewer. The soil categories such as Cambisol, Andosol, Fluvisol, Leptosol, Vertisol and Luvisol are identified and hydrologic soil group is assigned to each category based on US Natural Resource Conservation Service (NRCS) that may fall into four hydrologic soil groups (HSG) (A, B, C and D): high, moderate, slow and very slow infiltration rates respectively (USDA-NRCS, 1986).

Figure 8: Soil map of the area (MWIE, 2017)
Add Soil_WZ_2018_1 feature class from spatial dataset collected from Ethiopia MOWIE and in its attribute table create an empty field for storing soil group data as shown in Table 5. Hence the hydrologic soil group data can be populated to Soil_WZ_2018_1 after identifying the type of soil with its corresponding description.

Ethiopian Road Authority (2013) manual is used to generate the relationship of soil type and hydrologic soil group of Meki river watershed and also verified by HWSD viewer and also shape file data acquired from MOWIE as shown in Table 5.

Table 5: Hydrologic soil group of different soil types (ERA, 2013)

| Soil Types           | Hydrologic Soil Group (HSG) | Soil Types           | HSG | Soil Types           | HSG |
|----------------------|-----------------------------|----------------------|-----|----------------------|-----|
| Orthic Acrisols      | B                           | Calcaric Fluvisols   | B   | Eutric Nitosols      | B   |
| Chromic Cambisols    | B                           | Eutric Fluvisols     | B   | Dystric Histosols    | D   |
| Dystric Cambisols    | B                           | Chromic Luvisols     | B   | Eutric Histosols     | D   |
| Eutric Cambisols     | B                           | Orthic Luvisols      | B   | Cambric Arenosols    | A   |
| Humic Cambisols      | C                           | Vertic Luvisols      | C   | Calcaric Regosols    | A   |
| Calcic Cambisols     | B                           | Dystric Nitosols     | B   | Eutric Regosols      | A   |
| Vertic Cambisols     | B                           | Caloic Xerosols      | B   | Humic Andosols       | B   |
| Calcic Chernozems    | B                           | Luvic Xerosols       | C   | Mollic Andosols      | B   |
| Rendzinas            | D                           | Gypsic Yermosols     | B   | Vitric Andosols      | B   |
| Haplic Phaeozems     | C                           | Gleyic Solonchaks    | D   | Chromic Vertisols    | D   |
Accordingly, the HSG is assigned to each of the six soil types identified in the watershed as shown in Figure 9. During the assignment the HSG of Leptosol is assigned after referring the field characteristics of the soil and it has more similarity to Luvisol with its insignificant areal coverage to influence the value of the curve number and hence HSG of C is assigned to it.

Figure 9: Hydrologic soil group (HSG) assignment
Editing the Soil_WZ_2018_1 and transferring HSG, now we have a Soil Code (soil group) assigned to each polygon in Soil_WZ_2018_1. Following soil group assignment, create four more fields named PctA, PctB, PctC, and PctD all of type short integer in Soil_WZ_2018_1 feature class. For each feature (polygon) in Soil_WZ_2018_1 PctA will define what percentage of area within the polygon has soil group A, PctB will define what percentage of area within the polygon will have soil group B and so on (USDA-NRCS, 1986). This is critical when we have polygons with more than one soil group (for eg. A-B-A/D would mean that group A, group B and group A/D soils are found in one polygon; A/D would mean the soil behaves as A when drained and as D when not drained, and so on). If we have classifications such as these, we need to define how much area of a polygon is A/B/C/D.

For Meki river watershed area we have only one soil group assigned to each polygon so a polygon with soil group “A” will have PctA = 100, PctB = 0, PctC = 0, and PctD = 0. Similarly for a polygon with soil group D, only PctD = 100, and other three Pcts are 0. Now populate PctA, PctB, PctC and PctD based on Soil Code for each polygon. You can select features based on Soil Code and then use field calculator to assign numbers to polygons. The resulting attribute table should look like as shown in Figure 10.
The preparation of soil data is over at this point. The next step is to merge/union both soil data and land use data to create polygons that have both soil and land use information. Save the map document.

### 1.1.4. Merging of Soil and Landuse Data

To merge/union soil and land use data, use the Union tool in Arc Tool box available under Analysis Tools - Overlay. Browse/drag Soil_WZ_2018_1 and LULC_2017_March2019Pol as input features, name the output feature class as "Meki_Soil_LU", leave the default options, and click OK as shown in Figure 11.

Figure 10: Standard curve number matrix assignment for different soil groups
The result of union/merge features inherit attributes from both feature classes that are used as input. However, if the outer boundaries of input feature classes do not match exactly, the resulting merged feature class (Meki_Soil_LU in this case) usually will have features that will have attributes from only one feature class called “slivers” because the other feature do not exist in this area.

If we open the attribute table for Meki_Soil_LU, we will find that there are several sliver polygons in this feature class that have attributes only from LULC_2017_March2019Pol and the soil attributes are empty, and vice versa as shown in Figure 12:
One way to deal with sliver polygons is to assign missing values to all features or (easiest!) is to just delete them (Merwade, 2012).

1.1.5. Creating CN Look-up table

The next step is to prepare a look-up table that will have curve numbers for different combinations of land uses and soil groups. In this case, we will use SCS curve numbers that are available from the literature. The spatial features in conjunction with the lookup table can then be used to create curve number grid (Merwade, 2012).

Create a table named “CNLookUp”. In Arc tool box, select Data Management Tools … Table … Create Table. Now start the Editor to edit the newly created CNLookUp table, and populate it as shown in Figure 13.
Columns A/B/C/D store curve numbers for corresponding soil groups for each land use system (LUValue) that are obtained from Ethiopian Road Authority (2013), USDA-NRCS (1986) and the model output for EBLUS.

1.1.6. Creating CN Grid

HEC-GeoHMS uses the merged feature class (Meki_Soil_LU) and the lookup table (CNLookUp) to create the curve number grid. A field created in the merged feature class (Meki_Soil_LU) named “LandUse” that will have land use category information to link it to CNLookUp table. We already have this information stored in GRIDCODE field, but HEC-GeoHMS looks for this information in LandUse field. So create a field named LandUse (type: short integer), and populate it by equating it to GRIDCODE.

On the HEC-GeoHMS Project View toolbar, click on Utility ... Create Parameter Grids... Choose the lookup parameter as Curve Number (which is the default), Click OK, and then select the inputs as shown in Figure 14.
Figure 14: CN generation considering Enset-Based land use system

Fill for Hydro DEM, Meki_Soil LU (merged soil and land use) for input soil landuse polygon, CNLookUp table for input Curve Number Lookup, and leave the default CNGrid name for the Curve Number Grid.

2.8. Determination of watershed based curve number

Curve number is extracted from the soil type and land use data considering EBLUS using HEC-GeoHMS, which both affect the infiltration capacity of the soil and the Soil data acquired from the Ethiopian Ministry of Water Irrigation and Energy (MWIE) and Landsat image from USGS (Fleming and Brauer, 2018).

The factors of the CN model developed from the raster format of soil and LUS data with the same coordinate system (UTM WGS 1984 37° North) with a spatial resolution of 30m. Finally, the result is extracted and reported for the classified LUS of Meki river watershed and also it is extracted to 34 sub-watersheds and two major growing zones (Enset growing and non-Enset growing zones) of Meki river watershed.
3. Result and Discussion

3.1. Infiltration capacity of the soil

Field data were collected, summarized and presented in Error! Reference source not found. of appendix for the infiltration capacity of the soil for different land use systems. The silt loam and clay loam textural classes are dominant in the upper zone while almost all textural classes are found in the middle zone of the watershed. According to Oliver et al 2006, the soil textural class of Meki river watershed is dominantly occupied by Sandy Loam, Silt Loam, Clay Loam and Clay irrespective of the land use systems with a range of infiltration rate values of 20 to 30mm/hr, 10 to 20mm/hr, 5 to 10mm/hr and 0 to 5mm/hr respectively. EBLUS is not commonly practiced in acacia wooded grass land of Rift valley for which measurement is not done. Hence, the infiltration rate of soils in the acacia wooded grass land is not measured because of our focus was comparison of land use systems which are found in the same zone and the same soil type with EBLUS and the average value is presented in Table 6.

Sandy loam soil textural class has higher infiltration capacity than other textural classes followed by silt loam in all land use systems. High infiltration capacity is measured in the natural forest covered portion of the watershed followed by EBLUS. EBLUS improves the infiltration and water holding capacity of the soil by increasing the organic matter content of the soil through litter and pseudo stem cover falls and also the root fiber of 2 to 3 meters long away from the edge of the pseudo stem measured in the field that can enhance the void space of the soil to transmit rain water easily to the ground. The presence of wide leaves protects the direct impact
of the rain drop (Kebede Wolka, et al, 2015) and permit more through fall which reduces the speed of the rain drop and it will give more time for rain water to infiltrate to the ground.

Table 6: Mean infiltration rate of land uses

| Land Use                      | Soil Texture | Upper zone | Middle zone | Maen infiltration rate for LUSs | Basic infiltration rate (mm/hour) |
|------------------------------|--------------|------------|-------------|---------------------------------|-----------------------------------|
| Cultivated LUS               | Sandy Loam   | 19.125     |             |                                 | 20 to 30                          |
|                              | Silt Loam    | 12         | 13.9625     |                                 | 10 to 20                          |
|                              | Clay Loam    | 7.2125     | 5.825       | 10.375                          | 5 to 10                           |
|                              | Clay         | 4.125      |             |                                 | 1 to 5                            |
| Built up & degraded LUS      | Sandy Loam   | 8.75       |             | 7.0625                          | 20 to 30                          |
|                              | Silt Loam    | 7.0625     | 10          |                                 | 10 to 20                          |
|                              | Clay Loam    | 5.5        |             |                                 | 5 to 10                           |
|                              | Clay         | 4          |             |                                 | 1 to 5                            |
| Grass land & planted forest LUS | Sandy Loam | 19.25     |             | 11.1875                         | 20 to 30                          |
|                              | Silt Loam    | 15.8625    | 9.95        |                                 | 10 to 20                          |
|                              | Clay Loam    | 8.6        | 7.9625      |                                 | 5 to 10                           |
|                              | Clay         | 5.5        |             |                                 | 1 to 5                            |
| EBLUS                        | Sandy Loam   | 22.55      |             | 12.8125                         | 20 to 30                          |
|                              | Silt Loam    | 12.625     | 17.025      |                                 | 10 to 20                          |
|                              | Clay Loam    | 10.875     | 9.375       |                                 | 5 to 10                           |
|                              | Clay         | 4.425      |             |                                 | 1 to 5                            |
| Natural Forest LUS           | Sandy Loam   | 22.625     |             | 12.9675                         | 20 to 30                          |
|                              | Silt Loam    | 15.25      | 15.5        |                                 | 10 to 20                          |
|                              | Clay Loam    | 9.625      | 10.3475     |                                 | 5 to 10                           |
|                              | Clay         | 4.4575     |             |                                 | 1 to 5                            |
| Average                      | 11.0125      | 10.92625   |             |                                 |                                   |

The Upper zone of the watershed has higher mean infiltration rate (11.0125mm/hr) than the Middle zone (10.92625mm/hr) of the watershed. The high mean infiltration rate at the upper zone shows the presence of more forest LUS and EBLUS than the middle zone of the watershed which enhances infiltration and water holding capacity of the soil. In the cultivated LUS, high
rate of infiltration is recorded in upper zone of the watershed while middle zone has more infiltration rates in Grass LUS, forest LUS and EBLUS as shown in Figure 15, which is attributed to the high slope of upper zone that influences the carbon stock of the soil.

Figure 15: Vegetation zone based infiltration capacity of the soil (mm/hr)

There is a significant difference between infiltration rates at different land use systems at 5% significance level (α = 0.05) with a p-value of 0.0094 (<α) due to a low value in the Built-up & degraded and cultivated LUS and a high value in Forests and EBLUS and a non-significance difference is observed between infiltration rates among vegetation zones with p-value of 0.443 (>α) as shown in Table 7.

Table 7: Analysis of variance (ANOVA)

| Source of Variation     | SS    | df | MS    | F      | P-value | F crit   |
|-------------------------|-------|----|-------|--------|---------|----------|
| Land use systems        | 40.16427 | 4 | 10.04107 | 16.51739 | 0.009404 | 6.388233 |
| Vegetation zone         | 0.440475 | 1 | 0.440475 | 0.724574 | 0.442606 | 7.708647 |
| Error                   | 2.431635 | 4 | 0.607909 |        |         |          |
| Total                   | 43.03638 | 9 |        |        |         |          |
Therefore, a high mean infiltration rate in Forests and EBLUS show that there is an improvement in hydrological parameters for those land use systems to enhance water absorption to the ground water system. The improvement in infiltration capacity has a direct influence on water resources management. In addition, the increase in infiltration rate has a huge contribution in runoff reduction and alleviation of sedimentation problems in Meki river watershed.

### 3.2. Curve number modeling result

Soil Conservation Curve Number (SCS-CN) is an empirically derived relationship between location, land use, antecedent moisture conditions and runoff and it is used in many event-based models to establish the initial soil moisture condition and the infiltration characteristics (Iliasse & Adil, 2014). There is an inverse relationship between infiltration capacity and the runoff generation capacity of the area (A.R., H.A., & S.H.R., 2010; Zehetner & Miller, 2006; Zeiger & Fohrer, 2009); hence the infiltration capacity of the soil is considered as one of the criteria to model the curve number of EBLUS.

Studies showed that organic matter influences CN and results in low surface runoff due to an increasing in soil infiltration capacity (A.R., H.A., & S.H.R., 2010; Zehetner & Miller, 2006; Zeiger & Fohrer, 2009). According to Mesfin, et al (2017) and Barbora and Jaroslava (2014), compost improves and accelerated both the infiltration and water holding capacity of the soil for a longer period which in turn influences the CN of the watershed.

EBLUS exhibited a good carbon sequestration, which is equivalent to high-vegetation areas (Mesfin et al., 2017). Hence, Carbon stock considered as criteria to model the curve number of EBLUS next to the infiltration capacity of the soil as reported in Table 8.
Table 8: Hydrologic Soil Group based curve number of different LULCs excluding Enset LULC (Iliasse and Adil, 2014; ERA, 2013)

| Land Cover/Land Use              | Hydrologic Soil Group | Parameters to develop the CN model |
|----------------------------------|-----------------------|-----------------------------------|
|                                  | A | B | C | D | Carbon stock (ton/yr) | Average Infiltration (mm/hr) |
| Open Water                       | 100 | 100 | 100 | 100 | 0 | 0 |
| Built-up, Medium Intensity LUS   | 77 | 85 | 90 | 92 | 132 | 7.0625 |
| Natural Forest LUS               | 36 | 60 | 73 | 79 | 45,714 | 12.9675 |
| Grasslands & plantations LUS     | 49 | 69 | 79 | 84 | 8350 | 11.1875 |
| Cultivated LUS                   | 67 | 78 | 85 | 89 | 19,950 | 10.375 |
| EBLUS                            | 77,286 | 12.8125 |

Therefore, considering the infiltration capacity of forest LUS, grass LUS, cultivated LUS and built-up LUS and their Carbon stock, the following formulas are derived to compute the curve number matrix of EBLUS relative to the other land use systems dominantly practiced in the study area.

\[
EA = \frac{\sum_{i=1}^{n} EAI}{n} = \frac{CI(FA\cdot IF + GA\cdot IG + CA\cdot IC + BA\cdot IB)}{IE} + \frac{CSq(FA\cdot SqF + GA\cdot SqG + CA\cdot SqC + BA\cdot SqB)}{SqE} \quad \text{Eqn1}
\]

\[
EB = \frac{\sum_{i=1}^{n} EBi}{n} = \frac{CI(FA\cdot IB + GB\cdot IG + CB\cdot IC + BB\cdot IB)}{IE} + \frac{CSq(FB\cdot SqF + GB\cdot SqG + CB\cdot SqC + BB\cdot SqB)}{SqE} \quad \text{Eqn2}
\]

\[
EC = \frac{\sum_{i=1}^{n} ECi}{n} = \frac{CI(FC\cdot IF + GC\cdot IG + CC\cdot IC + BC\cdot IB)}{IE} + \frac{CSq(FC\cdot SqF + GC\cdot SqG + CC\cdot SqC + BC\cdot SqB)}{SqE} \quad \text{Eqn3}
\]

\[
ED = \frac{\sum_{i=1}^{n} EDi}{n} = \frac{CI(FD\cdot IF + GD\cdot IG + CD\cdot IC + BD\cdot IB)}{IE} + \frac{CSq(FD\cdot SqF + GD\cdot SqG + CD\cdot SqC + BD\cdot SqB)}{SqE} \quad \text{Eqn4}
\]

Where;

EA, EB, EC and ED are CN of EBLUS for HSG of A, B, C and D respectively
FA, FB, FC and FD are CN of Forest LUS for HSG of A, B, C and D respectively

GA, GB, GC and GD are CN of Grass LUS for HSG of A, B, C and D respectively

CA, CB, CC and CD are CN of Cultivated LUS for HSG of A, B, C and D respectively

BA, BB, BC and BD are CN of Built-up LUS for HSG of A, B, C and D respectively

IE, IF, IG, IC and IB are infiltration capacity of EBLUS, Forest, Grass, Cultivated and Built-up LUSs respectively.

SqE, SqF, SqG, SqC and SqB are Carbon stock of EBLUS, Forest, Grass, Cultivated and Built-up land use systems respectively.

Ci and Csq are coefficients for the relative influence of infiltration capacity and Carbon stock on curve number of land use systems respectively at 85% to 15% proportion.

Accordingly, the curve numbers are generated for EBLUS for each hydrologic soil group with their respective infiltration capacity and Carbon stock relative to other LUSs for which curve number is encoded and presented in Table 9. Carbon stock is modified by growth period and energy production of those LUSs. Hence, infiltration capacity of the soil powers 85% of the curve number of LUSs while 15% of the curve numbers of LUSs are influenced by carbon stock which is computed.

Table 9: Curve number of EBLUS

| Curve number | Hydrologic Soil Group (HSG) |
|--------------|-----------------------------|
|              | CN of EBLUS due to Infiltration capacity | A | B | C | D |
| E11 = \( \frac{BA \times IB}{IE} \) | 42.44 | 46.854 | 49.61 | 50.712 |
| E12 = \( \frac{FA \times IF}{IE} \) | 36.44 | 60.73 | 73.88 | 79.96 |
| E13 = \( \frac{GA \times IG}{IE} \) | 42.79 | 60.25 | 68.98 | 73.35 |
| E14 = \( \frac{CA \times IC}{IE} \) | 54.25 | 63.16 | 68.83 | 72.068 |
CN of EBLUS due to Carbon stock

| \( ESq1 \) = \( \frac{BA \times SqB}{SqE} \) | A   | B     | C     | D     |
|--------------------------------------------|-----|-------|-------|-------|
|                                            | 0.13| 0.145 | 0.154 | 0.16  |

| \( ESq2 \) = \( \frac{FA \times SqF}{SqE} \) | 21.294 | 35.49 | 43.18 | 46.73 |
|--------------------------------------------|--------|-------|-------|-------|
|                                            |        |       |       |       |

| \( ESq3 \) = \( \frac{GA \times SqG}{SqE} \) | 5.294 | 7.455 | 8.54  | 9.075 |
|--------------------------------------------|-------|-------|-------|-------|
|                                            |       |       |       |       |

| \( ESq4 \) = \( \frac{CA \times SqC}{SqE} \) | 17.295 | 20.13 | 21.94 | 22.97 |
|--------------------------------------------|--------|-------|-------|-------|
|                                            |        |       |       |       |

Cumulative CN of EBLUS for different HSG

\[
E = 0.85 \times \sum_{i=1}^{4} EI_i + 0.15 \times \sum_{i=1}^{4} ESq_i
\]

| A   | B     | C     | D     |
|-----|-------|-------|-------|
| 39  | 51.5  | 58.3  | 61.6  |

Therefore, finally the general formula developed for EBLUS is given as:

\[
E = \frac{0.85 \times \sum_{i=1}^{n} EI_i + 0.15 \times \sum_{i=1}^{n} ESq_i}{n}
\]

Alemu’s formula

Where:

\( EI_i \) = Infiltration based Curve number of EBLUS relative to i LUS

\( ESq_i \) = Carbon stock based Curve number of EBLUS relative to i LUS

Curve number matrix is computed for EBLUS using the model as 39, 51.5, 58.3 and 61.6 for HSG of A, B, C and D respectively. Therefore, the new lookup table for all land use systems including EBLUS is prepared as shown in Table 10 and fed to HEC-GEO-HMS together with that of the union of LUS and soil information in order to generate the curve number grid.

Table 10: Hydrologic Soil Group based curve number of different LUSs including EBLUS
Hence, the new CN matrix of the Meki river watershed is generated from the new lookup table including EBLUS and mapped as shown in Figure 16. This CN grid can be used in different models of rainfall-runoff modeling purposes and also researchers and runoff flow simulators.

![Figure 16: Average soil loss from sub-watersheds with respect to Rift valley limit](image)

### 3.3. Zone and sub-watershed based CN determination

CN of EBLUS is evaluated for two enset growing zones of Meki river watershed and the mean values of the upper zone is less than the middle one due to the high proportion of forest and EBLUS in the upper zone of the watershed as shown in Table 11.

| Zones       | Upper | Middle |
|-------------|-------|--------|
| Minimum     | 52    | 52     |
Almost all upper zone Sub-watersheds except U9 have a mean CN value of less than 80 while almost all middle zone Sub-watersheds have a mean CN of more than 80 except M1 and M3 as shown in Figure 17.

![Graph showing CN of EBLUS in the upper and middle zones](image)

**Figure 17:** Curve number of EBLUS in the upper and middle zones

### 3.4. Scenarios on mean CN of Meki river watershed with respect to EBLUS

Meki river watershed has a mean CN of 78.21 considering EBLUS as it has its own CN matrix while a mean CN of 81.72 by considering EBLUS as cultivated LUS as shown in the Table 12 below.

**Table 12:** Area coverage and average CN of land uses

| LU | Area (km²) | Mean CN, EBLUS as | Mean CN, EBLUS as | Area (%) |
|----|------------|------------------|------------------|---------|
|    |            |                  |                  |         |
The mean CN of Meki river watershed considering and without considering EBLUS are 78.21 and 81.72 respectively, hence, the sorpitivity and initial abstraction of the watershed decreases as CN increases as shown in Table 13.

Table 13: Initial abstraction and soil retention in millimeters

| CN   | Sorpitivity = \( S = \frac{25400}{CN} - 254 \) | Initial abstraction (Ia) = 0.2S | 0.8S |
|------|---------------------------------------------|--------------------------------|------|
| With | 78.2066 7 70.7804961 14.1560992 56.6243969 | 11.3649088 45.4596351 |
| WO   | 81.7181 3 56.8245439 11.3649088 45.4596351 |

The CN of EBLUS is computed with respect to other LUSs. According to Chow et al, (1988) and Merwade (2012), the precipitation excess is a function of cumulative precipitation, soil type, land use systems and antecedent moisture. Considering the initial loss and the potential maximum retention, the precipitation excess can be calculated; the maximum retention and the basin characteristics are related through the curve number. The standard SCS curve number method is based on the following relationship between rainfall depth, \( P \), and runoff depth, \( Q \).
(USDA, 1986; Schulze et al., 1992) which can easily be simulated using HEC-HMS using the CN as an input.

For the annual daily average rainfall of 50mm for Meki river watershed (ENMA, 2017), the runoff considering and without considering EBLUS is computed respectively as:

\[
Q_1 = \frac{(P-0.251)^2}{(P+0.881)} = \frac{(50-14.156)^2}{(50+56.6244)} = \frac{1284.792336}{106.6244} = 12.05\text{mm and} \quad (\text{Chow et al, 1988})
\]

\[
Q_2 = \frac{(P-0.252)^2}{(P+0.882)} = \frac{(50-11.365)^2}{(50+45.46)} = \frac{1492.663225}{95.46} = 15.6366\text{ mm}
\]

Where: Q is surface runoff (mm), P is precipitation (mm), S is the soil retention (Sorpitivity) (mm) and Ia is initial abstraction or initial loss (mm) and CN is curve number.

Hence a difference of runoff occurs due to consideration of EBLUS by 3.59 mm which can be cumulate to a huge volume of runoff (8340916 m³) from the whole area of Meki river watershed which can be a sign post for the improvement of the hydrological characteristics of the watershed by increasing the infiltration capacity of the soil.

**Conclusion & Recommendation**

**Conclusion**

Meki river watershed is dominantly covered by cultivated LUS (41.5%) followed by Bush and Chat LUSs (25.6%). EBLUS comprises about 10.65% of the watershed while Forest and plantations LUSs cover (14.14%) while urban and built up LUSs covers 7.4% with minimal portion is covered by water bodies including wetland (0.75%). Uppermost part of the Meki river watershed is covered by Erica, Enset and natural forest land use systems, while the middle and lower altitudes of the watershed is dominantly covered by agricultural LUSs.
The CN grid in a Meki river watershed can be used as an input for different research purposes concerning direct runoff generation capacity of the area. There is an improvement of average CN from 81.72 to 78.21 for the whole watershed. A significant volume of water (8340916 m³) is infiltrated due to the presence of EBLUS in the watershed.

Therefore, a high mean infiltration rate in Forests and EBLUS shows that there is an improvement in hydrological parameters for those LUSs to enhance water absorption into the ground water system. The improvement in infiltration capacity has a direct influence on water resources management. In addition, the increase in infiltration rate has a huge contribution in runoff reduction and alleviation of sedimentation problems in the Meki river watershed.

**Recommendation**

A significant CN reduction due to EBLUS shows there will be an improvement in the hydrological characteristics of the watershed by increasing the infiltration capacity of the soil and also by increasing the canopy cover of the area. Hence, increasing the coverage of EBLUS can reduce the CN and runoff volume which could be the cause of flooding in different parts of the watershed and also protect Lake Ziway against sedimentation.

Therefore, creating separate land use policy to EBLUS and incorporating other fruit as an agro-forestry to it will create harmony to the existing ecology. The extension program has to be initiated to the expansive production and processing of EBLUS which can help the production of sufficient inputs to the industries to be established in the area.

**Abbreviations**

| Abbreviation | Description |
|--------------|-------------|
| DEM          | Digital Elevation Model |
| EBLUS        | Enset-Based Land Use System |
| EGSIA        | Ethiopian geospatial information agency |
| ENMA         | Ethiopian National Meteorological Agency |
ERA  Ethiopian Road Authority
ERDAS  Earth Resources Data Acquisition System
GIS  Geographical Information System
GPS  Geographical Positioning System
HEC-GEO-HMS  Hydrologic Engineering Center’s Geospatial Hydrologic Modeling System
HEC-HMS  Hydrologic Engineering Center’s Hydrologic Modeling System
HSG  Hydrologic Soil Group
HWSD  Harmonized World Soil Data
LULCC  Land Uses and Land Cover Change
LUSs  Land use systems
m.a.s.l.  Meter above Sea Level
MOWIE  Ministry of Water, Irrigation and Energy
SCS-CN  Soil Conservation Services Curve Number

DECLARATION

Originality of work

We assure that, this paper is the original work and have not been presented for a degree in any other university, and all sources of material used for this paper have been duly acknowledged.

Ethics approval and consent to participate

'Not applicable'

Consent for publication
'Not applicable'

**Availability of data and material**

Data are acquired from Ministry of Water, Irrigation & Electricity (MOWIE) of Ethiopia for flow data, Ethiopian Meteorological Agency (EMA) for meteorological data, Ethiopian Central Statistical Agency (ECSA) for population data, Ethiopian Geospatial & Mapping Agency (EGMA) for Satellite images and topo-maps, Satellite images from USGS earth explorer and field materials acquired from Ethiopian Institute of Water Resources (EIWR) in Addis Ababa University.

**Competing interests**

"The authors declare that they have no competing interests"

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**Authors' contributions**

Authors in this article made substantial contributions to the conception and design of the work; the acquisition, analysis and interpretation of data and finally have drafted the work or substantively revised it together and the authors read and approved the final manuscript.

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