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Groundwater Recharge Estimation in Relation to Land Use Type and Soil: The Case of Hormat-Golina Sub-Basin, Northern Ethiopia

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Abstract: - *Comprehending the spatial variability of groundwater recharge, influenced by factors such as land use, soil texture, topography, groundwater levels, and hydrometeorological parameters, is essential for sustainable groundwater resource development. Thus, this study endeavors to estimate groundwater recharge in the Hormat-Golina sub-basin, northern Ethiopia, employing the WetSpass (Water and Energy Transfer between Soil, Plants, and Atmosphere under quasi-Steady State) hydrological model. The model inputs, consisting of 30m grid size maps and attribute tables, are meticulously prepared, drawing upon expert knowledge and scientific literature. Validation of the model against observed data reveals a robust agreement, with an* R^2 *value of 0.94 and NSE of 0.85 for simulated surface runoff. Analysis of the long-term temporal and spatial average annual rainfall, totaling 828.5 mm, delineates its distribution: 156.4 mm (19%) as surface runoff, 616.7 mm (73%) evaporating through evapotranspiration, and 55.4 mm (8%) contributing to recharge. This recharge volume amounts to* $4.2*10^5$ *cubic meters* (m^3) *for the Hormat-Golina sub-basin, spanning approximately 698.25* km^2*, with 83% occurring during the summer season and the remainder during the winter (dry) season. Notably, forested areas with sandy soil exhibit the highest recharge rates*

Keywords: Ethiopia, groundwater recharge, Hormat-Golina, WetSpass.

INTRODUCTION

Groundwater, as the largest source of fresh water, holds paramount importance for human survival [1]. Its indispensable qualities, including consistent temperature, widespread distribution, and continuous availability, make it a vital water supply source across diverse climatic regions. Recognizing its finite and vulnerable nature, sustainable utilization of groundwater resources is imperative for present and future generations [2].

Effective groundwater resource management hinges upon a thorough understanding of groundwater recharge and potential [3]. Groundwater recharge estimation methods, ranging from direct measurements to empirical techniques, play a crucial role in this endeavor[4]. The choice of method depends on factors such as spatial or temporal scale, range, and reliability of recharge estimates [5].

In the context of the Hormat-Golina sub-basin in Northern Ethiopia, characterized by rain-fed agriculture and erratic rainfall patterns, groundwater plays a pivotal role in ensuring food security. However, inadequate soil moisture due to rainfall variability necessitates supplementary irrigation, increasing reliance on groundwater resources. Despite its growing importance, previous studies focused primarily on point estimates of groundwater recharge, lacking robust methodologies.

To address this gap, this study aims to estimate long-term seasonal and annual average spatial groundwater recharge in the Hormat-Golina sub-basin using the GIS-based WetSpass model. By incorporating factors such as land use, soil texture, slope, and hydro-meteorological parameters, the model enables a more comprehensive understanding of groundwater recharge dynamics, essential for sustainable groundwater resource management and agricultural development in the region

MATERIALS AND METHODS

Description of the Study Area

The Hormat-Golina sub-basin is situated in the northern part of Ethiopia, spanning latitudes 11°56′–12°13′N and longitudes 39°25′–39°47′E (Figure 1). It is flanked by the Lasta Mountains to the west, the Zobel Mountains to the east, the Raya Valley to the north, and volcanic ridges to the south, covering a total area of 698.25 km2. Positioned on the western edge of the Danakil basin, it features distinct physiographic characteristics, including north–south oriented mountains in the west, a steep fault scarp in the east, and a major graben interspersed with isolated hills.

The sub-basin is primarily composed of quaternary sediments, with volcanic mountains of relatively high elevation bordering its eastern and western edges. These mountains predominantly consist of Tertiary-aged volcanic rocks such as basalts, rhyolite, and granite, which are exposed in the surrounding areas and underlie the valley's alluvial sediments. Geological structures, including major and inferred faults, fractures, and lineaments, exhibit alignments ranging from N-S to NE-SW and play a significant role in the catchment's hydrology [8].

Elevation within the sub-basin ranges from 1189 m in the valley floors to 2985 m above sea level in the western mountain ridges. The region experiences an erratic, bimodal rainfall pattern, with the primary rainy season occurring from late June to early September. Peak rainfall typically occurs in July and August, while a short spring rainy season extends from February to March. Monthly temperatures vary, with minimum averages of 4.7 °C in the Lasta plateaus and maximum averages of 35.5 °C in the Waja lowlands. June registers the highest temperatures, while November sees the lowest values. The sub-basin's western mountainous terrain is crisscrossed by streams and steep slopes, facilitating high runoff rates. Consequently, the valley floor receives seasonal recharge from runoff originating in the nearby hills. Rain-fed agriculture, often reliant on diverting seasonal flush floods, is a common agricultural practice in the area.

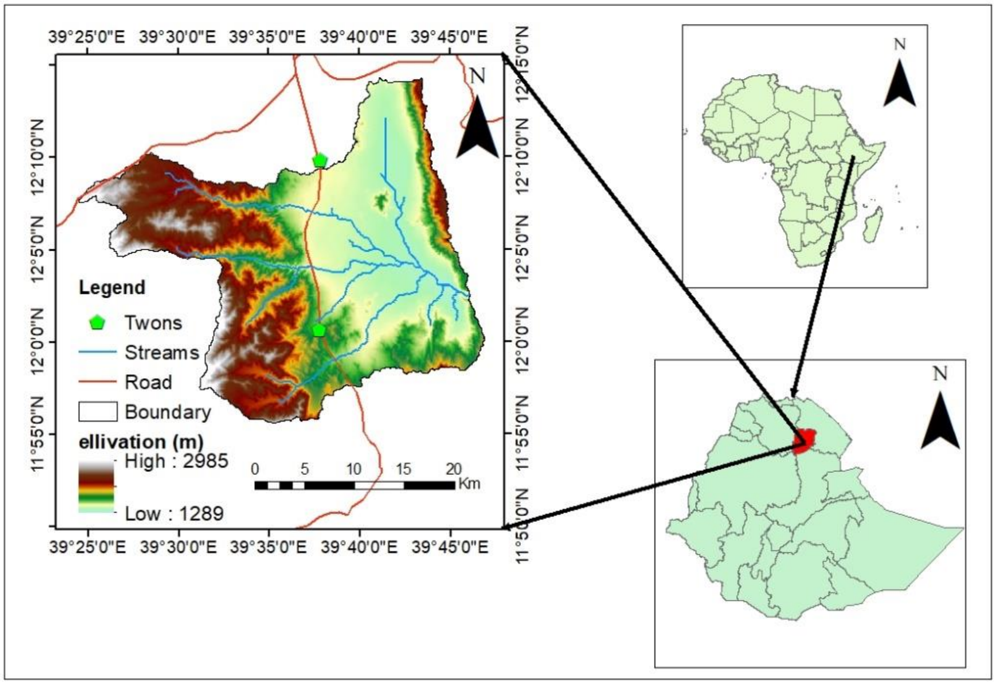


Figure 1:- Location map of the Hormat-Golina sub-basin.

Dataset and sources

This study relied on a combination of primary and secondary data sources. Secondary data included remote sensing datasets such as the Digital Elevation Model (DEM) obtained from the Alaska Satellite Facility (ASF), as well as land use/land cover data sourced from the Ethiopian Geospatial Institute (EGI). Additionally, meteorological data were collected from the national meteorological agency of Ethiopia.

The 12.5m resolution DEM was downloaded from the ASF website and processed using ArcGIS software. The soil map of the Hormat-Golina sub-basin was derived from the Soil Map of Ethiopia, developed by the Ministry of Water, Irrigation, and Energy (MWIE) of Ethiopia. Land use/land cover data for Ethiopia, with a 20m resolution, was provided by the Ethiopian Geospatial Institute (GSI), from which the specific land use/land cover map for the study area was modified and developed.

Elevation and slope maps of the watershed were generated from the DEM data. Primary data were obtained through direct measurements of groundwater depth (groundwater table) collected from existing boreholes using a deep meter. Meteorological data spanning 22 years (from 2000 to 2021) were sourced from seven meteorological stations with consistent data and low missing values. Potential evapotranspiration was calculated using the Hargreaves equation [9].

Data analysis

WetSpass model description

WetSpass, an acronym for Water and Energy Transfer between Soil, Plants, and Atmosphere under quasi–Steady State, is a physically based model designed to estimate long-term average spatial patterns of groundwater recharge, surface runoff, and evapotranspiration. It utilizes long-term average meteorological data in conjunction with land-use, soil, and groundwater level grid maps, employing both physical and empirical relationships (Gebrerufael H.,et al. 2018).

Integrated into ArcGIS as a raster model and coded in Avenue and Visual Basic, WetSpass provides various hydrologic outputs on a yearly and seasonal (summer and winter) basis [11]. Parameters such as land use and soil type are linked to the model through attribute tables of the respective raster maps. This allows for easy definition of new land cover or soil types and adjustments in parameter values to analyze future land and water management scenarios [12].

WetSpass treats a basin or region as a regular pattern of raster cells, with each cell's total water balance split into independent components for vegetated, bare-soil, open-water, and impervious parts. This approach accounts for the non-uniformity of land use within each cell, dependent on raster cell resolution. Processes within each part of a cell are arranged in a cascading manner, with an assumed order of occurrence after a precipitation event. This seasonal timescale ensures quantification of processes while considering physical and hydro-meteorological constraints .

Water balance components for vegetated, bare-soil, open water, and impervious surfaces are calculated using equations (1-3), where Eta represents total evapotranspiration, Sa denotes surface runoff, and Ra indicates groundwater recharge of a raster cell. These components are determined based on fractions of vegetated, bare soil, open water, and impervious areas within each cell.

$$\mathrm{ET}a = avETv + asEs + aoE0 + aiEi \tag{1}$$

$$Sa = vSv + asSs + aoRo + aiRi \tag{2}$$

$$R\,a = vRv + asRs + aoRo + aiRi \tag{3}$$

Where Eta Sa, and Ra are the total evapotranspiration, surface runoff, and groundwater recharge of a raster cell respectively, each having vegetated, bare soil, open water and impervious area fractions denoted by av, as, ao and ai respectively, E is evaporation.

Precipitation initiates the computation of water balance, followed by processes such as interception, surface runoff, evapotranspiration, and recharge, adhering to the predefined order of occurrence (Figure 2).

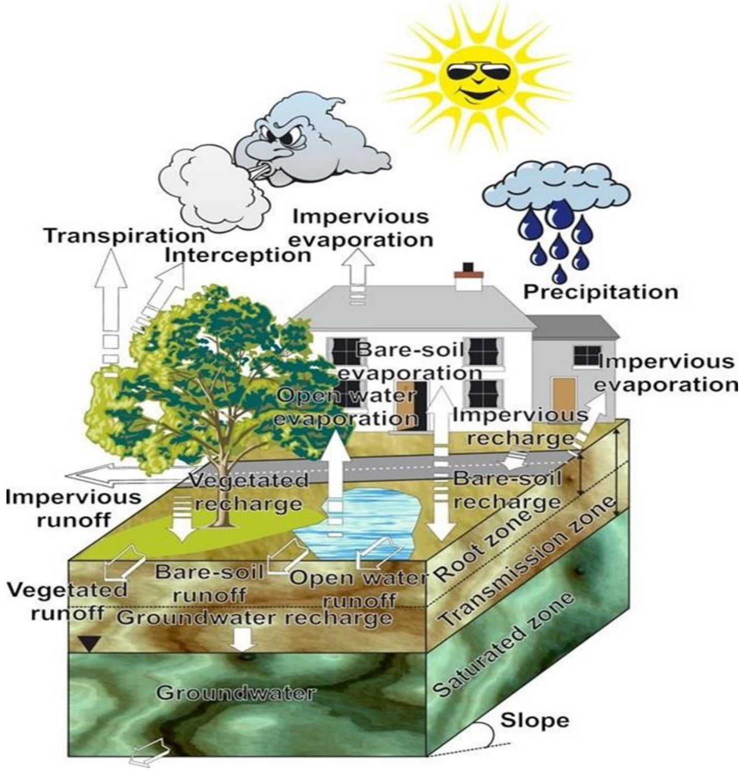


Figure 2. Schematic water balance of hypothetical raster cell (Batelaan and De Smedt, 2001).

WetSpass model data inputs preparation

The use of GIS-based hydrological models, such as the WetSpass model, is essential for analyzing groundwater systems, particularly in steady-state conditions. These models require long-term average hydro-meteorological data and spatial patterns of biophysical layers specific to the watershed as primary inputs. In the case of the Ethiopian conditions, particularly in the study area, WetSpass operates on a seasonal basis, dividing the year into two main periods: summer (comprising June, July, August, and September) and winter (encompassing the remaining 8 months). This seasonal division aligns with the country's climatic patterns.Preparation of input data for the WetSpass model involves the creation of grid maps and parameter tables using ArcGIS tools. These input datasets include: Land-use/land-cover maps, Soil texture maps, Slope maps, Topography maps, Groundwater level data, Rainfall data, Temperature data, Potential evapotranspiration data, and Wind speed data

These grid maps and parameter tables serve as essential inputs for the model, facilitating the simulation of groundwater recharge, surface runoff, and evapotranspiration processes within the watershed. Input files are organized into parameter tables, typically stored in a database file format (dbf), and include separate tables for summer and winter conditions. These tables contain information on land use/land cover, soil texture, and runoff coefficient specific to each season, enabling the model to account for seasonal variations in hydrological processes effectively.

Parameter tables /lookup tables preparation

Creating lookup tables is essential for running the WetSpass model effectively. This study involved preparing four parameter tables: summer and winter land use/land cover, soil texture, and runoff coefficient parameters, all formatted in DBF (database file) format to ensure compatibility with the model. Adjusting parameter values to suit the specific characteristics of the sub-basin was crucial, informed by the model user guide and relevant literature reviews. To simplify this process, an Excel to DBF file format converter software was utilized, facilitating the conversion of data from Excel spreadsheets to the required DBF format and streamlining the creation of parameter tables for the WetSpass model.

Adaptation of WetSpass to the case of Hormat-Golina sub-basin

The WetSpass model was originally developed for temperate regions, with a particular focus on Europe. However, it has been adapted and applied worldwide under various conditions by modifying its parameters. In Ethiopia, for example, researchers have customized the WetSpass model to suit the semi-arid regions, such as the Upper Bilate Catchment, Birki watershed, and Werii watershed.

The differences in land-use classes, soil textures, and seasonal patterns between temperate and tropical regions necessitate modifications to the WetSpass model for application in countries like Ethiopia. While some land-use classes may exist in both regions, their characteristics can vary significantly. Additionally, the distinction between summer and winter seasons in temperate regions differs from that in tropical regions like Ethiopia, where winter corresponds to the dry season and summer to the main rainy season. Therefore, adjustments to the model are essential to ensure its suitability for Ethiopian conditions before conducting watershed simulations. Thus, a modified WetSpass model, was developed for Hormat-Golina sub-basin where the land-use parameter tables (summer and winter seasons) for Hormat-Golina sub-basin were modified and adjusted to represent the condition of Hormat-Golina sub-basin using expert knowledge and scientific literatures. 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 Hormat-Golina watershed. Moreover, the vegetative area, bare area, impervious area, and open water area proportions of each land-use class in Hormat-Golina watershed have been modified (Table 1 and 2). The year was divided into two seasons' summer (from June to September) and winter (from October to May) with their respective input data (land-use, precipitation, potential evapotranspiration, temperature, and wind speed and groundwater depth).

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 1-: summer land-use parameter table modified for the Hormat-Golina sub-basin

Table 2:- winter land-use parameter table modified for the Hormat-Golina 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 stomatal opening, Interc_per interception per- centage, Veg_height vegetation height

Analysis and grid maps combination

The WetSpass model generates hydrological outputs on both an annual and seasonal basis, distinguishing between summer and winter periods. These results can be analyzed in various ways to understand the spatial variations of recharge and runoff, particularly in relation to land use and soil type. Since the model outputs are grid maps rather than tabular values, combining multiple grid maps can provide valuable insights. To accomplish this, the 'combine' function in ArcGIS is utilized, merging different grid maps to create database files suitable for further analysis and graphical presentations. In this study, for example, land-use and soil maps were combined with surface runoff, recharge, and actual evapotranspiration maps. This integration allowed for the visualization of how different land covers and soil textures influence evapotranspiration, surface runoff, and groundwater recharge, providing a comprehensive understanding of the hydrological processes within the study area.

Generating Hydrometric Data for the Outlet of the Sub-Basin

Obtaining accurate input data, including precipitation and stream flow data, is crucial for successful hydrological modeling. This data is essential for evaluating the performance of hydrological models by comparing simulated values with observed data. However, in the Hormat-Golina sub-basin of northern Ethiopia, the absence of stream flow measuring stations poses a challenge for implementing hydrological models and predicting the impacts of both human-induced and natural stresses on surface and subsurface water resources. To address this challenge, regionalization techniques were employed to produce stream flow data for the sub-basin. This allowed for the evaluation of the WetSpass model's performance and facilitated the development of appropriate water resources management strategies despite the lack of direct stream flow measurements.

Validation of WetSpass Mode

The validation of the WetSpass model involved the use of flow data generated through physical similarity regionalization techniques, which were then subjected to hydrograph analysis. To derive base flow from the streamflow data, the Automated Web-Based Hydrograph Analysis Application (WHAT) was utilized. WHAT offers three separating filters: the Eckhardt recursive digital filter method (RDF), the one-parameter digital filter method (OPM), and the local-minimum method (LMM).

In this study, the Eckhardt recursive digital filter method (RDF) was specifically employed. The RDF method is represented by the following equation:

$$\mathrm{b_t} = \frac{1-\mathrm{BFI_{max}}\mathrm{x}\alpha\mathrm{bt}-1+1-\alpha\mathrm{xBFI_{max}}\mathrm{xQ_t}}{1-\alpha\mathrm{xBFI_{max}}} \qquad (4)$$

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 stream flow; *Qt* is the total stream flow at time step t (m^3/s) and α is the filter parameter

Eckhardt (2005), recommended different \ (BFI_ {max} \) values depending on the hydrogeological characteristics of the streams: 0.50 for ephemeral streams with porous aquifers, 0.25 for perennial streams with hard rock aquifers, and 0.80 for perennial streams with porous aquifers. In this case, proposed values of 0.80 for \ (BFI_ {max} \) and 0.98 for the filter parameter were utilized, reflecting the hydrogeological characteristics of the watershed under study.

RESULT AND DISCUSSION

Validation of WetSpass Mode

Traditionally, the validation of the WetSpass distributed hydrologic water balance model involved manual adjustment or modification of model parameters within predefined ranges. The objective function typically focused on achieving a high correlation coefficient (R^2) between simulated surface runoff and observed discharge. Parameters such as the alfa coefficient, interception coefficient "a," Lp coefficient, and runoff delay factor "x" were adjusted iteratively until a satisfactory agreement was reached between calculated and observed discharge, recorded at the Hormat-Golina river, as well as base flow obtained through separation techniques.

The simulation analysis depicted in Figure 3 indicates excellent performance, with a correlation coefficient (R^2) of the "line of the goodness of fit" (Figure 4) and Nash-Sutcliffe efficiency (NSE) reaching 0.94 and 0.85, respectively. Additionally, the standard error was determined to be 0.21. The evaluation of the WetSpass model demonstrated representative results for total discharge and favorable outcomes for base flows, affirming the model's reliability and accuracy in simulating hydrological processes within the study area.

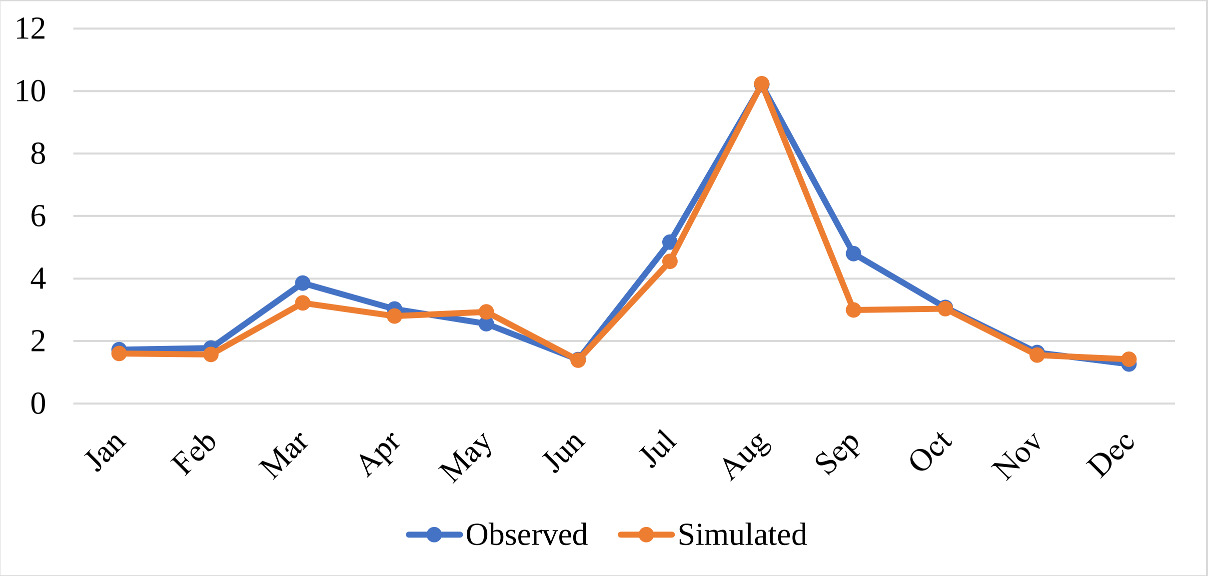


Figure 3: Compression between simulated and observed flow data.

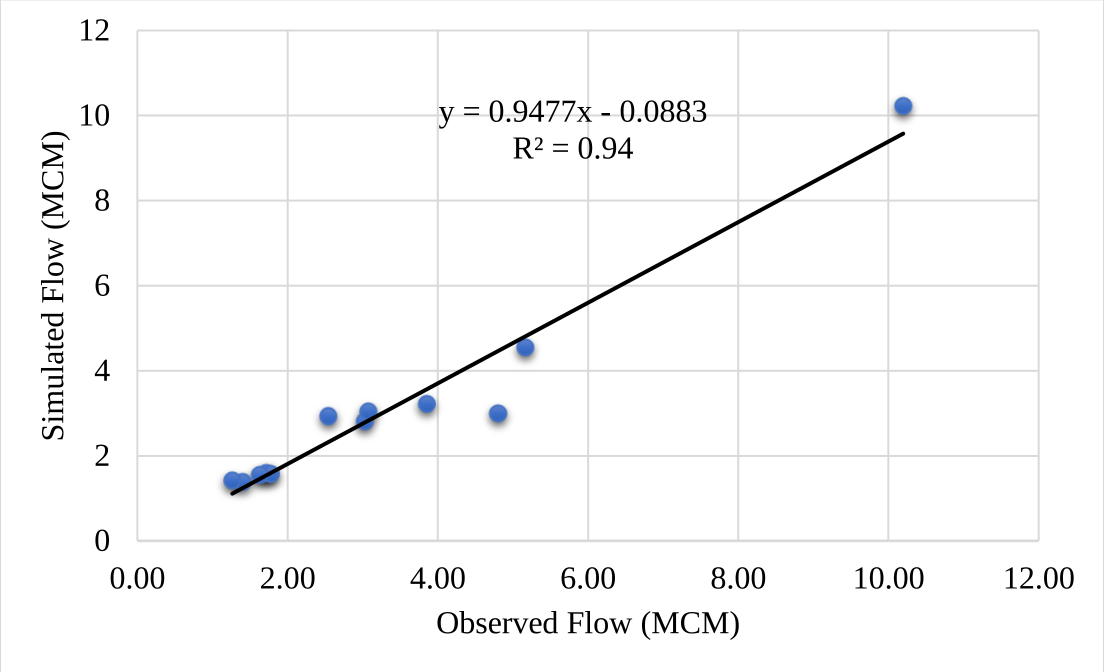


Figure 4: Model validation using coefficient of determination.

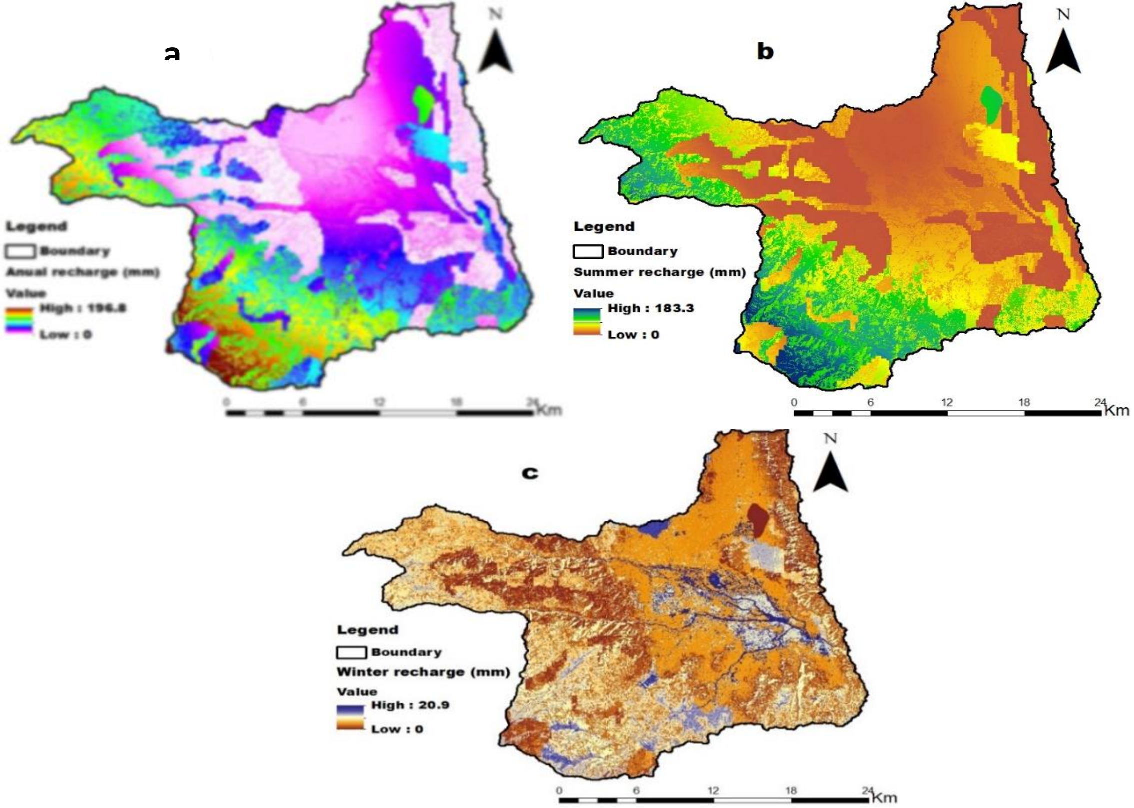
Outputs of WetSpass Model

The primary outputs of the WetSpass model consist of raster maps illustrating annual and seasonal groundwater recharge, surface runoff, and actual evapotranspiration spanning from 2000 to 2021. These maps are structured so that each pixel represents the magnitude of the corresponding water balance component, measured in millimeters. In essence, these raster maps provide a detailed visualization of the spatial distribution and variation of groundwater recharge, surface runoff, and evapotranspiration across the study area over the specified time period.

Groundwater recharge

The seasonal and annual groundwater recharge within the Hormat-Golina watershed exhibits spatial variability influenced by basin characteristics and topography (Figure 5). According to the WetSpass model, the annual long-term groundwater recharge in the sub-basin ranges from 0 mm to 196.8 mm, with a mean value of 55.4 mm. This mean recharge represents only 8% of the areal average rainfall. Temporal variability indicates that 83% of recharge occurs during wet periods, while 17% occurs during dry periods. Annually, approximately 4.2*10^5 m^3 of water is replenished into the groundwater from the entire watershed area of 698.25 km^2.

The mean annual spatial groundwater recharge varies significantly across the sub-basin (Figure 5). The southern and western highlands exhibit high annual groundwater recharge due to factors such as permeable soils, elevated rainfall, and dense vegetation cover. Similarly, the western foothill areas experience high groundwater recharge, attributed to their flat topography and coarse permeable soils. Conversely, the lowlands and central southeastern regions display low



groundwater recharge, largely due to their function as discharge areas and the prevalence of less permeable fine-textured soils. Forested areas with sandy-textured soils demonstrate high groundwater recharge, benefiting from the high permeability of sandy soils and minimal runoff on the gentle slopes. Conversely, bare land with clay soils shows low infiltration, contributing to increased surface runoff (Table 3).

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

	Settlement	Bare land	Agriculture	Grassland	Wetland	Forest	Shrub land	Mean
Sandy loam	80	50	142	71	115	150	130	105
Silty loam	40	30	85	53	80	115	103	72
Silty clay loam	36	22	41	35	30	–	35	33
Clay loam	42	30	143	90	52	96	35	70
Mean	50	33	103	62	69	120	76	

Figure 5*:* Ground water recharge map of Hormat-Golina sub-basin.

Actual evapotranspiration

The WetSpass model estimates the mean annual evapotranspiration for the Hormat-Golina sub-basin at 616.7 mm, representing approximately 78% of the area's annual average rainfall. This underscores evapotranspiration as the primary water loss process in the sub-basin, largely attributed to high radiation rates and the presence of strong dry winds. The seasonal distribution shows that a higher proportion of evapotranspiration occurs during the summer season (62%), with the remaining 38% occurring during the winter season. Notably, actual evapotranspiration during the summer season surpasses that of the winter period by 24%, reflecting the bimodal nature of precipitation in the region.

Areas with lower elevation within the sub-basin exhibit higher annual evapotranspiration rates. Additionally, regions experiencing higher precipitation, such as the Gaba basin, also demonstrate elevated evapotranspiration levels. Consequently, evapotranspiration accounts for a significant portion of the average rainfall, emphasizing its role in water loss within the sub-basin (Figure 6).
Spatial variations in evapotranspiration were further analyzed by integrating average annual evapotranspiration with different land-use and soil classes. Regions characterized by water availability in the soil texture and high transpiration rates from vegetation, particularly forests, grasslands, and shrubs with sandy loam and clay soil textures, exhibit higher evapotranspiration rates (table 4).

Table 4: Simulated mean annual evapotranspiration for combinations of land-use and soil texture.

	Settlement	Bare land	Agriculture	Grass land	Wet land	Forest	Shrubs	Mean
Silty clay loam	520	500	518	580	580	----	547	541
Sandy loam	605	642	590	695	710	671	712	661
clay loam	640	656	646	730	650	710	692	675
silty loam	569	590	539	639	674	654	619	612
Mean	584	597	573	661	654	678	643	

Surface runoff

Surface runoff within the Hormat-Golina sub-basin exhibits spatial variability influenced by slope and other catchment characteristics (Figure 7). The simulated annual surface runoff in this sub-basin ranges from 21.9 mm to a maximum of 448 mm, with a mean value of 156.4 mm. This mean runoff represents approximately 19% of the total mean annual precipitation for the area, amounting to about 1.2 million cubic meters for the entire basin. Seasonally, 53% of the runoff occurs during the summer season, with the remaining 47% occurring during the winter season.

The western highlands of the Hormat-Golina watershed demonstrate the highest mean annual surface runoff, characterized by clay and silty loam soils with low permeability, leading to increased surface runoff. Conversely, the northern and central parts of the watershed exhibit the lowest runoff, attributed to the presence of sandy loam soils. Clay loam soils, along with settlement and wetlands, contribute to high runoff generation, whereas grasslands and forests with sandy loam soils contribute less to runoff (Table 5). Additionally, highland areas experiencing relatively high rainfall produce more runoff compared to valley floors with lower rainfall.

Table 5: Mean annual surface runoff for different combinations of land-use and soil texture.

	Settlement	Bare land	Agriculture	Grassland	Wetland	Forest	Shrubs	Mean
Silty clay loam	142	130	133	120	136	–	131	132
Clay loam	210	205	201	179	220	175	185	196
sandy loam	37	20	29	19	13	14	22	22
Silty loam	58	38	34	33	30	31	31	36
Mean	112	98	99	88	100	73	92	

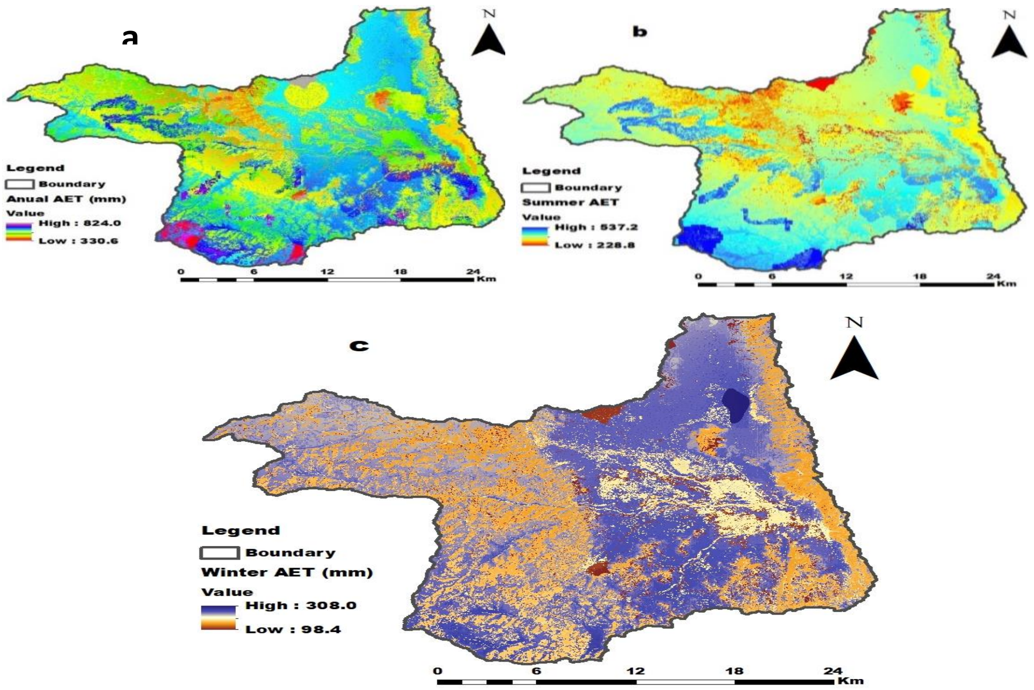


Figure 6. Actual evapotranspiration from Hormat-Golina sub-basin.

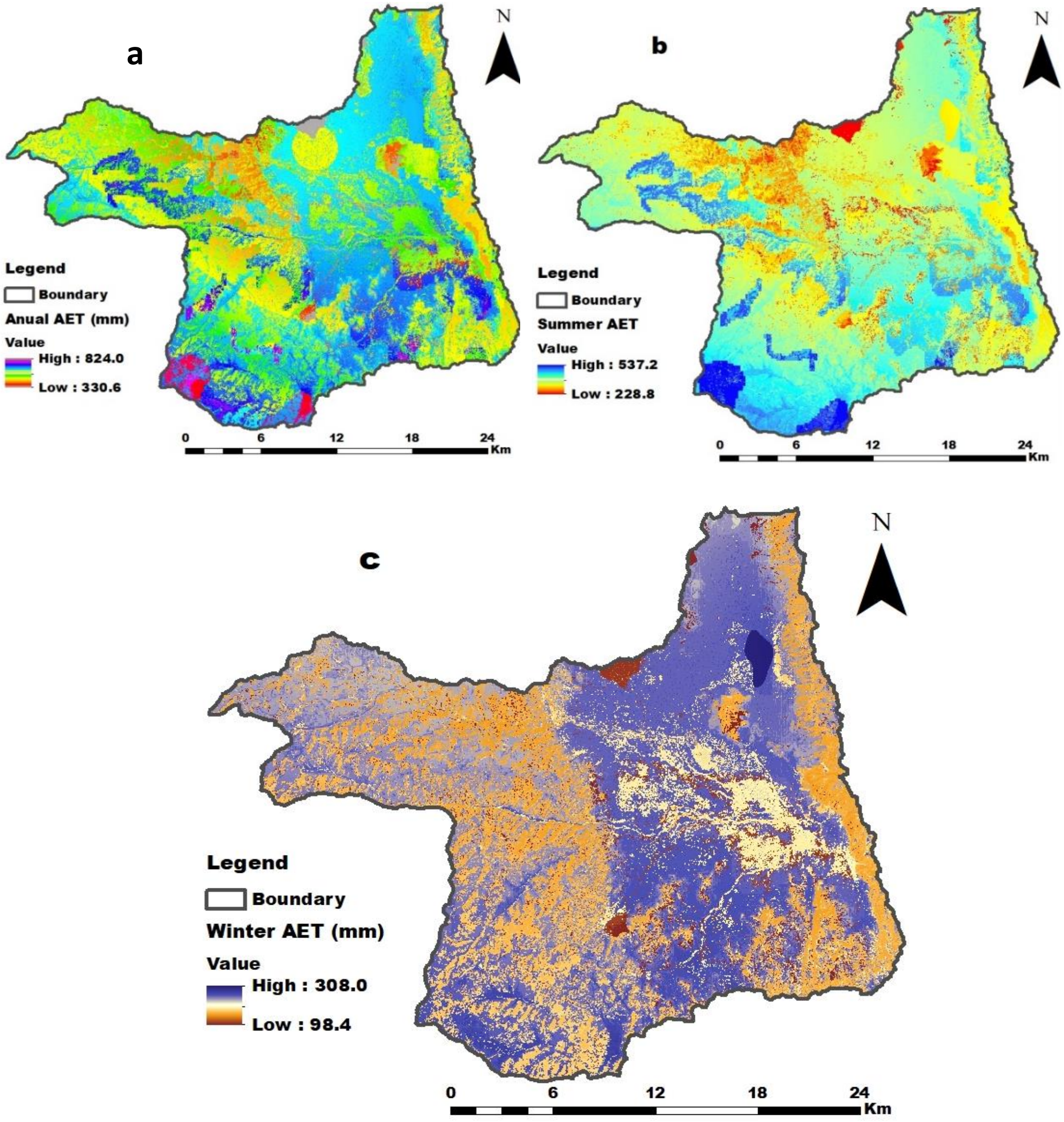


Figure 7. Surface runoff from Hormat-Golina sub-basin.

Water balance components

The comprehensive water balance analysis of the Hormat-Golina sub-basin, as shown in Table 6, highlights that only a small portion of the annual rainfall contributes to recharging the groundwater reservoir within the watershed. The majority of the rainfall is lost from the watershed primarily through evapotranspiration, with a smaller proportion exiting via surface runoff. The higher standard deviation values observed in the water balance components signify significant spatial variation in these elements within the basin. This variability is predominantly driven by the uneven distribution of climatic parameters, influenced by variations in land use/land cover, soil type, topography, and slope across the sub-basin.

Table 6: Water balance components of Hormat-Golina watershed

Water balance components	Annual values (mm/year)			
	min	max	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			

CONCLUSION

The WetSpass model was employed to estimate the spatially distributed long-term average recharge of the Hormat-Golina sub-basin. The model output revealed that the mean annual recharge in the basin amounted to 55.4 mm, representing approximately 8% of the mean annual rainfall. Annually, a total of 4.2*105 m3 of water was added to the watershed. Seasonally, recharge accounted for 83% during the wet season and 17% during the dry season. Areas characterized by sandy textured soils and forest land use exhibited higher recharge rates, whereas lower recharge was observed in clay soils with settlement.

The WetSpass model proved to be suitable for analyzing the impact of land use changes on the water balance of the watershed, demonstrating its effectiveness in simulating groundwater recharge in the Hormat-Golina sub-basin. Additionally, the model estimated 616.7 mm of evapotranspiration, which represents 78% of the annual rainfall in the catchment. Evapotranspiration emerged as the primary process of water loss in the area, driven by the presence of strong dry winds and high radiation.

Water balance analysis results indicated that the majority of annual rainfall was lost from the sub-basin through surface runoff and evapotranspiration, with only a small fraction contributing to groundwater recharge. This underscores the importance of understanding and managing these processes to ensure sustainable water resource management in the region.

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