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**Research Article**

# Groundwater-recharge estimation in Waja-Golesha Sub-basin, Northern Ethiopia: An approach using WetSpass Model

***Seyoum Bezabih Kidane*[1]**

[1] Department of Water resource Engineering and Management, Ethiopian Institute of Agricultural Research, Ethiopia

**Corresponding author:** seyoumb18@gmail.com

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**Abstract:** *Understanding the spatial variability of groundwater recharge in response to distributed Land-use, soil texture, topography, groundwater level, and hydrometeorological parameters is significant when considering the safety of groundwater resource development. Thus, this study aimed to estimate the groundwater recharge of the Waja-Golesha watershed, in northern Ethiopia using the WetSpass (Water and Energy Transfer between, Soil, Plants, and Atmosphere under quasi Steady State) hydrological model. The model inputs are prepared in the form of 20m grid size maps and attribute tables. The model parameters table was prepared using expert knowledge and scientific literature. The modeling results of long-term spatial-temporal annual rainfall of 664.5 mm were fractionated as 161.5 mm (24%) of runoff, 438.2 mm (71%) evapotranspiration, and the remaining 29 mm (5%) of groundwater recharge. From the entire area of the sub-basin (532.6 km2), 1.6*105 cubic meters (m3) of water was added to the groundwater through infiltration. The seasonal distribution of the recharge indicates that 72% occurred in the wet season while the rest 28% resulted in the dry season. The evaluation of the modeled output indicates that WetSpass works well to model the groundwater recharge of the Waja-Golesha sub-basin. To preserve the resource's long-term viability, the balance between groundwater recharge and projected abstraction rates for agriculture and domestic water supply must be considered in future groundwater resource development plans in the watershed.*

**Keywords:** Ethiopia, groundwater recharge, Waja-Golesha, WetSpass



## 1. Introduction

Groundwater is the largest source of fresh water and one of the most curtail resources for human beings (Mengistu et al., 2019). Due to its essential qualities such as consistent temperature, wide distribution and continuous availability, excellent natural quality, limited vulnerability, low development cost, and draught reliability, groundwater is a very critical and dependable source of water supply in all climatic regions. Sustainable utilization of groundwater resources is crucial for the present and future generations because groundwater is a finite and vulnerable resource (Yenehun et al., 2017). Consequently, Groundwater resource management and sustainable use directly depend on knowledge of groundwater recharge and potential (Fenta et al., 2015). For efficient and sustainable groundwater water resource management, evaluation of groundwater recharge is a prerequisite and vital for economic development (Arefayne and Abdi, 2015).

Depending on the source and mechanisms of recharge, direct measurements, water balance methods, tracer techniques, and empirical methods are the techniques used to estimate groundwater recharge (Simmers, 2017). As stated by Gidafie et al., (2016), space or time scale, range, and reliability of recharge estimates are the factors considered during selection of recharge estimation methods. WetSpass (Water and Energy Transfer between Soil, Plants, and Atmosphere under quasi Steady State) hydrological model was used for this study by considering the specially distributed factors such as land use, soil texture, slope, and hydrometeorological parameters to model long-term average spatial distribution of groundwater recharge. This is because considering groundwater resource safety is highly dependent on understanding variability of recharge as a function of variables such as land cover, soil type, slope, groundwater depth, and hydrometeorological parameters.

Rain-fed agriculture is the main activities in the case of Ethiopian condition even if the rainfall variability is high (Dereje and Nedaw, 2019). Less productivity is the result of shortage and variability of rainfall during the growing periods of crops. The mean annual potential evapotranspiration which ranges between 1900 and 2100 mm much greater than the mean annual precipitation that ranges from 300 to 800 mm occurred in northern Ethiopia (Kahsay et al, 2018) and the area has a growing period of about 60 days and annual air temperature ranges from 16 to 27 °c. As a result, food security in the area is largely dependent on supplementary irrigation.

Waja-Golesha watershed is one of the groundwater based irrigation areas located in North Wollo zone of Amhara national regional state. Local farmers fail to keep soil moisture requirements for growing crops in the area because of the erratic nature of rainfall (time and space) distribution. Accordingly, groundwater resource use in the area for agricultural development is growing continuously. Therefore, groundwater recharge estimation and groundwater potential assessments were not supported adequately for expanding irrigation in the area. Point estimate of groundwater recharge for groundwater resource development and potential site delineation was the focus of previous studies (Ayenew et al., 2008; Belay, 2015). However, groundwater recharge estimation needs reliable methods (Rwanga, 2013). Therefore, the objective of this study was to estimate long-term seasonal/annual average spatial groundwater recharge in the Waja-Golesha watershed northern Ethiopia by adapting GIS-based WetSpass model.

## 2. Materials and Methods

### 2.1. Description of the study area

Waja-Golesha watershed is located in northern part of Ethiopia between latitude of 12°08′–12°19′N and longitude of 39°23′–39°10′E (Figure 1). The study area is bounded by the North-Western Ethiopian Plateau in the west and the Afar Rift in the east with an area of about 532.6 $km^2$. It is among the watersheds on the western edge of the Danakil basin. The main physiographic features prevailing in the area were north–south oriented mountains in the west, a steep fault scarp in the east, a major graben and isolated hills within the graben. The study area is elongated intermountain graben filled with quaternary sediments, bordered to the east and west by rugged volcanic mountains with relatively high elevation. The watershed is constituted of different types of volcanic rocks and alluvial sediments. The volcanic rocks (basalts, rhyolite, and granite) having Tertiary age cover the majority of the area and are found exposed in the surrounding mountains and underlying the alluvium in the valley. The alluvium sediments are mainly found occupying the valley floor. Major and inferred faults, fractures, and lineament having an alignment of N-S, NNW-SSE, NW-SE, NNE-SSW, and NE-SW are the major geological structures that are found in the catchment (Tadesse et al., 2015).

The elevation of the watershed ranges from 1,352 m within the valley floors to 3,032 m above sea level in the western mountain ridges. The watershed is characterized by an erratic, bimodal rainfall pattern with the main rainy season lasting from late June to early September. The highest rainfall record occurs in July and August, whereas the short spring rainy season extends from February to March. The average monthly temperature of the Waja-Golesha watershed varies from a minimum average of 4.7 °C in the Lasta plateaus to a maximum average of 35.5 °C in the Waja lowlands. The highest temperature is recorded in June and the lowest value is in November. The western mountainous part of the area is highly dissected by streams and steep slope topography which favors high runoff. As a result, the valley floor is seasonally recharged via the incoming runoff from the nearby hills (Kahsay et al, 2018). Thus rain-fed agriculture by diverting seasonal flush floods is a common practice (Fenta et al., 2015).

### 2.2. Dataset and sources

In this study, the main data sources were both primary and secondary. The secondary source includes remote sensing data such as the Digital Elevation Model (DEM) from Alaska Satellite Facility (ASF), land use/land cover, which was collected from the Ethiopian Geospatial Institute (EGI), soil map of FAO (1998), and meteorological data collected from the national meteorological agency of Ethiopian. Digital elevation model with 12.5m resolution was downloaded from Alaska Satellite Facility (ASF) webpage (https://asf.alaska.edu/) and processed in ArcGIS and used to develop the elevation and slope map of the watershed. The Waja-Golesha watershed soil texture map was downloaded from the Food and Agriculture Organization website (http://www.fao.org) (FAO, 1998). Using the United States Department of Agriculture (USDA) textural classification standards, the soil texture was determined. The land use/land cover map of Ethiopia was prepared by Ethiopian Geospatial Institute (GSI) for 2020 with a 20 m resolution and the land use land cover map of the Waja-Golesha watershed was modified and developed from this map.

The primary source includes the groundwater depth (groundwater table) data, which was directly collected by measuring from the existing boreholes using the deep meter.

Meteorological datas were collected from seven meteorological stations which covered the data from 2001 to 2020 (20 years). Potential evapotranspiration was calculated by using Enku simple temperature method (Enku and Melesse, 2014) was used.

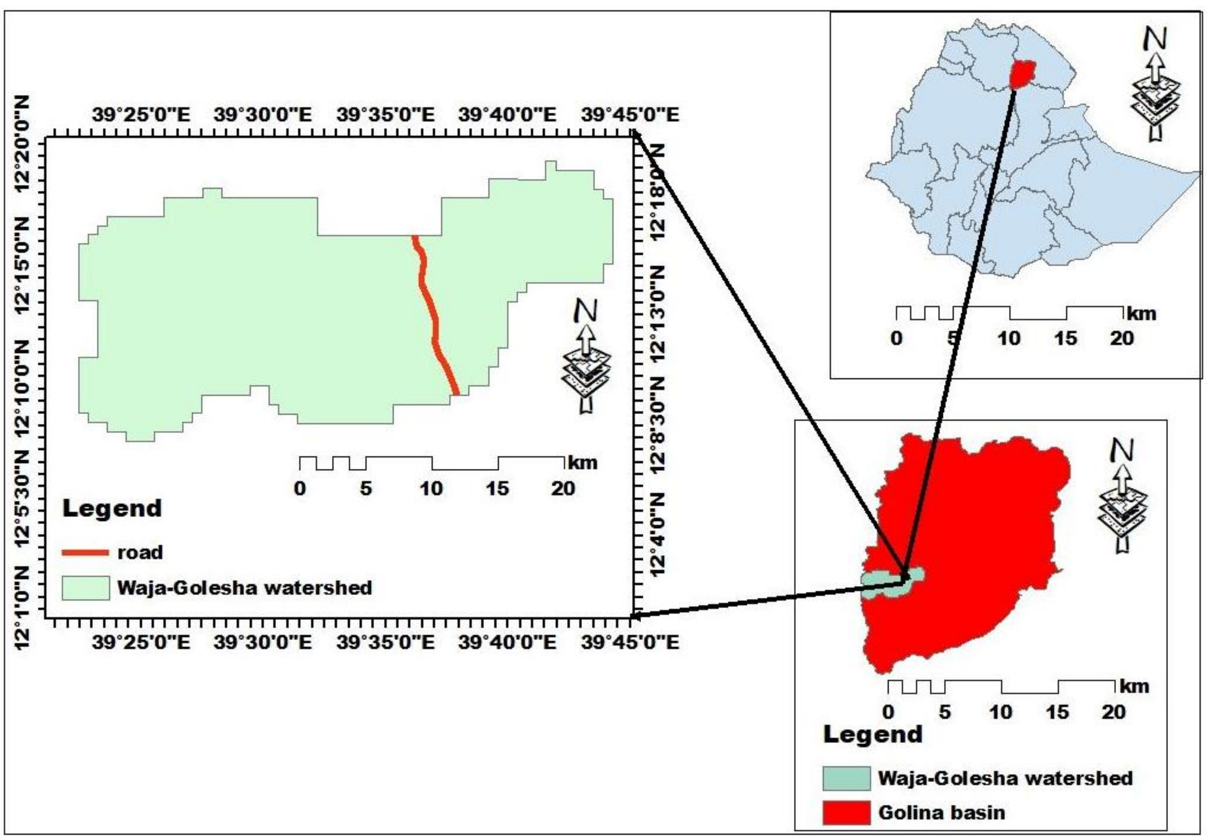


**Figure 1: Location map of the Waja-Golesha watershed**

## 2.3. Data analysis

### 2.3.1. *WetSpass model description*

WetSpass is an acronym for Water and Energy Transfer between, Soil, Plants and Atmosphere under quasi Steady State (Al Kuisi and El-Naqa, 2013). It is a physically based model for the valuation of the long-term average spatial patterns of groundwater recharge, surface runoff and evapotranspiration from long-term average meteorological data together with land-use, soil, and groundwater level grid maps by employing physical and empirical relationships (Gebrerufael et al., 2018). WetSpass gives different hydrologic outputs on a yearly and seasonal (summer and winter) basis (Gebremeskel and Kebede, 2017). The model is integrated with ArcGIS as a raster model and coded in Avenue and Visual Basic. Parameters such as land-use and related soil type are connected to the model using attribute tables of the land-use and soil raster maps. The attribute tables also allow defining new land cover or soil types easily, as well as changes in the parameter values, which permits analysis of future land and water management scenarios (Ghouili et al., 2017). The WetSpass model treats a basin or region as a regular pattern of raster cells (Al Kuisi and El-Naqa, 2013). The total water balance for a given raster cell (Figure 2) is split into independent water balance components for the vegetated, bare-soil, open-water and impervious parts of each cell. This allows one to account for the non-uniformity of the land-use per cell, which is dependent on the resolution of the raster cell. The processes in each part of a cell were set in a cascading way. This means that an order of occurrence of the processes, after the precipitation event, is assumed. Defining such an order is a prerequisite for the seasonal timescale with which the processes will be quantified. The quantity determined for each process is consequently limited by a number of physical and hydro-meteorological constraints of the given area under investigation (Esayas and Gebeyehu, 2019).

Water balance components of vegetated, bare-soil, open water and impervious surfaces are used to calculate the total water balance of a raster cell using the Equations [1-3].

$$ETa = avETv + asEs + aoE0 + aiEi \quad [1]$$

$$Sa = vSv + asSs + aoRo + aiRi \quad [2]$$

$$R\ a = vRv + asRs + aoRo + aiRi \quad [3]$$

Where

- Eta = Total evapotranspiration
- Sa = surface runoff
- Ra = Groundwater recharge
- av = vegetated area
- as = bare soil area
- ao = open water area
- ai = impervious area
- E = evaporation

Precipitation is taken as the starting point for the computation of the water balance of each of the above-mentioned components of a raster cell. The rest of the processes, such as interception, surface runoff, evapotranspiration, and recharge follow in an orderly manner.

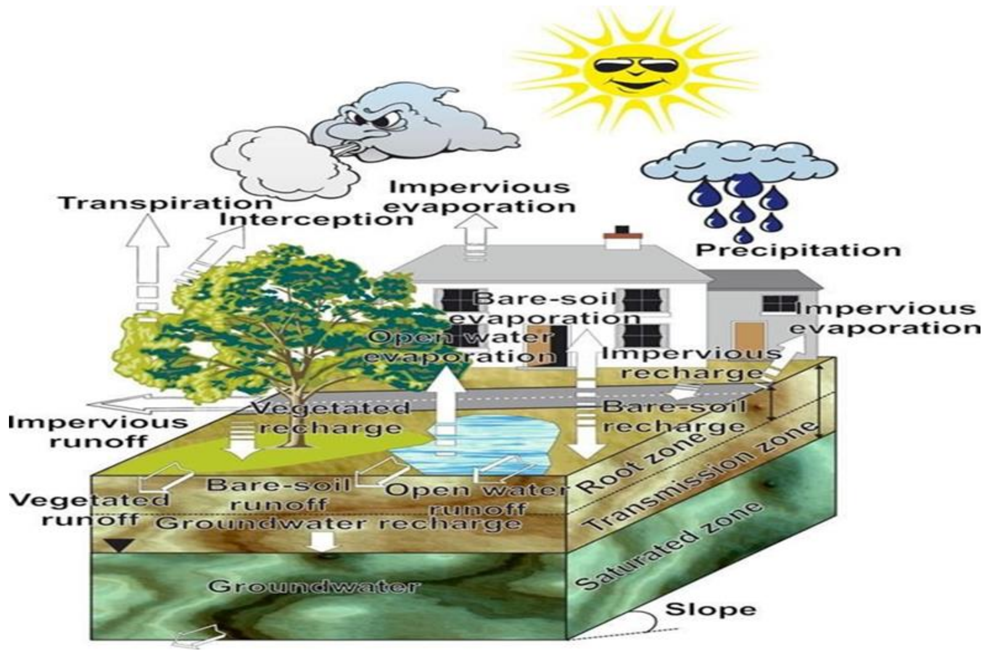



**Figure 2: Schematic water balance of hypothetical raster cell (Batelaan and De Smedt, 2001)**

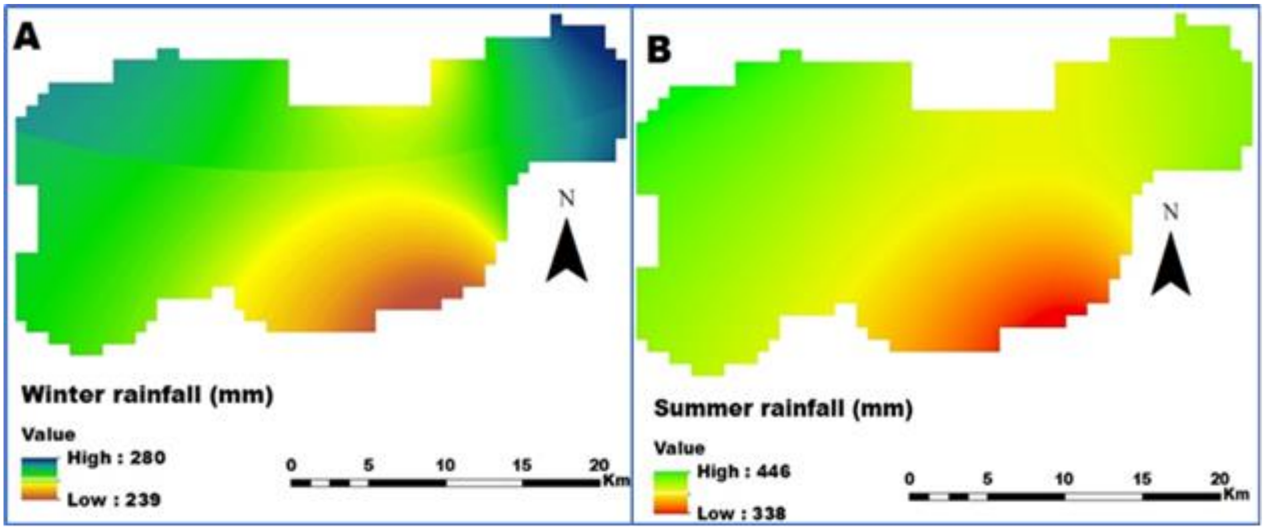
### 2.3.2. *WetSpass model data inputs preparation*

GIS-based hydrological models such as the WetSpass model was used for analyzing groundwater systems in steady-state condition and needs long-term average hydro-meteorological data and spatial patterns of watershed-based biophysical layers as the main inputs. WetSpass needs the parameters in seasonal basis, as a result, four months of June, July, August, and September are considered summer (main rainy season) and the remaining 8 months are considered as winter (dry season) in the case of Ethiopian condition particularly at the study area. Grid maps and parameter tables are required as inputs for the model and were prepared with the help of ArcGIS tools. These grid maps were a land-use land cover, soil texture, slope, topography and groundwater levels, rainfall, potential evapotranspiration and wind speed. The input files prepared as parameter tables were also prepared in a database file format (dbf); these are summer and winter land use land cover, soil texture and runoff coefficient.

***Hydro-meteorological data***

Meteorological data obtained from seven stations of the Ethiopian Meteorological Agency (EMA) were used for the preparation of metrological input data for the WetSpass model. Missing meteorological data record was a common problem in the stations of the watershed. Each station data was analyzed for the calculation of the seasonal and annual meteorological values. Rainfall and temperature data were available for all seven stations while wind speed was recorded only at Kobo, Maichew and Chercher meteorological stations. Enku simple temperature method (Enku and Melesse, 2014), was used to calculate potential evapotranspiration.

The seasonal and annual grid maps of the climatic variables were developed using an interpolation method to predict values from a limited number of sample data points at unknown geographic point data. Inverse Distance Weighted (IDW) interpolation method was applied as it gives consistent result with known values. The WetSpass input grid maps of major meteorological parameters of Waja-Golesha watershed (Figure. 3) indicated high spatial variation as a function of topography. For example, there was a significant spatial variation of rainfall in the watershed which is strongly influenced by orographic effect within the Lasta and Zoble highlands receives high rainfall as compared to the valley bottoms of Waja-Golesha watershed (Figure 3) shows high spatial variation as a function of topography.


A
N
Winter rainfall (mm)
Value
High : 280
Low : 239
0 5 10 15 20
Km
B
N
Summer rainfall (mm)
Value
High : 446
Low : 338
0 5 10 15 20
Km

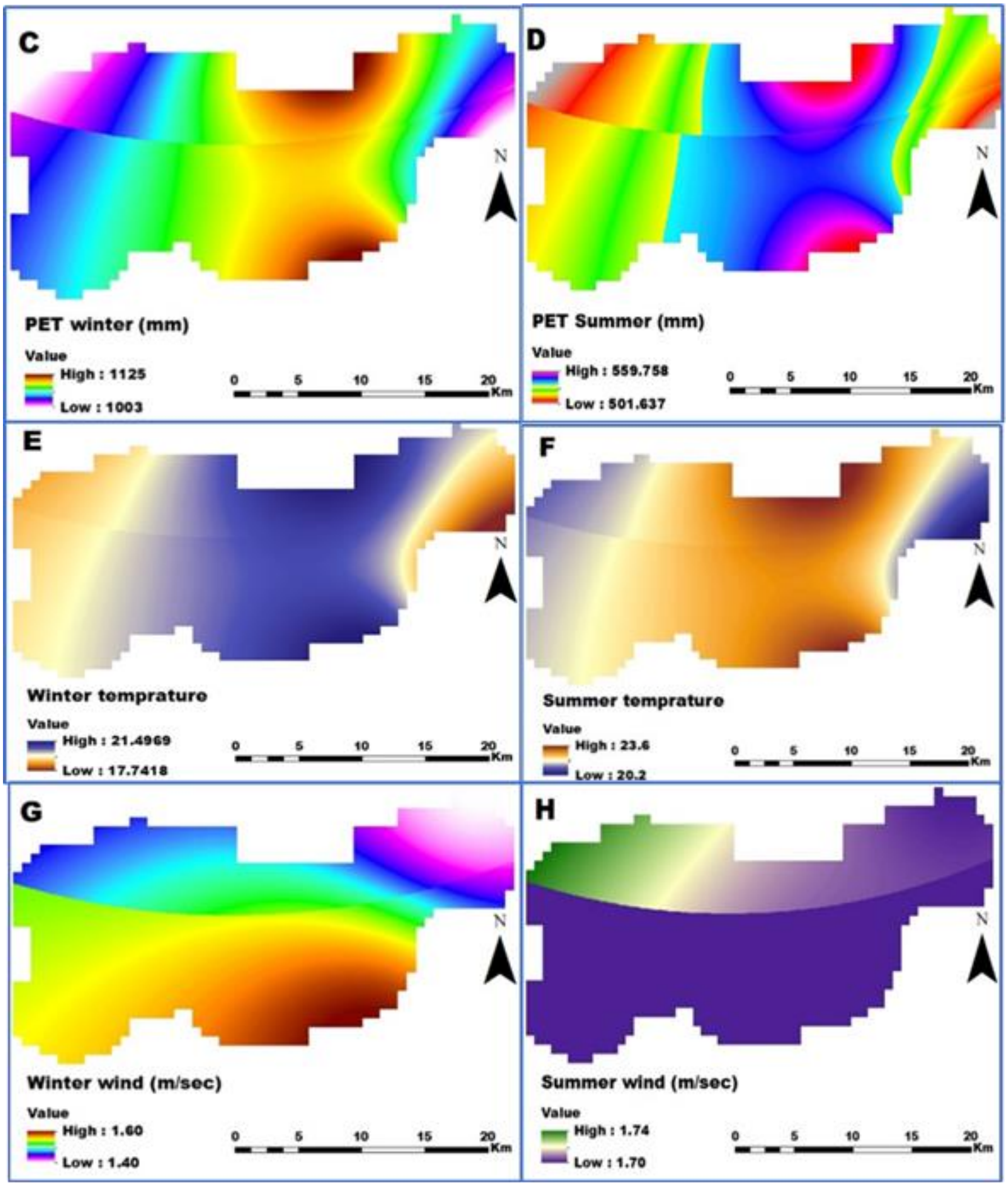



**Figure 3: WetSpass input grid maps of major meteorological parameters in Waja-Golesha watershed: (A) winter rainfall, (B) summer rainfall, (C) winter PET, (D) summer PET, (E) winter temperature, (F) summer temperature, (G) winter wind speed, and (H) summer wind speed**

Groundwater depth data was produced from the elevation of static water level measurements in boreholes and springs. Overall 67 static water level measurements which were mostly concentrated in the valley area were used for interpolation to produce the groundwater depth grid map (Figure 4). The groundwater depth grid map was prepared by subtracting the static water level from the surface elevation of the boreholes and springs found within the watershed and interpolated by kriging Arc GIS tool.

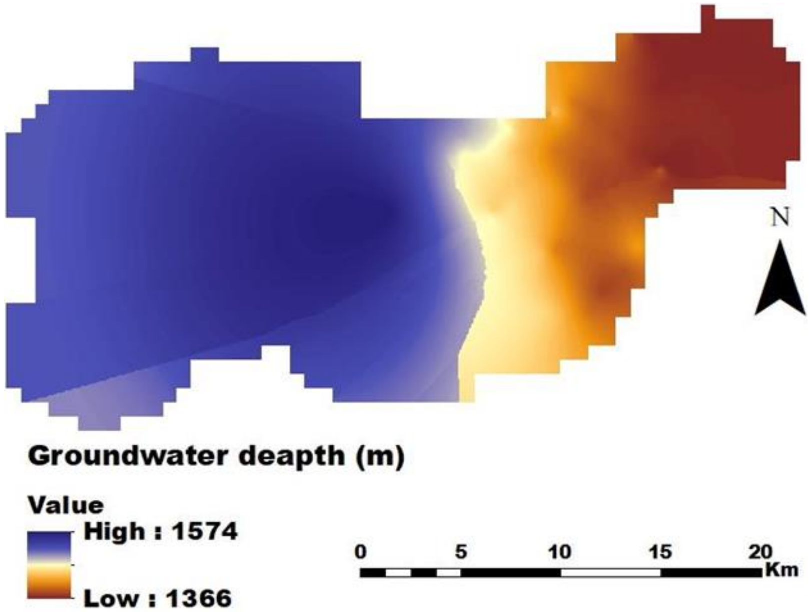



**Figure 4: Groundwater depth map of Waja-Golesha watershed**

***Biophysical input data***

The dominant land use of the Waja-Golesha watershed was crop land which accounts for 49.5% of the total area, followed by wood land 13.2 %, shrubs 12.3%, bare land 11.6%, forest, and grassland and settlement collectively cover 13.4 % (Figure 5a). Using the United States Department of Agriculture (USDA) textural classification standards, the soil texture of the watershed was classified into three classes: sandy loam, silty loam and clay (Figure 5b). Based on the soil map of Waja-Golesha watershed, Silty loam covers 25.5%, sandy loam 28.3% and clay covers 46.2%. The Waja-Golesha watershed was developed from land-use land cover map of Ethiopia. The elevation (Figure 6a) and slope (Figure 6b) of the Waja-Golesha watershed were developed from 12.5 m DEM. The slope is an important component determining the watershed hydrological features. It is categorized according to the degree of steepness, which represents 0-5% level to gentle slope, 5-10% moderate slope, 10-15% strong slope, 15-20% steep slope, and slopes greater than represent very steep slope.

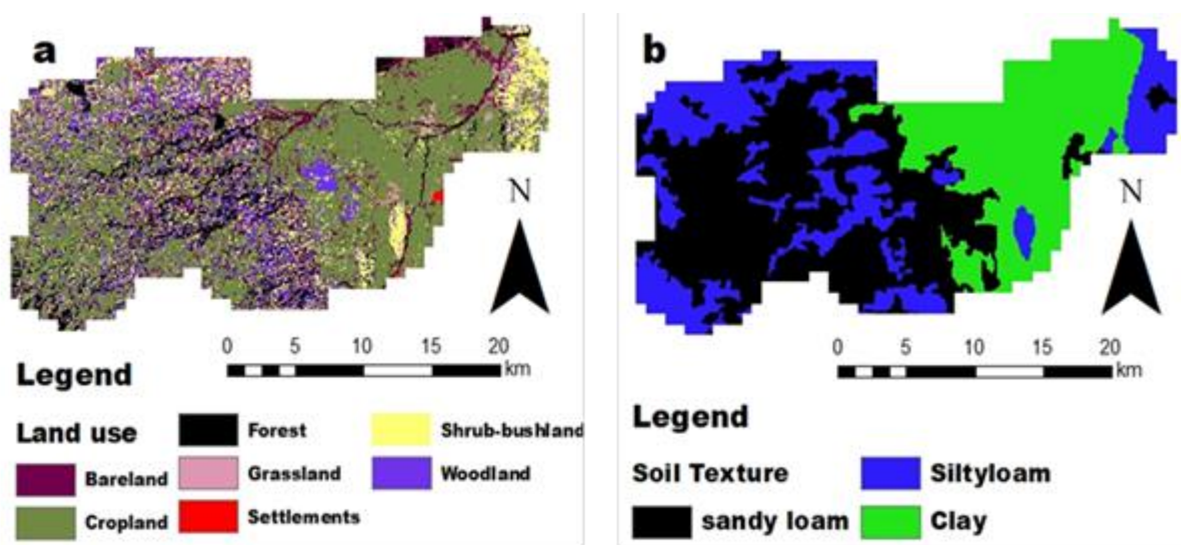



**Figure 5: Land use land cover (a) and soil map of Waja-Golesha watershed (b)**

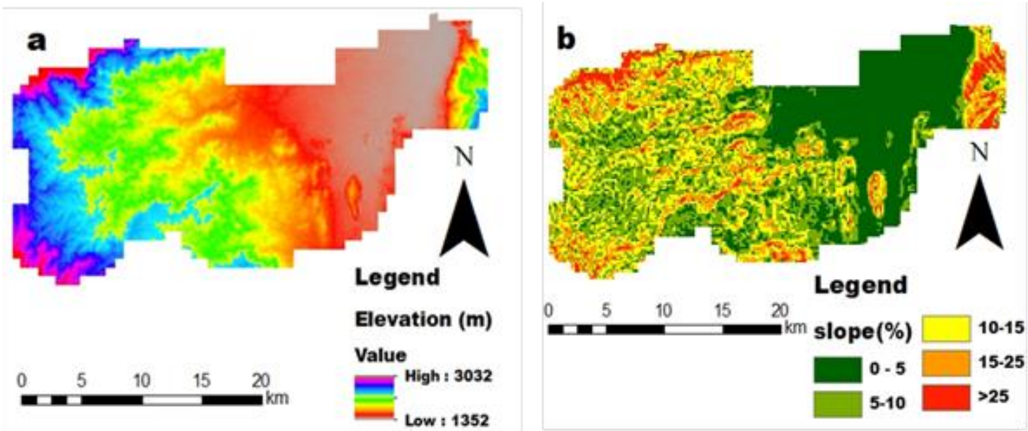



**Figure 6: Elevation (a) and slope map of *the* Waja-Golesha watershed (b)**

**2.3.3.** ***Parameter tables /lookup tables preparation***

Parameter tables are also important for running the WetSpass model. Therefore four parameter tables were prepared such as summer and winter land use land cover, soil texture and runoff coefficient parameters in DBF (database file) format. Basically, the model user guide and some other literature reviews were used to adjust and develop the parameter values to the watershed characteristics. In this study excel (xls) file to dbf file format converter software was used to prepare the lookup tables.

**2.3.4.** ***Adaptation of WetSpass to the case of Waja-Golesha sub-basin***

WetSpass is originally developed for conditions in the temperate regions in general and Europe in particular (Gebrerufael *et al*, 2018). Later the model was applied all over the world under different conditions by modifying its parameters (Fenta *et al*., 2015; Meresa *et al*., 2019; Salem et al, 2019). The modified WetSpass model was applied in semi-arid region of Ethiopia to simulate the hydrological water balance of the Upper Bilate Catchment (Dereje and Nedaw, 2019), Birki watershed (Esayas and Gebeyehu, 2019) and Werii watershed (Gebremeskel and Kebede, 2017). The land-use classes and textural composition and classification of soils for tropical countries like Ethiopia are apparently different than the case of temperate regions. Even though some similar land-use classes literally exist in both temperate and tropical regions, they are not the same in characteristics. Summer and winter seasons of temperate regions are not the same as those of tropical regions. Taking the case of Ethiopia, winter is the dry season while summer is the main rainy season. Hence, before doing any watershed simulation modification of the model is required so as to adapt it in Ethiopian condition.

Thus, a modified WetSpass model was developed for Waja-Golesha watershed where the land-use parameter tables (summer and winter seasons) for Waja-Golesha watershed were modified and adjusted to represent the condition of Waja-Golesha watershed using expert knowledge and scientific literature. Land-use (summer and winter), soil and runoff coefficient are the parameter tables used by WetSpass. The land-use attribute table includes parameters such as land-use type, rooting depth, leaf area index, and vegetation height. The soil parameter table contains soil parameters such as textural soil class, plant available water contents and others. Whereas, the runoff coefficient attribute table contains parameters for runoff classes of various land uses, slope, runoff coefficient etc.

Necessary modification was done on the land-use parameters mainly for the leaf area index, crop height, interception percentage, to fit the condition of Waja-Golesha watershed. Moreover, the vegetative area, bare area, impervious area, and open water area proportions of each land-use class in Waja-Golesha watershed have been modified (Tables 1 and 2). The year was divided into two seasons' summer (June to September) and winter (October to May) with their respective input data (land use, precipitation, potential evapotranspiration, temperature, wind speed and groundwater depth).

**Table 1: Summer land-use parameter table modified for the Waja-Golesha sub-basin**

| Number | Luse_type | Runoff_veg | Num_veg_ro | Num_imp_ro | Veg_area | Bare_area | Imp_area | Openw_area | Root_depth | Lai | Min_stom | Interc_per | Veg_height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Settl | Grass | 2 | 2 | 0.5 | 0.2 | 0.3 | 0.0 | 0.3 | 0.20 | 100.0 | 10.0 | 0.12 |
| 7 | Bare | Bare soil | 4 | 0 | 0.0 | 0.7 | 0.3 | 0.0 | 0.05 | 0.00 | 110.0 | 0.0 | 0.001 |
| 21 | Agri | Crop | 1 | 0 | 0.8 | 0.1 | 0.1 | 0.0 | 0.4 | 0.20 | 180.0 | 35.0 | 0.7 |
| 23 | Grass | Grass | 2 | 0 | 1.0 | 0.0 | 0.0 | 0.0 | 0.3 | 2.00 | 100.0 | 10.0 | 0.2 |
| 31 | Wood | Forest | 3 | 0 | 0.8 | 0.0 | 0.2 | 0.0 | 2.0 | 5.00 | 250.0 | 25.0 | 15.0 |
| 33 | Forest | Forest | 3 | 0 | 0.80 | 0.0 | 0.20 | 0.0 | 2.50 | 3.50 | 310.0 | 50.0 | 10.00 |
| 36 | Shrub | Grass | 2 | 0 | 0.80 | 0.0 | 0.2 | 0.0 | 0.6 | 6.00 | 110.0 | 42.0 | 2.50 |

**Table 2: Winter land-use parameter table modified for the Waja-Golesha sub-basin**

| Number | Luse_type | Runoff_veg | Num_veg_ro | Num_imp_ro | Veg_area | Bare_area | Imp_area | Openw_area | Root_depth | Lai | Min_stom | Interc_per | Veg_height |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Settl | Grass | 2 | 2 | 0.4 | 0.50 | 0.10 | 0.0 | 0.3 | 0.2 | 100.0 | 10.0 | 0.12 |
| 7 | Barel | Bare soil | 4 | 0 | 0.00 | 0.70 | 0.3 | 0.0 | 0.05 | 0.0 | 110.0 | 0.0 | 0.001 |
| 21 | Agric | Crop | 1 | 0 | 0.20 | 0.40 | 0.4 | 0.0 | 0.35 | 2.0 | 180.0 | 22.0 | 0.6 |
| 23 | Grass | Grass | 2 | 0 | 0.60 | 0.30 | 0.10 | 0.0 | 0.30 | 1.0 | 140.0 | 10.0 | 0.12 |
| 31 | Wood | Forest | 3 | 0 | 0.20 | 0.80 | 0.0 | 0.0 | 2.00 | 4.0 | 250.0 | 10.0 | 15.0 |
| 33 | Forest | Forest | 3 | 0 | 0.80 | 0.10 | 0.10 | 0.0 | 2.00 | 4.0 | 340.0 | 42.0 | 10.0 |
| 36 | Shrub | Grass | 2 | 0 | 0.65 | 0.30 | 0.05 | 0.0 | 0.60 | 3.0 | 110.0 | 30.0 | 2.0 |

Luse_type = land-use type, Runoff_veg = runoff vegetation, Num_veg_Ro = runoff class for vegetation type, Num_imp_Ro = impervious runoff class for impervious area types, Veg_area = vegetated area, Bare_area = bare area, Imp_area = impervious area, Openw_area = open-water area, Root_depth = Root Depth, Lai = Leaf Area Index, Min_stom = minimum stomata opening, Interc_per = interception percentage, Veg_height = vegetation height

**2.3.5.** ***Analysis and grid maps combination***

WetSpass gives various hydrologic outputs on a yearly and seasonal (summer and winter) basis (Gidafie *et al*., 2016). The results from the WetSpass model can be analyzed in various ways (Kahsay *et al*, 2018). The spatial variations of recharge and runoff can be obtained as a function of land use and soil type. As all output from the model are grid maps and not tabular values, it would be helpful to combine two or more grid maps. The ArcGIS function called 'combine' is used to combine different grids to produce database files for further analysis and graphical presentations. Accordingly, the land-use and soil maps were combined with surface runoff, recharge and actual evapotranspiration maps to visualize the impact of different land covers and soil texture on evapotranspiration, surface runoff, and groundwater recharge.

**2.3.6.** ***Validation of WetSpass Mode***

The validation of the WetSpass model was performed by using stream flow data recorded at the Golina river gauging station for the period 2012–2019 obtained from the Ministry of Water and Energy of Ethiopia (MoWE) to perform the hydrograph analysis. The automated Web-Based Hydrograph Analysis Application (WHAT) was applied to derive a base flow from stream-flow data. WHAT has three separating filters: the Eckhardt recursive digital filter method (RDF) (Eckhardt, 2005), the one-parameter digital filter method (OPM) (Lyne and Hollick, 1979; Nathan and McMahon, 1990; Arnold and Allen, 1999; Arnold *et al*., 2000) and the local-minimum method (LMM) (Lim *et al*., 2005) where the Eckhardt recursive digital filter method was applied in this study as indicated in the equation [4] below.

$$b_t = \frac{1 - BFI_{max} x \alpha bt - 1 + 1 - \alpha x BFI_{max} x Q_t}{1 - \alpha x BFI_{max}} \quad [4]$$

Where, *bt* represents base flow at time step t ($m^3/s$); *bt−1* represents the filtered base flow at time step t−1 ($m^3/s$); BFImax presents the maximum long-term ratio of base flow/total streamflow; *Qt* is the total streamflow at time step t ($m^3/s$) and $\alpha$ is the filter parameter. Eckhardt (2005) suggested BFImax values of 0.50 for ephemeral streams including porous aquifers, 0.25 for perennial streams containing hard rock aquifers, and 0.80 for perennial streams containing porous aquifers. The proposed values of 0.80 for BFImax and 0.98 for the filter parameter, which correlates to the hydrogeological characteristics of the watershed, were used in this case.

## 3. Results and Discussion

### 3.1. Validation of WetSpass Mode

Conventionally, the validation processes of the WetSpass distributed hydrologic water balance model were implemented through manual adjusting or modifying the model parameters existing in the WetSpass model within a given range of values. The objective function is typically the correlation of the coefficient of determination R2 between the simulated surface runoff and observed discharge. The adjusted parameters include alfa coefficient, "a" interception, Lp coefficient, and runoff delay factor "x." These parameters were held in reserve optimizing up to the attainment of a final agreement between the calculated against observed discharge recorded at Hormat-Golina river and base flow obtained from separating the observed discharge using base flow separator techniques (Figure 7).

Figure 8 shows that the simulation analysis has attained excellently with a correlation coefficient of the "line of the goodness of fit" and Nash-Sutcliffe efficiency (NSE) of 0.94 and 0.93, respectively, with a standard error of 0.21. Evaluation of the WetSpass model showed representative results for the total discharge and good results for the base flows.

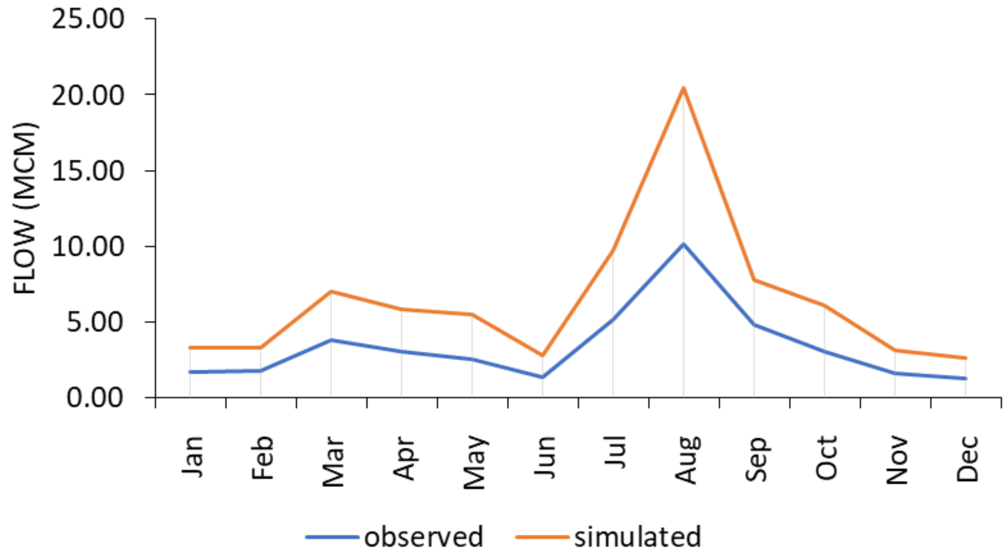



**Figure 7: Compression between simulated and observed flow data**

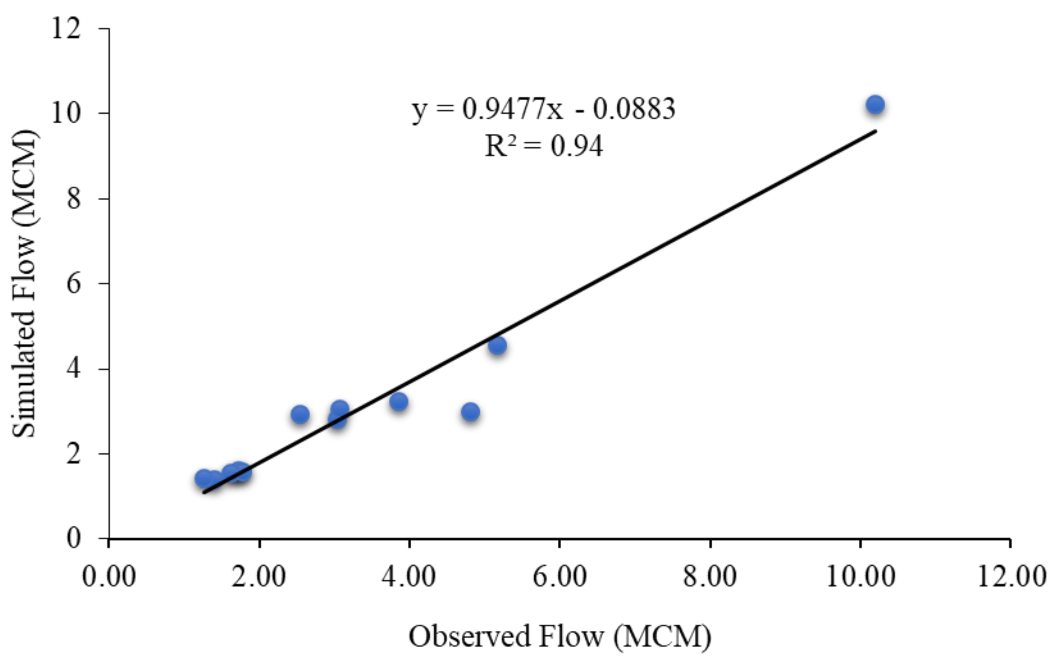



**Figure 8: Model validation**

### 3.2. Outputs of WetSpass Model

The main outputs of the WetSpass model are raster maps of annual and seasonal groundwater recharge, surface runoff and actual evapotranspiration for the period 2001 to 2020. In these maps, every pixel represents the magnitude of the water balance component in mm.

#### 3.2.1. *Groundwater recharge*

The seasonal and annual groundwater recharge of the Waja-Golesha watershed changes spatially with the basin characteristics and topography (Figure 9). The WetSpass model evaluates the annual long-term groundwater recharge of the Waja-Golesha watershed to be 5 mm and 86 mm as minimum and maximum values, respectively, with a mean value of 29 mm. The Average recharge represents only 5% of the areal average rainfall. The temporal variability of the recharge was 72% and 28% for the wet and dry periods respectively. About 1.6*105 $m^3$ of water was added to the groundwater annually from the entire area of the watershed (532.6 $km^2$). In other research areas, similar studies have been undertaken to estimate average groundwater recharge using the WetSpass model. Accordingly, average recharge was found to be 28 mm (5% of annual precipitation) by Esayas and Gebeyehu (2019), 37 mm (6%) by Gidafie et al. (2016), 24.90 mm (7.4%); Meresa et al. (2019), 30.06 mm (4.2%) by Gebremeskel and Kebede (2017), 116 mm (9.4%) ; Dereje and Nedaw (2019), 66 mm (12%); Haile (2015) and 55 mm (8%) by Gebreruael et al (2018).

The mean annual spatial groundwater recharge is highly variable depending on the factors that govern groundwater recharge (Figure 9). The southern and western highlands of the Waja-Golesha watershed had high annual groundwater recharge due to the presence of permeable soils, high rainfall and vegetation cover. The western foothill side areas were also characterized by high groundwater recharge occurrence mainly due to the flat topography and coarse permeable soils. On the contrary, the lowlands and central southeastern of the area had low groundwater recharge due to their being discharge areas and the dominance of less permeable fine-textured soils. Grass land and sandy-textured soil class results high ground water recharge (Table 3) due to high permeability of sandy soils, less runoff on the relatively gentler slopes of grass lands. While bare land with clay soils results low infiltration and contributed to high surface runoff.

### 3.2.2. *Surface runoff*

Depending on slope and other catchment characteristics, surface runoff resulting from Waja-Golesha watershed was varied specially (Figure. 10). The average surface runoff from Waja-Golesha watershed was 131.5 mm with minimum and maximum values of 22 and 361 mm respectively. The surface runoff accounts 24% of annual rainfall which is equivalent $2.2*10^5$ cubic meters of water exit the catchment as runoff. The seasonal variation of surface runoff was 51% and 49% in the wet and dry seasons respectively. This shows the bi-modal nature of precipitation distribution in the watershed.

In different sub-catchments of Ethiopia, similar results were presented: 20.8% of precipitation, Upper Bilate Catchment, Southern Ethiopia (Dereje and Nedaw, 2019),7.1% of precipitation, Birki Watershed, Eastern Tigray, Northern Ethiopia (Meresa *et al*., 2019), 6% of annual precipitation, Werii watershed of the Tekeze River Basin, Ethiopia (Gebremeskel and Kebede, 2017), 7.2% of annual precipitation, Geba basin, Northern Ethiopia (Yenehun *et al*., 2017) and 7% of precipitation, Illala Catchment, Northern Ethiopia (Teklebirhan *et al*., 2012).

The highest mean annual surface runoff of the Waja-Golesha watershed was observed in western highlands, which are characterized by clay and silty loam soil which had low permeability, which increases the surface runoff. On the other hand, the lowest runoff occurs in the northern and central parts of the watershed due to the presence of sandy loam soils. Clay soil with settlement and bare land contributes high runoff generation whereas grassland and forest with sandy loam soil produce low runoff (Table 4). Areas across the high lands which have relatively high rainfall produce high runoff than the valley floor which had low rainfall.

**Table 3: Simulated mean annual recharge (mm) for the combinations of land-use and soil texture**

| Soil texture | Forest | Shrubs | Agriculture | Grass land | Bare land | Settlement | Mean |
|---|---|---|---|---|---|---|---|
| Sandy loam | 47.5 | 36.5 | 45.8 | 52.2 | 28.1 | 27.1 | 38.7 |
| Silty loam | 29 | 27 | 20.2 | 28.5 | 22.5 | 22.5 | 24.7 |
| Clay | 6.5 | 12.9 | 4.8 | 5.2 | 17.5 | 3.7 | 8.7 |
| Mean | 27.7 | 25.5 | 23.6 | 28.6 | 22.7 | 17.8 | |

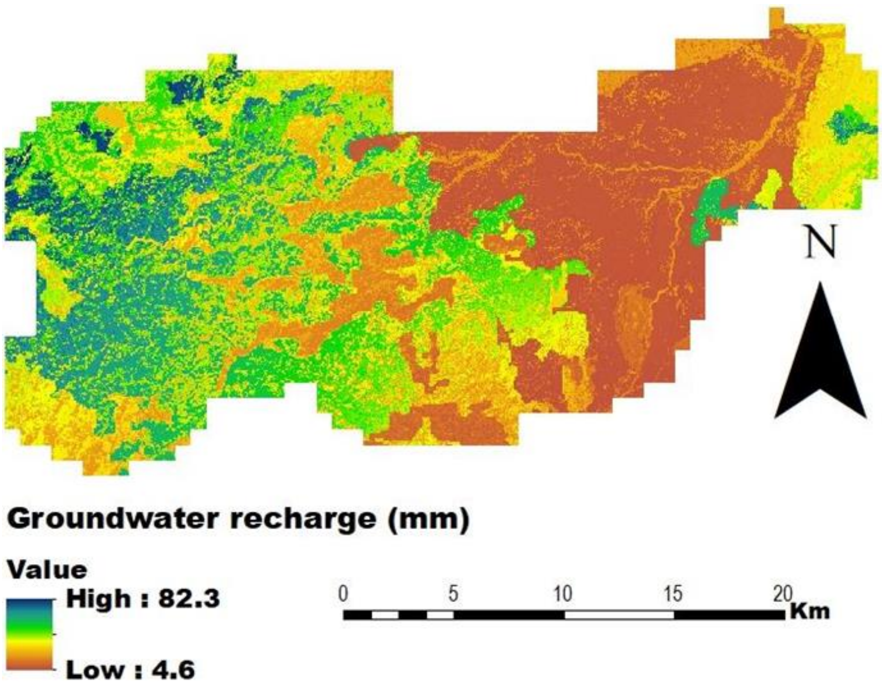



**Figure 9: Ground water recharge map of Waja-Golesha watershed**

**Table 4: Mean annual surface runoff for different combinations of land-use and soil texture**

| Soil texture | Forest | Shrubs | Agriculture | Grassland | Bare land | Settlement | Mean |
|---|---|---|---|---|---|---|---|
| Clay | 92.2 | 173.1 | 173.7 | 97.1 | 315.5 | 322.2 | 195.6 |
| Silt loam | 85.3 | 163.5 | 164 | 88 | 299.3 | 301.3 | 183.6 |
| Sandy loam | 76.6 | 154.5 | 152.4 | 79 | 276.9 | 268.7 | 168.0 |
| Mean | 84.7 | 163.7 | 163.4 | 88.0 | 297.2 | 297.4 | |

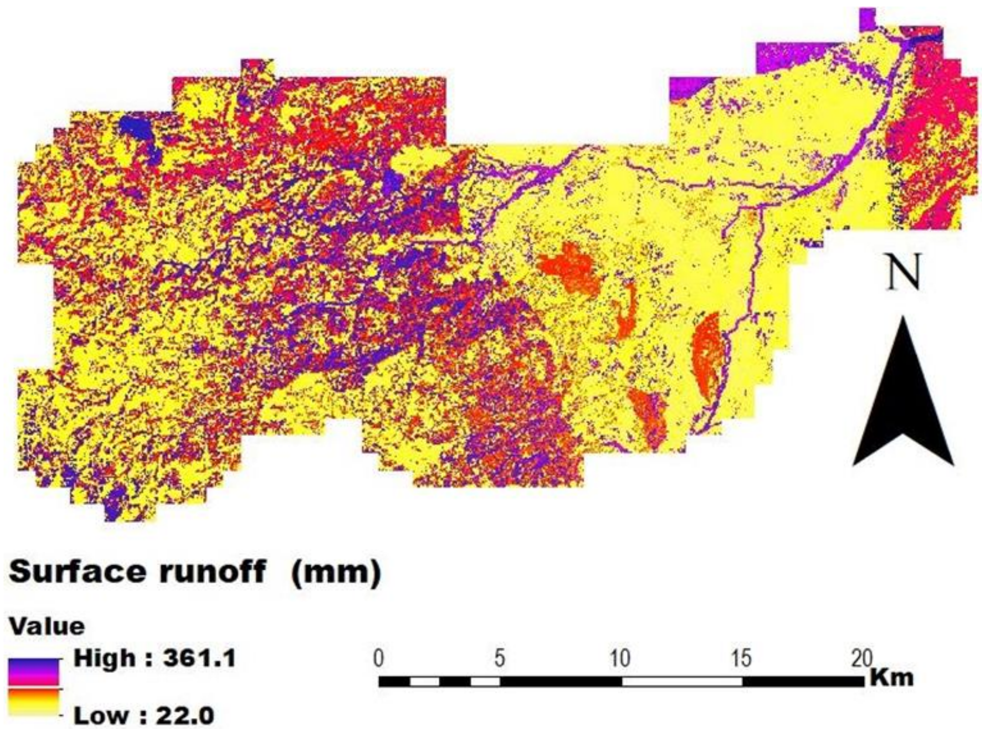



**Figure 10: Surface runoff from Waja-Golesha watershed**

### 3.2.3. *Actual evapotranspiration*

The WetSpass simulated mean annual evapotranspiration of the Waja-Golesha watershed was 474mm constituting about 71% of the annual average rainfall of the area. This indicated that evapotranspiration was the main process of water loss in the watershed mainly due to the high rate of radiation and existence of strong dry winds. The higher evapotranspiration took place during the summer season (63%) while the remaining 37% took place during the winter season. The actual evapotranspiration during the summer season was 26% higher than the simulated actual evapotranspiration that took place during the winter period which indicates the bimodal nature of the precipitation in the study area. Low land parts of the area were responsible for higher annual evapotranspiration (Figure. 12). Similarly, areas with high precipitation like Gaba basin have high evapotranspiration (Gebreyohannes et al., 2013).

Similarly, Gebremeskel and Kebede, (2017), reported that actual evapotranspiration is 90.7% of the average rainfall in the Werii watershed of the Tekeze River Basin, Ethiopia, Yenehun et al., (2017), reported 90.7% of the average rainfall in Geba basin, Northern Ethiopia, Meresa et al., (2019), get 85.5% of average rainfall in the Birki Watershed, Eastern Tigray, Northern Ethiopia, Dereje and Nedaw, (2019), also simulates 69.8% of average rainfall in the Upper Bilate Catchment, Southern Ethiopia and Gebrerufael et al, (2018), reported that 84% of average rainfall in the Raya valley, Northern Ethiopia. As a result, evapotranspiration removes the majority of average rainfall. The spatial variation of evapotranspiration was analyzed by combining average annual evapotranspiration with different land-use and soil classes. Because of water availability in the soil texture and high transpiration from the vegetation forest, grass land and shrubs with sandy loam and clay soil texture have high evapotranspiration (Table 5).

### 3.2.4. *Water balance components*

The overall water balance analysis of the Waja-Golesha watershed (Table 6) indicated that only a small fraction of the annual rainfall remains to recharge the groundwater reservoir of the watershed. While the rest leaves the watershed mainly through evapotranspiration and to a lesser extent via surface runoff. The higher standard deviation value revealed in the water balance component indicates high spatial variation of the water balance element within the basin. This is mainly in response to the uneven distributions of the climatic parameters associated with variations of Land-use/land cover, soil type, topography and slope.

**Table 5: Simulated mean annual evapotranspiration for combinations of land-use and soil texture**

| Soil texture | Forest | Shrubs | Agriculture | Grassland | Bare land | Settlement | Mean |
|---|---|---|---|---|---|---|---|
| Sandy loam | 549.7 | 552.5 | 358.8 | 557.3 | 485.8 | 483.9 | 498.0 |
| Silty loam | 576.5 | 572.6 | 364.7 | 570.6 | 501.6 | 497.2 | 513.9 |
| Clay | 578.1 | 564.6 | 375.9 | 584.7 | 495.4 | 498.4 | 516.2 |
| Mean | 568.1 | 563.2 | 366.5 | 570.9 | 494.3 | 493.2 | |

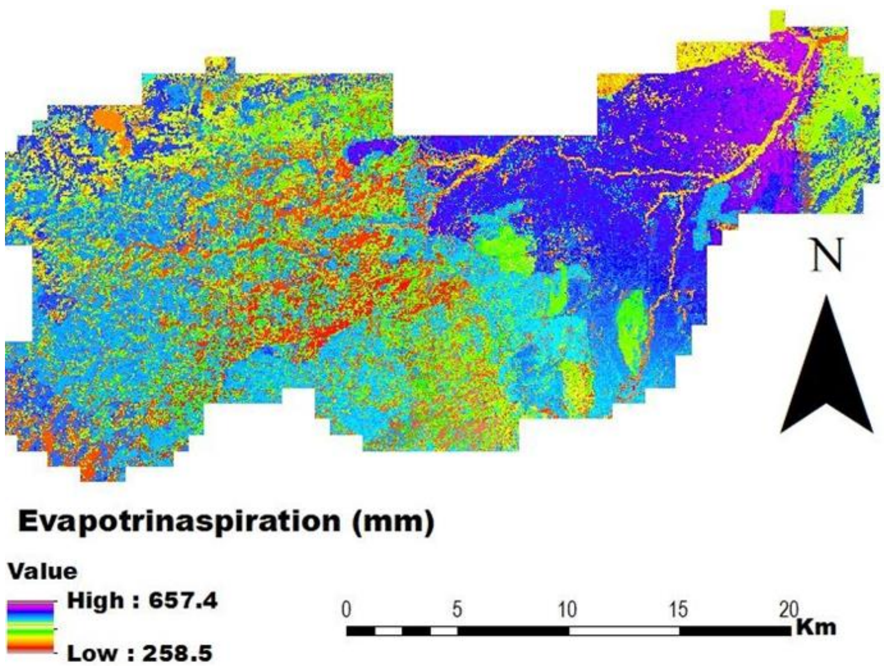



**Figure 11: Actual evapotranspiration from Waja-Golesha watershed**

**Table 6: Water balance components of Waja-Golesha watershed**

| Water balance components | Annual values (mm/year) | | | |
|---|---|---|---|---|
| | minimum | maximum | Mean | Standard deviation |
| Precipitation (PCP) | 577.2 | 726.3 | 664.5 | 13.6 |
| Evapotranspiration (ET) | 259 | 657 | 474 | 89. |
| Runoff (Ro) | 22 | 361 | 161.5 | 91 |
| Recharge (Re) | 5 | 82.0 | 29.0 | 18 |
| Water balance | PCP-ET-Ro-Re = 0.0 | | | |

## 4. Conclusion and Recommendation

Specially distributed long-term average recharge of Waja-Golesha sub-basin was estimated by distributed water balance model (WetSpass). WetSpass model output indicates that the mean annual recharge in the basin was 29 mm and was estimated to represent about 5% of the mean annual rainfall. From the entire area of the Waja-Golesha watershed $1.6*10^5$ $m^3$/yr. water was added annually. The seasonal recharge of the area was 72% and 28% in wet and dry season respectively. Sandy textured soils with grass land use results high recharge while low recharge was observed in clay soils with settlement and bare lands. Wetspass was suitable model for analysis of land use change on water balance of the watershed and therefore wetSpass is good enough to simulate groundwater recharge of the Waja-Golesha watershed. 474 mm of evapotranspiration which is 71% of annual rainfall was simulated in the catchment. Due to the presence of strong dry wind and high radiation in the catchment, evapotranspiration was the main process of water loss in the area. From the water balance analysis result most of the annual rainfall lost the sub-basin through surface runoff and evapotranspiration while small fraction of the rainfall was responsible for groundwater recharge.

The groundwater recharge map along with other thematic maps can serve as a source of information database which can be updated from time to time by adding new information. Therefore there should be well organized data base system in different governmental organization so as to provide accurate data about the hydrogeological as well as hydrological systems for feature studies.

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**Data availability statement**

Data will be made available on request.

**Declaration of interest's statement**

The authors declare no competing interests.

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