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Groundwater Recharge Assessment Using WetSpass and MODFLOW Coupling: The Case of Hormat-Golina Sub-basin, Northern Ethiopia

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Abstract: Water scarcity in northern Ethiopia, as well as its socio-economic relevance in terms of water demand for agriculture and domestic use, are at the root of the search for new groundwater resources and the development of groundwater models that can be used to control and manage the resource. The groundwater recharge of the Hormat-Golina sub basin was assessed using WetSpass-MODFLOW coupling. The goal of this paper is to assess the groundwater recharge in the Hormat-Golina sub-basin. These findings are then used to simulate the hydraulic head distribution using the MODFLOW groundwater flow simulation model. By comparing measured and simulated hydraulic heads, the steady state groundwater flow calibration was obtained. WetSpass calculated the mean annual evapotranspiration, surface runoff, and groundwater recharge to be 516.6, 204.9, and 35.6 mm, respectively. Groundwater recharge accounted for 4.7% of precipitation, while actual evapotranspiration and surface runoff accounted for 27% and 68% of precipitation, respectively. In such seasonal variations, the groundwater head distribution is 9.37 to 29.86 m in the winter (dry season), 9.53 to 29.89 m in the summer (wet season), and 9.58 to 30.17 m in the annual stress periods (recharges). For all stress periods, the estimated hydraulic heads in steady state fit well with the measured ones, with a correlation coefficient of 0.86 (summer, winter, and annual recharge). 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 valley.

Keywords: Ethiopia, Groundwater Recharge, Hormat-Golina, MODFLOW, WetSpass

1. Introduction

"Water has always been a valuable resource for humans." Not only do humans utilize it virtually every day, but it will be required to measure everything physical. Despite the fact that water is a natural resource, the world's supply of clean water is constantly decreasing. Increased global demand for potable water has resulted in a persistent water scarcity problem in many places around the world [1].

In hydrogeologic research for sustainable groundwater development, determining groundwater recharge has evolved from a basic problem to an urgent and fundamental issue [2]. It's worth mentioning that the bulk of methods for evaluating groundwater recharge do so over a small area (point or small basin scale) and over short periods of time [3].

The most difficult and uncertain components to estimate in the groundwater budget are recharge and evapotranspiration rates. This is due to the fact that they frequently change in space and time, particularly in dry and semi-arid environments [4, 5]. With the introduction of Geographic Information Systems (GIS) [6], physicallybased hydrologic modeling has become essential in contemporary hydrology as a cost-effective means of monitoring the water balance at a spatial scale. The spatial variance in recharge caused by scattered land use and land cover, soil texture, topography, and meteorological conditions are all essential factors to consider when estimating recharge [7, 8].

Groundwater recharge is one of the most significant parameters to consider when assessing a resource. Scientific research in the Hormat-Golina Sub-basin was not undertaken in accordance with the quantification and mapping of groundwater recharge area in the sub-basin. The components of the water balance were not properly defined and the hydraulic head distribution in relation to stress was not modeled. Lack of good understanding of groundwater recharge was a serious concern for sound and suitable groundwater management in the sub-basin, given the high pace of population growth and increased reliance on groundwater. As a result, estimating groundwater recharge in the area is critical for resource sustainability as well as protection against pollution and depletion. As a result, this research might be started to quantify groundwater recharge, runoff, evapotranspiration, and groundwater head /hydraulic head/ in the study area. The goal of this research is to quantify the groundwater recharge of the Hormat-Golina sub basin by Wetspass and MODFLOW coupling with several spatial and hydrological information. MODFLOW was used to simulate the hydraulic head distribution using the groundwater recharge distributions acquired by WetSpass.

2. Materials and Methods

2.1. Description of the Study Area

The research was conducted in northern Ethiopia. It is defined by latitudes of 11°55'35" to 12°13'10" north and longitudes of 39°24'45" to 39°47'44" east (figure 1). It is known as the Hormat–Golina sub-basin and encompasses a total area of 689.25 km^2. It is bordered on the west by the Lasta Mountains, on the east by the Zobel Mountains, on the north by the Raya Valley, and on the south by volcanic ridges. It is regarded as being a part of the Ethiopian rift system that interconnects the valleys.

The Hormat-Golina sub-basin features an open surface water drainage system that opens into the Afar region at the Golina outlet. It is located within the Denakil dry basin. The basin is drained by three major streams that originate in the western highlands. These are the steams: Golina, Hormat, and Kelkelit (figure 1).

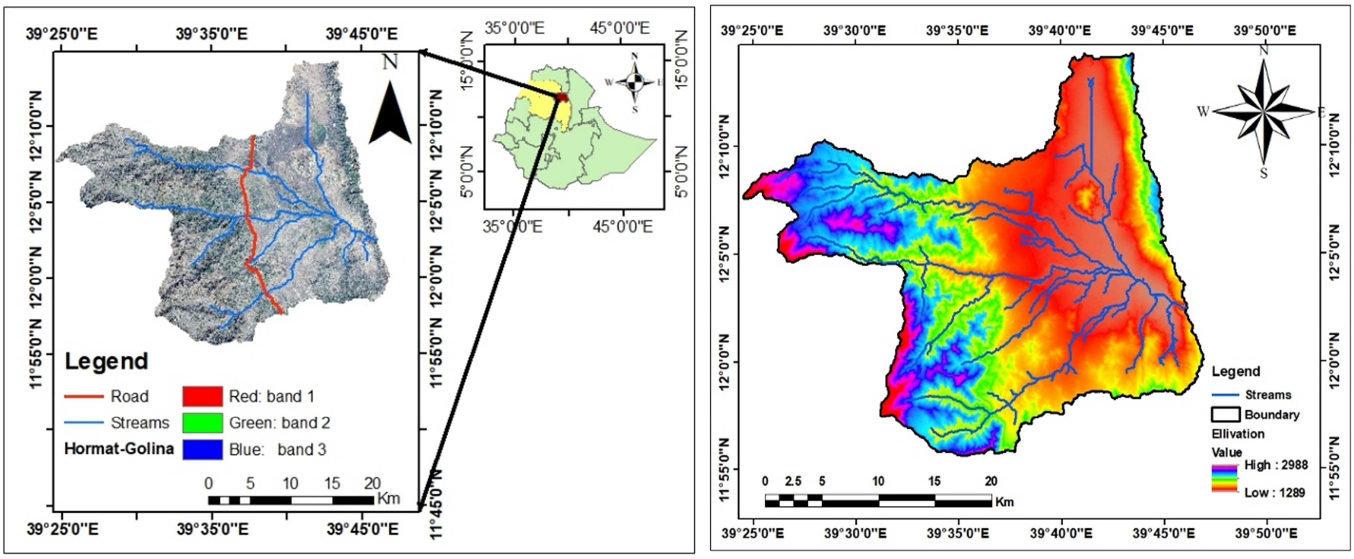

Figure 1. *Location map and Drainage of the study area.*

During the rainy season, all streams and ravines convey significant volumes of sediment from the mountains and dump them on the valley plain. The climate of the Hormat-Golina bub-basin is semi-arid in the valley plain and sub-humid in the hills. In the valley plain, the average yearly temperature ranges from 17.5 °C to 26 °C, with an average annual temperature of 21.6 °C. The sub-basin average annual rainfall is estimated to be around 756.85 mm with a potential evapotranspiration of 1669.6 mm during the study period between 2000 and 2019.

2.2. Recharge Modeling Approach

The groundwater recharge of the Hormat-Golina subbasin was assessed using a WetSpass and MODFLOW coupling. The data interchange between MODFLOW and WetSpass is guaranteed until the recharge rates and hydraulic heads have stabilized. The first simulation was run using the WetSpass model with a variety of input data. MODFLOW was used to simulate groundwater head using the calculated groundwater recharge.

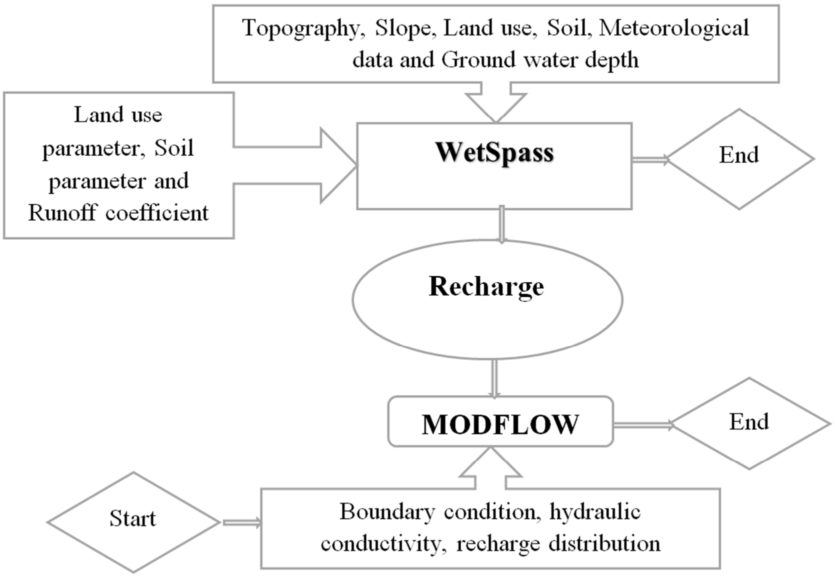

Figure 2. *Recharge assessment approach.*

WetSpass solves the water balance equation cell by cell for the vegetated area, bare soil, open water, and impermeable surfaces, allowing for the calculation of surface runoff, actual evapotranspiration, and groundwater recharge for seasonal periods [9]. The water balance for a vegetated area is estimated using the equation below [10];

$$P = I + Sv + Tv + Rv \quad (1)$$

where P is the average seasonal precipitation, I is the interception fraction, Sv is the surface runoff, Tv is the actual transpiration, and Rv is the groundwater recharge, all in [LT-1].

The interception (I) is calculated first. It is a fixed percentage of the annual precipitation amount. It is primarily determined by the type of plant. Second, the relationship between precipitation amount, precipitation intensity, interception, and soil infiltration capacity are used to determine surface runoff (S). There are two stages to estimating surface runoff. Firstly, calculate the potential surface runoff (Sv-pot) as follows:

$$S_{v-pot} = C_{sv}(P - I \quad (2)$$

where Csv is the surface runoff coefficient for vegetated regions; it varies with vegetation, soil type, slope, and groundwater saturated areas; P is the average seasonal precipitation [LT–1], and I is the interception fraction [LT–1]. Second, S is computed by taking seasonal precipitation intensities into account with respect to soil infiltration capabilities [10].

$$S = C_{HOR} S_{v-pot} \quad (3)$$

where CHOR is a coefficient parameterizing seasonal precipitation, which contributes to the Hortonian overland flow [11]. It considers the effective precipitation contributing to runoff.

The evapotranspiration is computed using open-water evaporation and the vegetation coefficient, which is the ratio of reference vegetation transpiration to the potential open-water evaporation [10]. First, the reference transpiration is calculated using a fraction of the open-water evaporation:

$$T_{rv} = cE_0 \quad (4)$$

Where Trv is the reference transpiration of a vegetated surface [LT–1], E0 is the potential open-water evaporation [LT–1], and c is the vegetation coefficient, which can be calculated as the ratio of reference vegetation transpiration to potential open-water evaporation [10].

When the groundwater is above the root depth, WetSpass calculates evapotranspiration in a vegetated area by taking into account the root depth and the tension saturation height; otherwise, evapotranspiration is calculated as a function of water content. Finally, the result of the water balance is used to compute the groundwater recharge for the vegetated area:

$$Rv = P - Sv - ETv - Es - I \quad (5)$$

where R denotes groundwater recharge, P denotes precipitation, Sv denotes surface runoff, ETv denotes actual evapotranspiration, and I indicate interception fraction, all with the unit [LT–1].

On the other hand, there is no interception and transpiration term in the calculation of the water balance for bare soil, open water, and impervious surfaces due to the fact that there is no vegetation, so the ETv becomes Es. The water balance components of each area are then used to calculate the total water balance using the following equations [10]:

$$\mathrm{ET}a = avETv + asEs + aoE0 + aiEi \quad (6)$$

$$Sa = vSv + asSs + aoRo + aiRi \quad (7)$$

$$R\,a = vRv + asRs + aoRo + aiRi \quad (8)$$

Where ET, S, and R are the whole evapotranspiration, surface runoff, and groundwater recharge of a raster cell respectively, each having vegetated, bare-soil, open water and impervious area component denoted by av, as, ao, and ai, respectively.

2.3. WetSpass Input Data

The input data includes topography, slope, and soil texture grids, as well as seasonal grids of groundwater level, land use, and meteorological data (precipitation, wind speed, temperature, and potential evapotranspiration). The attribute tables for land use and soil are linked to the model [12]. The different inputs of the model are prepared using Geographic Information Systems (ArcGIS 10.7 and ArcView GIS 3.3). The cell size is 30 m × 30 m with columns and rows of 1356 and 1149.

The input and output grids are then configured to have identical coordinate projections and lateral extents using the resample tool of ArcGIS, because the determined recharge by WetSpass is utilized for the groundwater flow model MODFLOW. The period 2000–2019 is used to process meteorological data (precipitation, evapotranspiration, temperature, and wind speed), with an average value for each seasonal time step, i.e., the winter /dry/ and summer /wet/ seasons, which correspond to the months of October to May and June to September, respectively. During the steady state, this period corresponds to the groundwater flow model calibration. The database file format (dbf) was used to prepare the input files for land use, soil texture, and runoff coefficient, which were generated as parameter tables.

Table 1. *WetSpass input parameters.*

Input variables		Sources
1	Topography	DEM (12.5*12.5m) resolution
2	Slope	DEM (12.5*12.5m) resolution
3	Land use land cover	Landsat 8 and own processing
4	Soil textural class	FAO web page
5	Temperature (summer & winter)	National meteorological agency
6	Precipitation (summer & winter)	National meteorological agency
7	PET (summer & winter)	Estimated by using R-programming
8	Wind speed (summer & winter)	National meteorological agency
9	Depth to groundwater	Direct measurement from existing boreholes
10	Soil parameter, runoff coefficient and Land use parameters	WetSpass user guide

The average seasonal precipitation was computed for seven metrological stations. It was calculated from daily precipitation data measured for the period 2000 to 2019 for 20 years. The spatial precipitation is produced using the inverse distance weighting (IDW) method. It is the most commonly used method because it is easy and gives generally good results [13].

It's especially useful when the rainfall network is dispersed unevenly. The precipitation values range from 236.7mm to 334.6mm for the winter with a mean of 297.03mm (Figure 3a) and from 350.6 mm to 586.8 mm for the summer with a mean of 459.9mm (Figure 3b). High values are located mainly in the western parts of the Hormat-Golina sub basin. The mean annual precipitation of the Hormat-Golina sub basin was 756.85mm.

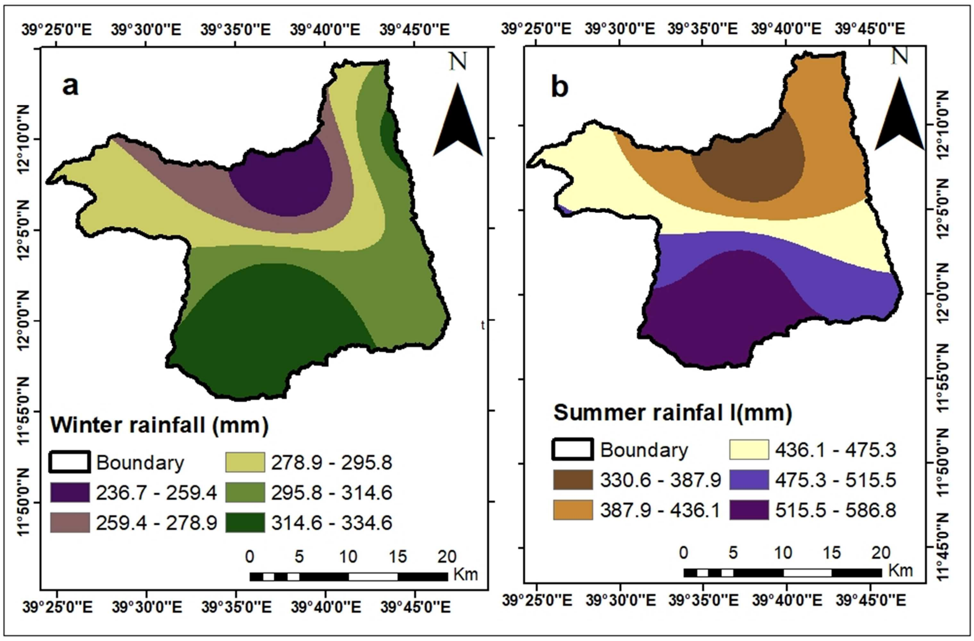

Figure 3. *Rainfall distribution map of Hormat-Golina sub basin.*

Due to the absence of data, the PET was calculated using the Hargreaves equation [14], which is justified in semiarid areas when only the temperature is available as climatic data. If there is inadequate meteorological data for the Penman-Monteith approach, the FAO recommends the Hargreaves method [15] as an alternate method for predicting PET.

The average monthly PET was calculated during the period 2000–2019 for seven (7) stations using monthly average temperature values. The highest value (1076.7 mm) was recorded during the dry season /winter/ season (October to May). The winter/dry/season had minimum and maximum values of 1020.7mm and 1076.7mm, with a mean value of 1048.8mm (figure 4a), while the summer/wet/season had minimum and maximum values of 590.4mm and 620.6mm, with a mean value of 620.6mm (figure 4b). In the winter/dry/ season (figure 4a), the minimum and maximum values of 590.4 mm and 620.6 mm, with a mean value of 620.6 mm, for the summer /wet/ season (figure 4b).

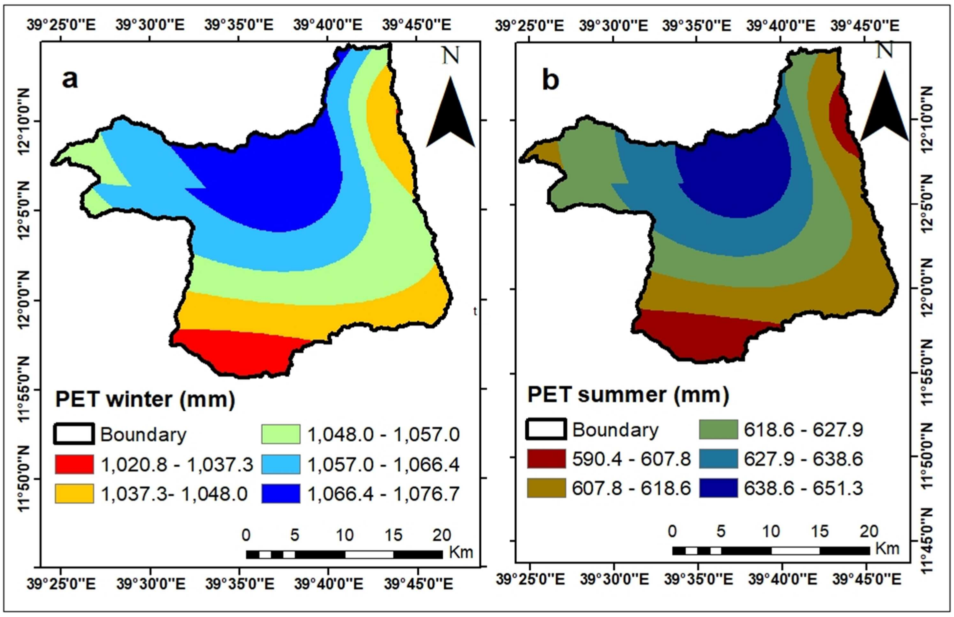

Figure 4. *Potential evapotranspiration of Hormat-Golina sub basin.*

The average temperature and wind speed were also computed for the same weather station using monthly measured values during the period 2000–2019. The minimum and maximum temperatures for the dry season /winter) ranged from 18.6°C to 21.6°C (figure 5a) with a mean value of 20.4°C, whereas the minimum and maximum temperatures of the summer /wet/ season ranged from 20.1°C to 24°C (figure 5b) with a mean value of 22.5°C.

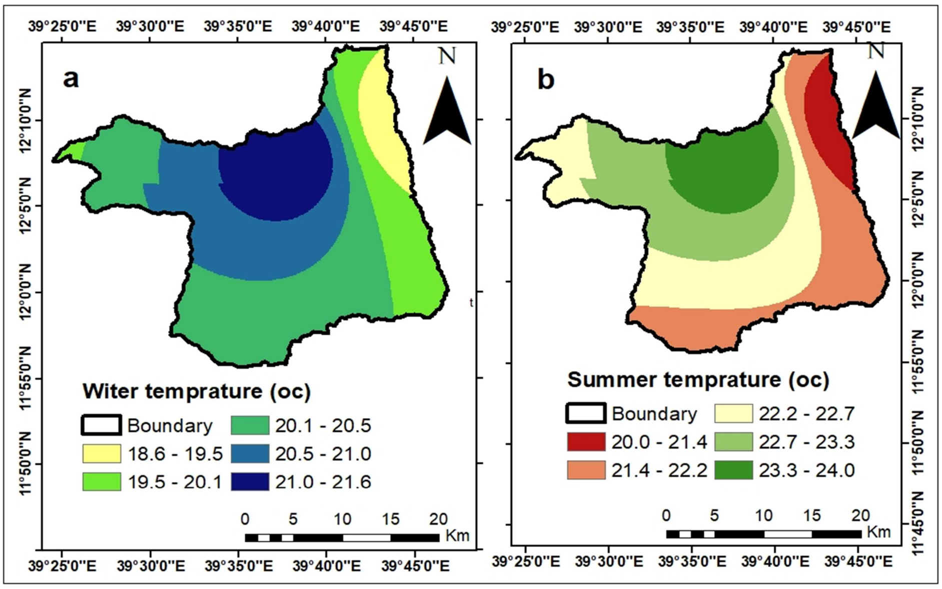

Figure 5. *Average temperature of Hormat-Golina sub basin.*

In the Hormat-Golina sub-basin, the average summer wind speed is 1.99 m/s with the minimum and maximum values ranged from 1.67 m/s to 2.1 m/s (*figure* 6b), while the average winter wind speed is approximately 1.66 m/s with minimum and maximum values ranged from 1.58 m/s and 1.89 m/s (*figure* 6a).

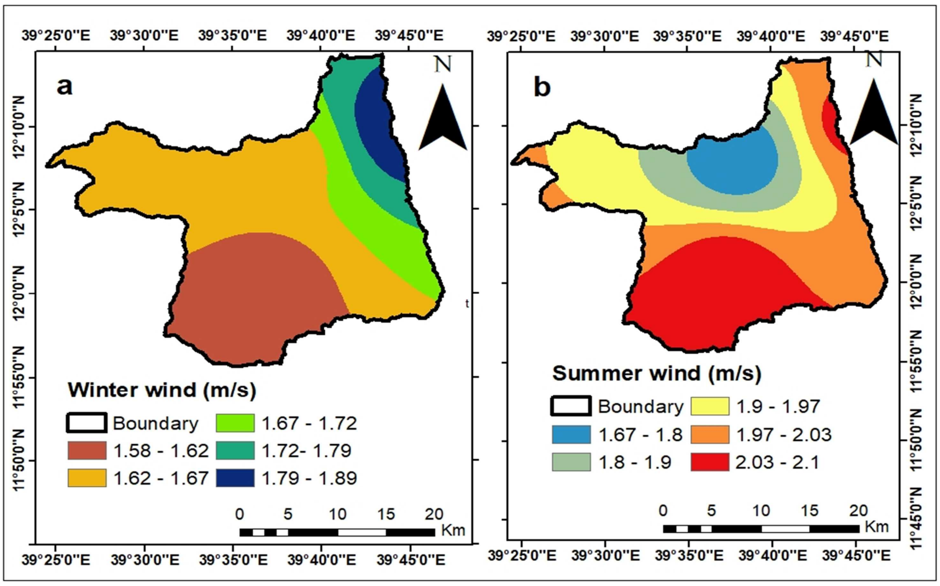

Figure 6. *Average wind speed of Hormat-Golina sub basin.*

The Alaska satellite facility (ASF) data set was used to create an elevation and slope map of the study area. The ASF provides a digital elevation model with a resolution of 12.5*12.5m (DEM). The sub-basin's highest point, at 2988 meters, is found upstream on the western escarpment, while the lowest point, at 1289 meters, is found in the eastern/downstream section. Slope is an important component in determining the watershed's hydrological features. It is categorized according to the degree of steepness, which ranges from 0 to 43^0. The value of 0^0 represents gentle/lowland, while the value of 43^0 represents steep/escarpment.

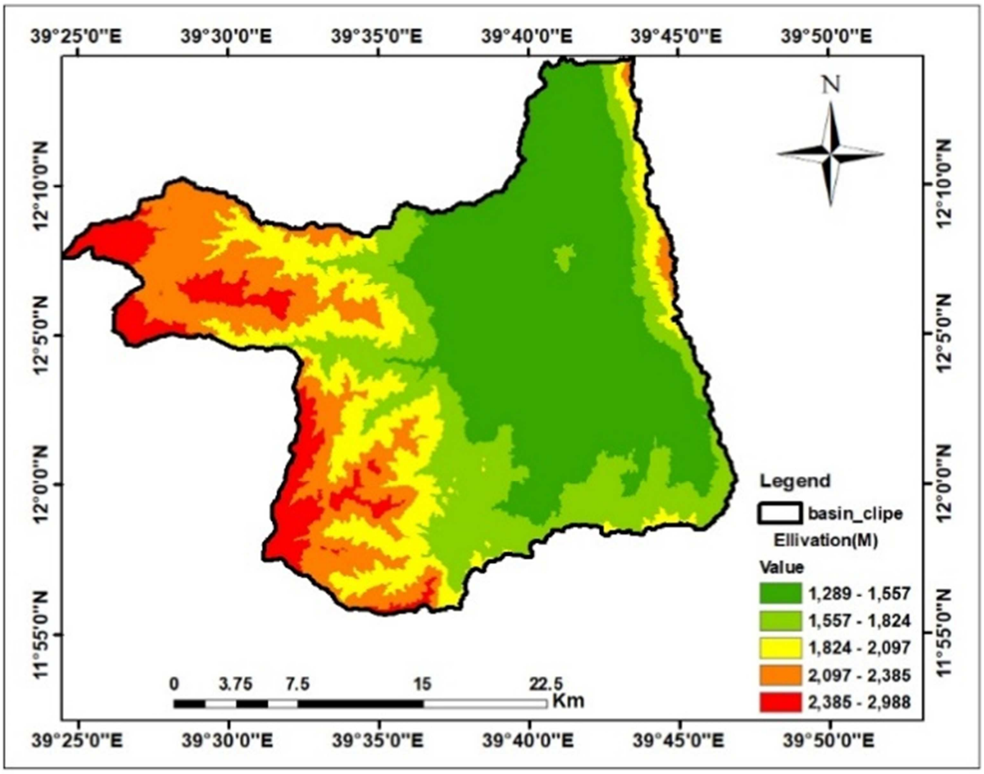

Figure 7. *Elevation of the area.*

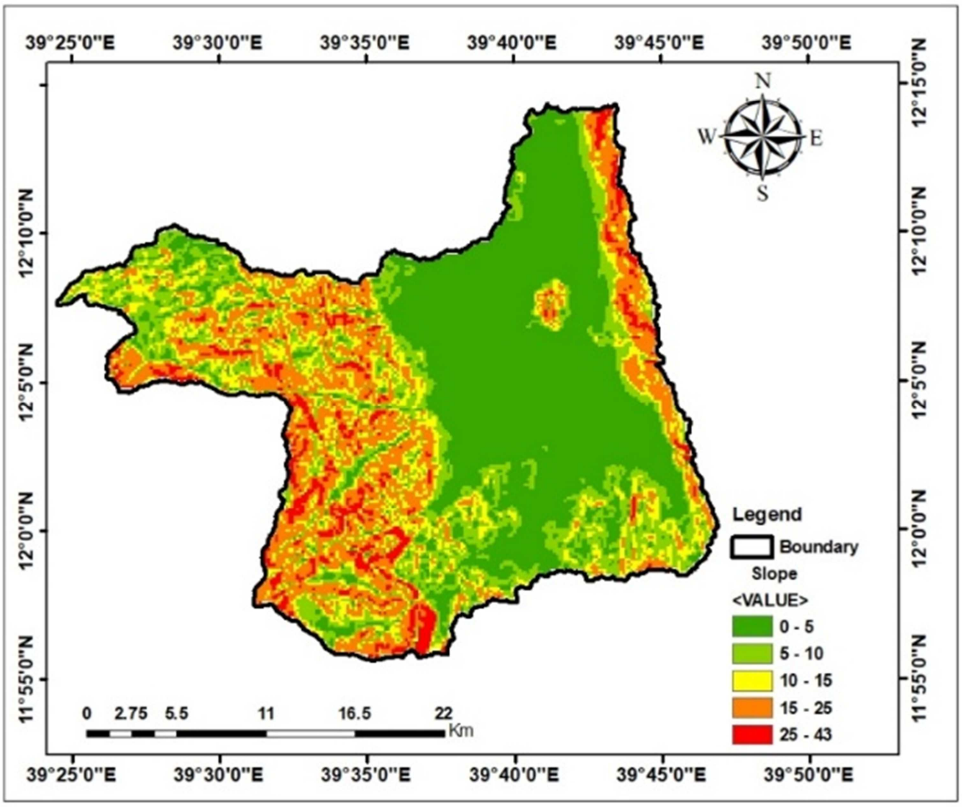

Figure 8. *Slope of the area.*

The land use grid was prepared from Landsat 8 products by supervised land use classification using bands from 1 to 7. As indicated by the figure (figure 9), the dominant land use of the sub basin was agriculture, which accounted for 49.7% of the total area, followed by shrubs (37.3%), bare land (9.3%), riverain vegetation 1.6%, trees/forest 1.4, and settlement accounted for 0.7%.

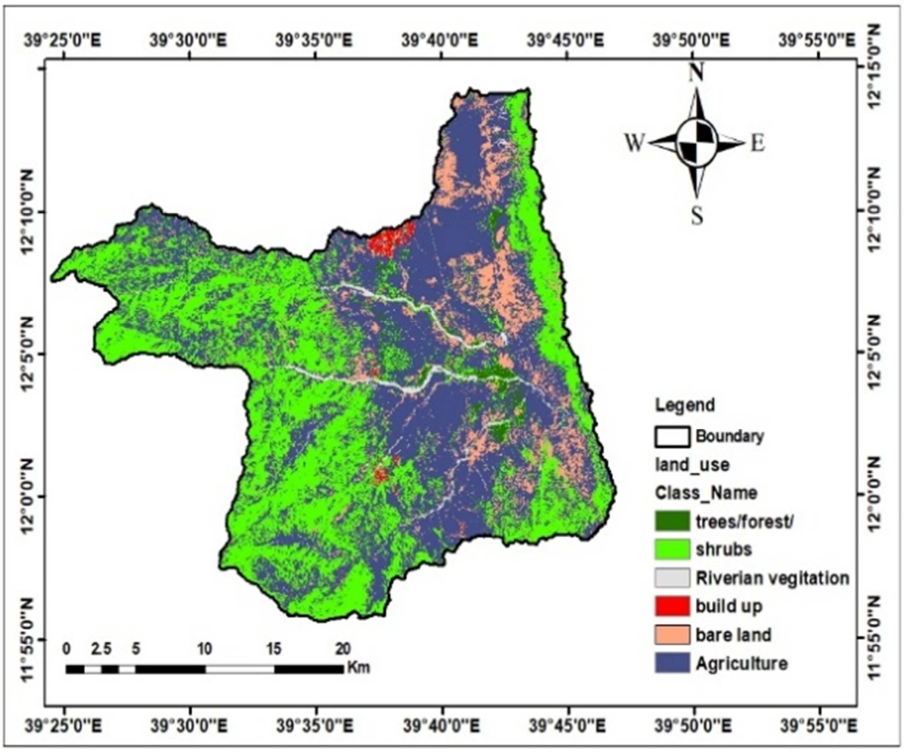

Figure 9. *Land use of the area.*

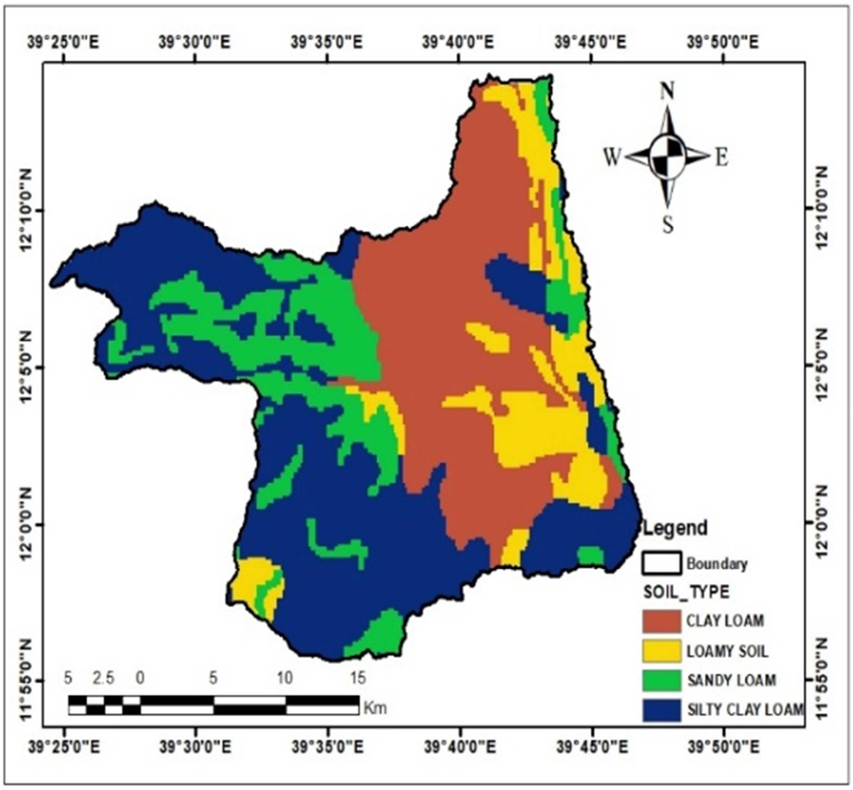

Figure 10. *Soil map of the area.*

The Hormat-Golina sub basin soil texture map was downloaded from the Food and Agriculture Organization (FAO) website (http://www.fao.org). Using the United States Department of Agriculture (USDA) textural categorization standards, the soil texture of the research region was divided into four classes: sandy loam, silty clay loam, loam, and clay loam (Figure 10). Silty clay loam covers the majority of the land.

The groundwater depth for the WetSpass model was collected by direct measurement from the Kobo Girana Valley Development project and interpolated by IDW interpolation, and it ranged from 11.8m to 27 m with an average value of 21.3m (figure 11).

2.4. Development of Groundwater Flow Model

The groundwater flow model was created using Visual MODFLOW 2005 software. The model's construction consists of a set of possible assumptions that reduce the real situation and result in a conceptual model that is appropriate for the modeling goal. The following assumptions were made about the modelled area: (i) the system was assumed to be in a steady state throughout the year, and (ii) the geological formations of concern were assumed to be horizontal in extent.

To build the model, MODFLOW requires three input packages to build a model: (i) wells, (ii) model properties, and (iii) model boundary conditions. Data from boreholes was gathered from the Kobo Girana Valley Development Project. Two types of well data were prepared during this process: (i) pumping wells and (ii) observation wells. Water levels were generated during aquifer pumping using data from pumping wells. For the model, data was collected from 34 boreholes, which were then imported into MODFLOW using the import tool. For the purpose of model calibration, observation wells were added to the model. This work required the use of 34 observation wells. The import tool was used to import observation wells into MODFLOW.

MODFLOW divides the model's hydrogeological characteristics into inputs such as flow properties, hydraulic conductivity (Kx, Ky, and Kz), and storage (Ss, Sy). Aquifer parameters and initial heads are among the model property inputs. Log test data was used to determine aquifer properties (transmissivity, hydraulic conductivity, and storage coefficient). Only horizontal hydraulic conductivities were significant since the groundwater flow model was single-layered.

Initial heads were measured directly from existing boreholes and interpolated within the model to produce initial heads for the whole model. The inverse distance weighting (IDW) technique was used to interpolate the observation heads. Recharge was used as a boundary condition in this study.

The model was discretized into 1149 columns and 1356 rows, resulting in 155,844 active cells (figure 12). The grid cell size was 30 m in both the x and y directions, and the modelled domain covered an area of 698.25 km^2.

A groundwater flow model requires hydraulic conductivity, storage, and initial head values for each grid cell in order to run a flow simulation. The values of each property used for model input are shown in table 2.

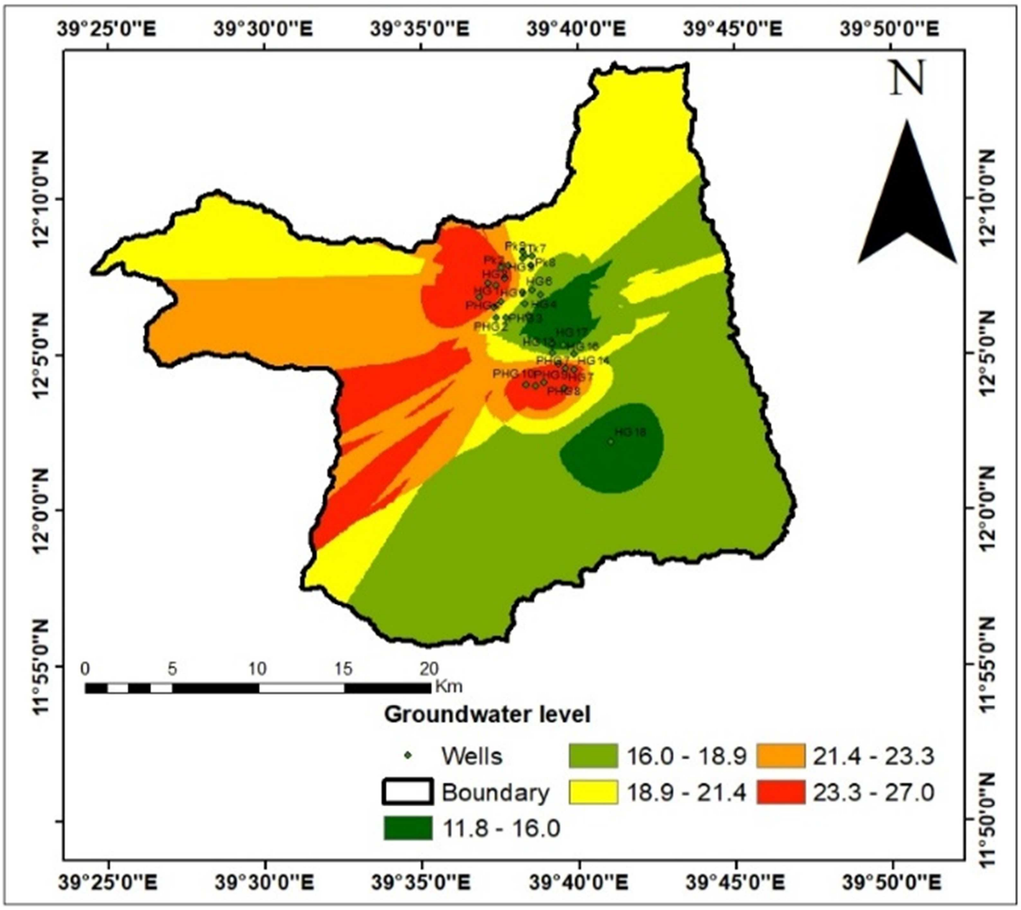

Figure 11. *Groundwater level.*

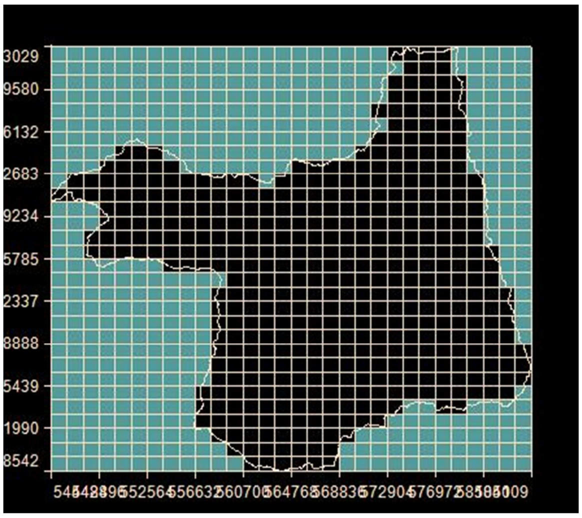

Figure 12. *Discretization of the area.*

Table 2. *Property value for model inputs.*

Parameters	Value
Hydraulic conductivity (m/d)	2.04-48.19
Specific yield	0.2
Initial heads (m)	8-45.75

3. Results and Discussion

3.1. WetSpass Model Simulation

After running the WetSpass model, spatial average grid maps for winter, summer, and annual periods were simulated for the sub-basin. The model produces different grid maps during simulation. The water balance components, such as surface runoff, actual evapotranspiration, and recharge, were produced for the sub-basin. The model simulated results of the Hormat-Golina sub basin were presented in table 3.

Table 3. *Long-term annual and seasonal averages of Wetspass simulated water balance parameters.*

Hydrological parameters	Seasonal average		
	Dry/winter/(mm)	wet/summer/(mm)	Annual average (mm/yr)
Precipitation	297.03	459.95	756.85
Runoff	100.6	104.3	204.9
AET	183.7	334.9	516.6
Groundwater recharge	12.8	22.8	35.6

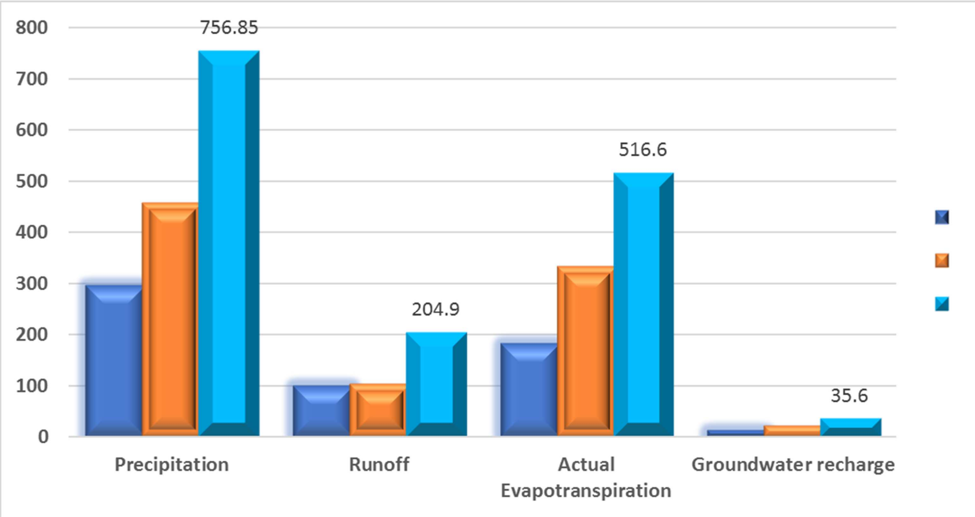

Figure 13. *Comparison of precipitation with model simulated runoff, actual evapotranspiration, and recharge for winter (October-May), summer (June-September), and annual averages.*

3.1.1. Groundwater Recharge

Slope, land use, soil texture, and groundwater level all influence the amount of infiltration-percolation into groundwater replenishment [16].

The result shows an average recharge of 12.8, 22.8, and 35.6 mm was simulated for winter, summer, and on a yearly basis, respectively. The minimum and maximum values are 6.4 and 18.0 mm for dry /winter, -0.65 and 126.72 mm for wet /summer/ and 6.6 and 140.70 mm yearly. Hence, 35.6 mm of annual recharge water is added annually to the available groundwater. The average annual long-term groundwater recharge for the watershed is about 4.7% of the average annual precipitation (756.85 mm) (Figure 13). Considering the area of the sub basin (698.25 km^2), the average annual recharge (35.6 mm) is equivalent to 2.5*107m^{3}year^{-1}.

About 64% of the annual groundwater recharge occurs during the wet season (summer), with the remaining 36% occurring in the dry season (winter) season. The southern and south eastern parts of the sub-basin, which receive more rainfall during the summer season, have a relatively higher rate of annual groundwater recharge that ranges from 64.5 to 140.7 mmyr-1 (figure 14).

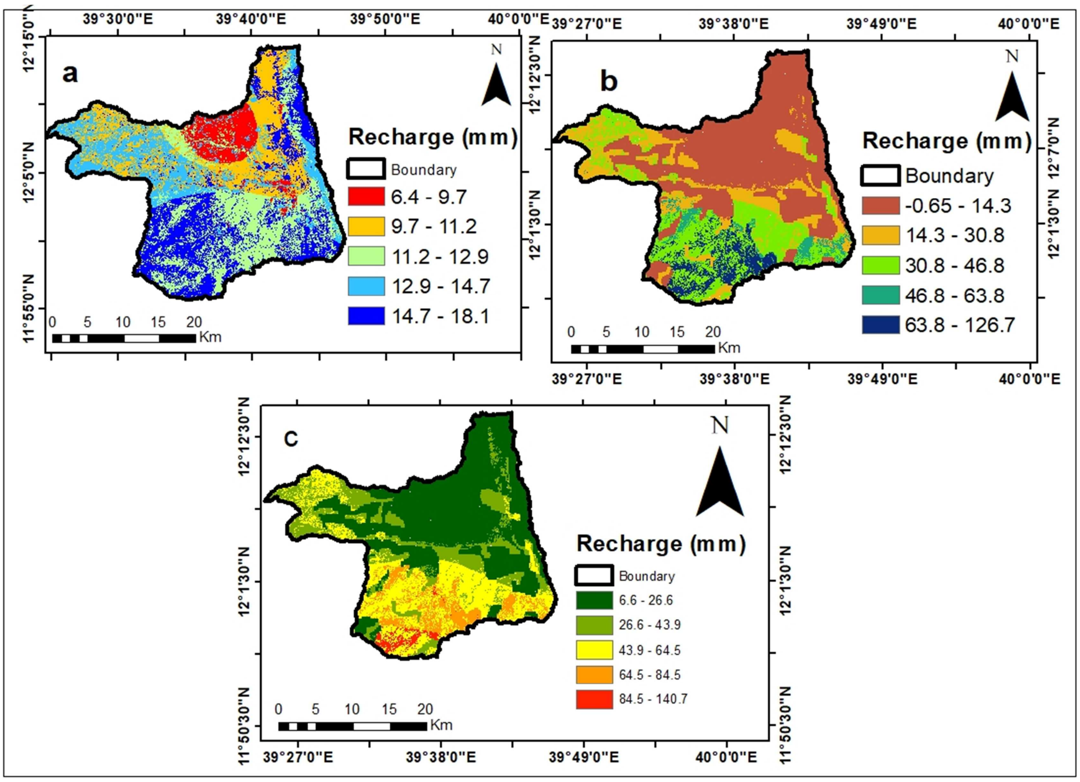

Figure 14. *Ground water recharge map of Hormat-Golina sub basin.*

3.1.2. Water Balance Components

The simulated results from the WetSpass model showed that about 68% of precipitation is lost through evapotranspiration, especially in water courses and shrub areas characterized by sandy loam and silty loam soils. The obtained evapotranspiration values ranged from 342.1 to 758.9 mm/year (*Figure* 15c) with a mean value of 461 mm/year and the seasonal average evapotranspiration was estimated to be 183.7 and 334.9 mm for the winter /dry/ and summer /wet/seasons, respectively.

The minimum and maximum values of dry season evapotranspiration were 111.6mm and 284.6mm (*figure* 15a) and also for the wet season, the minimum and maximum value ranged from 210.8mm to 489.4mm (*figure* 15b). Considering the area of the sub basin (698.25 km^2), the average annual evapotranspiration (461 mm) is equivalent to 3.22*108 m^{3}year^{-1}. Due to active solar radiation, greater surface temperatures, and dry winds in the watershed, evapotranspiration plays a crucial role in water losses.

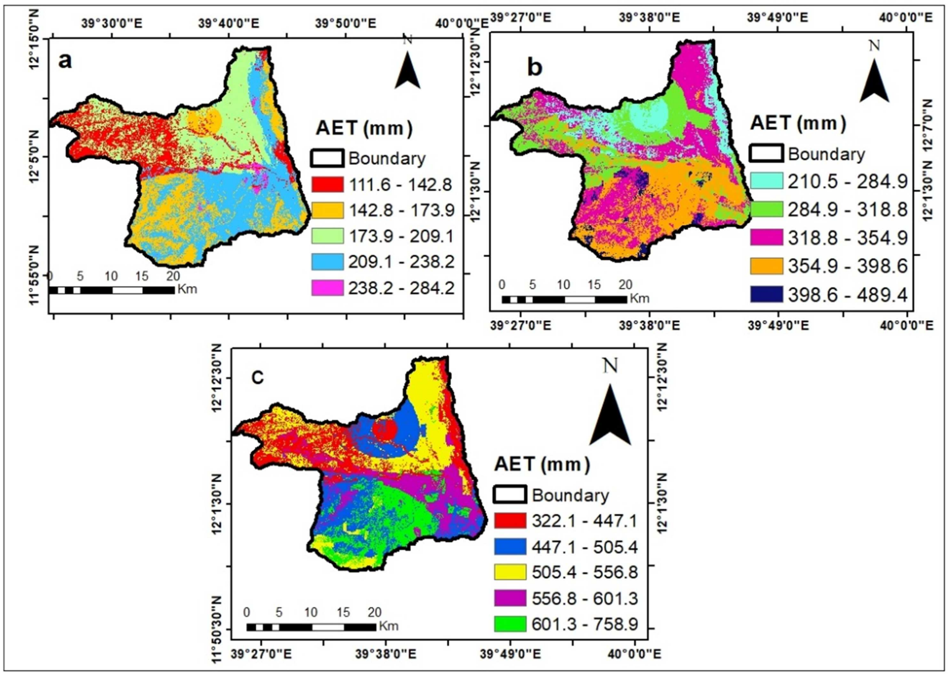

Figure 15. *Actual evapotranspiration from Hormat-Golina sub basin.*

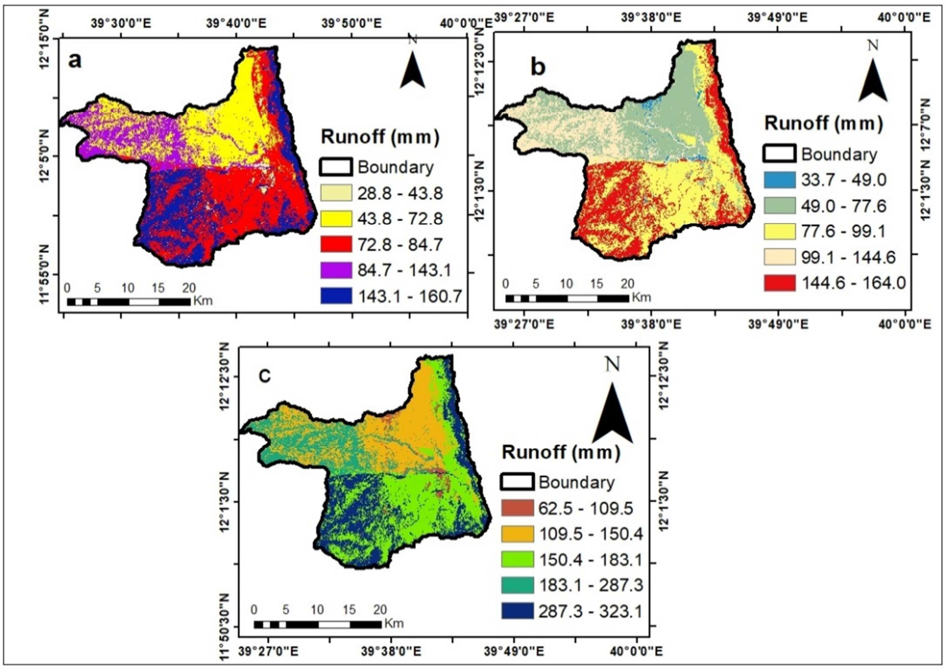

Figure 16. *Surface runoff from Hormat-Golina sub basin.*

Surface runoff is influenced by the availability of vegetation, soil type, and slope of the watershed [11]. Spatially explicit annual and seasonal values of surface runoff simulated by the model are presented in Figures 16 (a–c) and compared with annual precipitation in Figure 13. Seasonal and annual average values of surface runoff are also shown in Table 3.

The surface runoff during the main rainy season from June to September ranges from 33.7 to 164.0 mm with a mean value of 104.3 mm (Figure 16b), while the surface runoff during the long dry season is found at 28.8 to 160.7 mm with a mean value of 100.6 mm (Figure 16a), and the annual surface runoff ranges from 62.5 to 343.1 mm with a mean value of 204.9 mm, which accounts for 27% of the total long-term mean annual precipitation of 756.85 mm (Figure 16C). Because biophysical and hydro-meteorological parameters vary by season and are strongly related to rainfall amount, surface runoff is higher in the summer than in the winter. Considering the area of the watershed (698.25 km^2), the average annual surface runoff (204.9 mm) is equivalent to 1.43*108 m^3 $year^{-1}$.

3.2. Groundwater Head (Hydraulic Head) Distribution with Respect to Stress

The groundwater head in Hormat-Golina Sub-basin has been analyzed by different stress periods (dry season, wet season, and annually). After calibration, the model completed different stress periods. The model result (*Figure* 17a) shows the groundwater head due to dry/winter stress period (recharge) varied from 9.37m in the eastern parts to 29.86m in the Northwestern parts of the sub-basin. While in the wet season /summer/ stress period (recharge) (*figure* 17b), the groundwater head varied from 9.53m in the eastern and 30.89m in the north western parts of the sub basin, and also from the *figure* (*figure* 17c), which shows the groundwater head due to the annual stress period /recharge) varied from 9.58m in the eastern and 30.17m in the north western parts of the sub basin.

From the simulation result, there is a change in the groundwater head by 0.16 m in the eastern and 0.03 m in the northwestern parts of the catchment in dry and wet stress periods, whereas there is no groundwater head change between annual and seasonal stress periods /recharges/. The groundwater head between the dry stress period and the annual stress period varied from 0.21m in the eastern and 0.31m in the northwest parts of the sub basin, and the groundwater head between the wet and annual stress periods varied from 0.05m in the eastern and 0.28m in the northwestern parts of the sub basin.

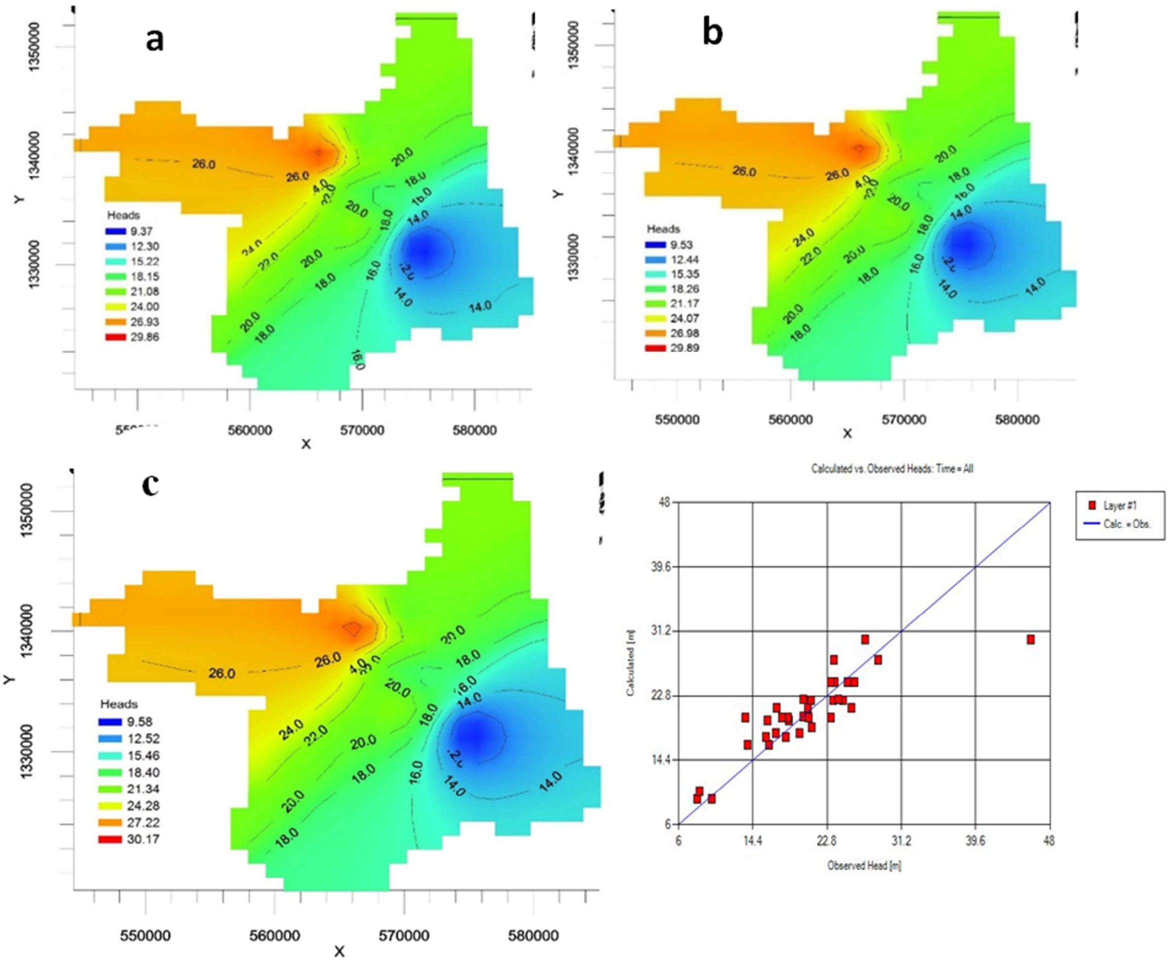

Figure 17. *Groundwater head with respect to stress (recharge) a) winter /dry season/ b) summer /wet season c) yearly.*

Table 4. Model evaluation criteria.

Type of error	Value		
	Winter	Summer	Annual
ME (m)	0.6	0.62	0.62
RMSE (m)	3.54	3.59	3.59
NRMSE (%)	9.38	9.53	9.53
MAE (m)	2.35	2.38	2.38
Correlation coefficient	0.86	0.86	0.86

The validation result indicated a reasonable match between simulated and observed heads with an RMS error of 3.54m, 3.59m, and 3.59m for the winter, summer, and annual stress periods with a correlation coefficient of 0.86 in all stress periods (table 4).

To compare the variation in head distributions, the model generated hydraulic heads under different stress levels were plotted together.

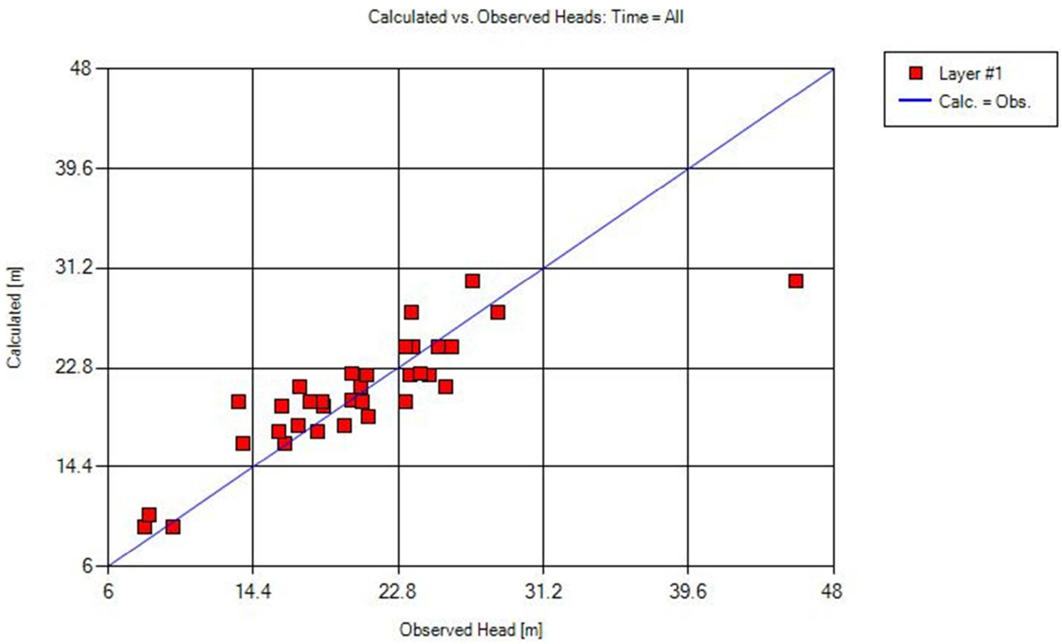

Figure 18. The scatter plots of simulated versus observed.

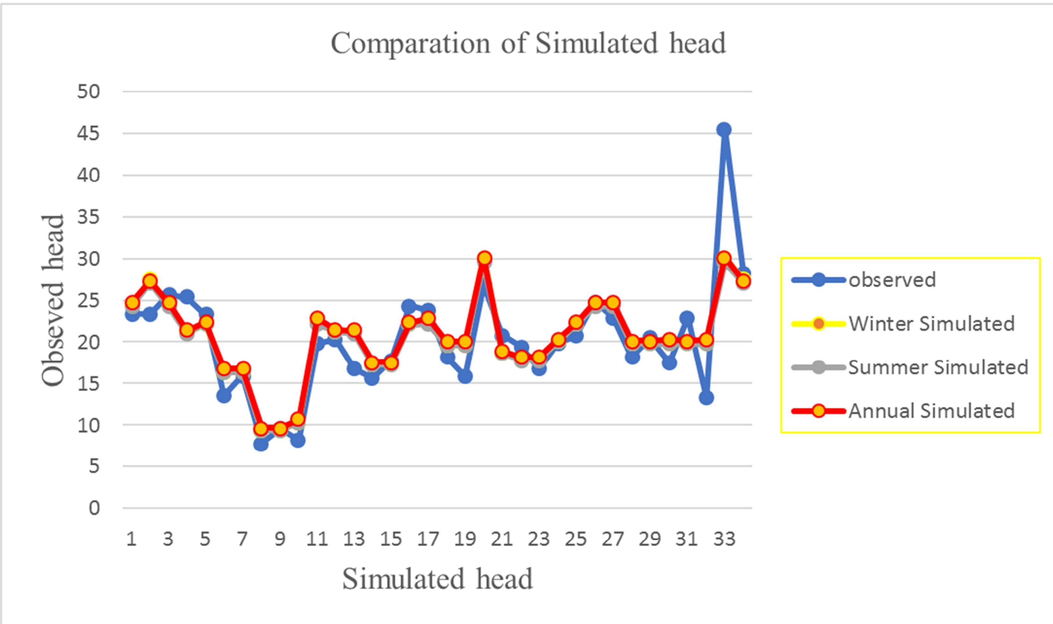

Figure 19. Comparison between the observed and simulated heads of different tress periods.

4. Conclusion

Coupled WetSpass and MODFLOW were used to assess the groundwater recharge of the Hormat-Golina sub basin. The model considers all meteorological, hydrological, and biophysical factors of the area. In order to evaluate groundwater recharge and other water balance components of the watershed, hydro-meteorology, land use, soil texture, topography, and slope of the area have been investigated.

Based on the model output, the annual groundwater recharge in Hormat-Golina is 6.6 and 140.7 mm as the minimum and maximum values, with a mean of 35.6 mm, which represents 4.7% of the total annual rainfall. 64% (22.8mm) of the recharge occurred in summer (June to September) and the rest (36% (12.8mm) of the recharge percolated in winter (October to May). The minimum and maximum values of annual actual evapotranspiration of the Hormat-Golina sub basin are 342.1mm and 758.9mm, with a mean value of 516.6mm, which accounts for 68% of total rain fall (756.85mm). 64% (334.mm) occurred during the wet season, while the remaining 36% (183.7 mm) occurred during the dry season. The annual runoff from the model was 62.5 to 343.5 mm with a mean of 204.9 mm, which represents 27% of the annual precipitation (756.85 mm). 51% (104.3 mm) of runoff occurred in the wet season and the remaining 49% (100.6 mm) occurred in the dry season.

The groundwater head in the Hormat-Golina Sub-basin was studied under various stress conditions (dry season, wet season, and annually). The groundwater head distribution varies from 9.37 to 29.86 meters in the winter (dry season), 9.53 to 29.89 meters in the summer (wet season), and 9.58 to 30.17 meters during yearly stress periods (recharges). With a correlation coefficient of 0.86, the calculated hydraulic heads in steady state fit well with the measured ones for all stress periods (summer, winter, and annual recharge). Furthermore, the model-simulated head contour map revealed that the overall hydraulic gradient in the sub-basin follows the hydraulic gradient from the western boundary to the eastern boundary. In terms of groundwater management, a lower pumping rate with a higher recharge rate was an acceptable range, and future sustainability has been harmed by excessive groundwater exploration from the unconfined aquifer.

To preserve the groundwater resource's long-term viability, it is critical to consider the balance between groundwater recharge and projected abstraction rates for agriculture and domestic water supply in future groundwater resource development plans in the valley.

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