Vol. 10(1), pp. 8-23, January 2022
https://doi.org/10.14662/ijarer2022010

ISSN: 2360-7866

International Journal of Academic Research in Education and Review

Full Length Research

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

Seyoum Bezabih[1*] and Dr. Taye Alemayehu[2,]

[1]Department of Water resource engineering and management, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia. Corresponding author 's E-mail: seyoumb18@gmail.com, phone:- 0920028497)
[2]Department of Water resource engineering and management, Ethiopian Institute of Water Resource, Addis Ababa University, Addis Ababa, Ethiopia. E-mail: altay2121@gmail.com

Accepted 24 January 2022

Abstract

Water scarcities 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. WetSpass-MODFLOW coupling was used to estimate groundwater recharge in the Hormat-Golina sub basin. The goal of this study was to assess the amount of groundwater recharge in the Hormat-Golina sub basin. Following that, the MODFLOW groundwater flow simulation model is utilized to simulate the hydraulic head distribution. The Steady state groundwater flow calibration was determined by comparing measured and simulated hydraulic heads. The mean annual evapotranspiration, surface runoff, and groundwater recharge, according to WetSpass result, were 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%t and 68% of precipitation, respectively. In such seasonal variations, the groundwater head distribution is 11.24 to 31.73 m in winter (dry season), 9.53 to 29.89 m in summer (wet season), and 10.26 to 31.02 m in 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). The balance between groundwater recharge and expected abstraction rates for agriculture and domestic water supply must be considered in future groundwater resource development plans in the valley to ensure the resource long-term sustainability.

Key words: Ethiopia, Groundwater recharge, Hormat-Golina, MODFLOW, WetSpass

Cite This Article As: **Seyoum, B., Taye, A.** (2022). Groundwater Recharge Assessment using WetSpass and MODFLOW Coupling: The Case of Hormat-Golina sub-basin, Northern Ethiopia. Inter. J. Acad. Res. Educ. Rev. 10(1): 8-23

INTRODUCTION

"Water has always been a valuable resource for humans." Not only humans utilize it virtually every day, but it will be required to measure every physical thing. Despite the fact that water is a natural resource, the world 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]. Water use has increased at a pace roughly double that of growth over the last century[2]. Water scarcity affects a number of countries, despite the fact that it should not be evident. In both urban and rural regions, groundwater sources are helpful for a variety of uses [3]

In hydrogeologic research for sustainable groundwater development, determining groundwater recharge has evolved from a basic problem to an urgent and fundamental issue [4]. It is important to note that the majority of groundwater recharge technologies are applied across a small region (point or small basin scale) and for short periods of time [5].

Recharge and evapotranspiration rates are the most complex and uncertain components to estimate in the groundwater budget. This is because they are constantly changing in space and time, especially in dry and semi-arid regions [6].

Physically-based hydrologic modeling has been more essential in contemporary hydrology as a cost-effective means of monitoring the water balance at a spatial scale with the introduction of Geographic Information Systems (GIS). 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 also 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 main objective of this paper 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.

MATERIALS AND METHODS

Description of the Study Area

The research was conducted in northern Ethiopia. It is located latitudes of 11^0 55'35" to $12^0$13'10" north and longitudes of 39^0 24'45" to 39^0 47'44" east (figure 1). It is known as the Hormat – Golina sub basin and encompasses a total area of 689.25 km2. 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 to be a part of the Ethiopian rift system interconnecting 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).

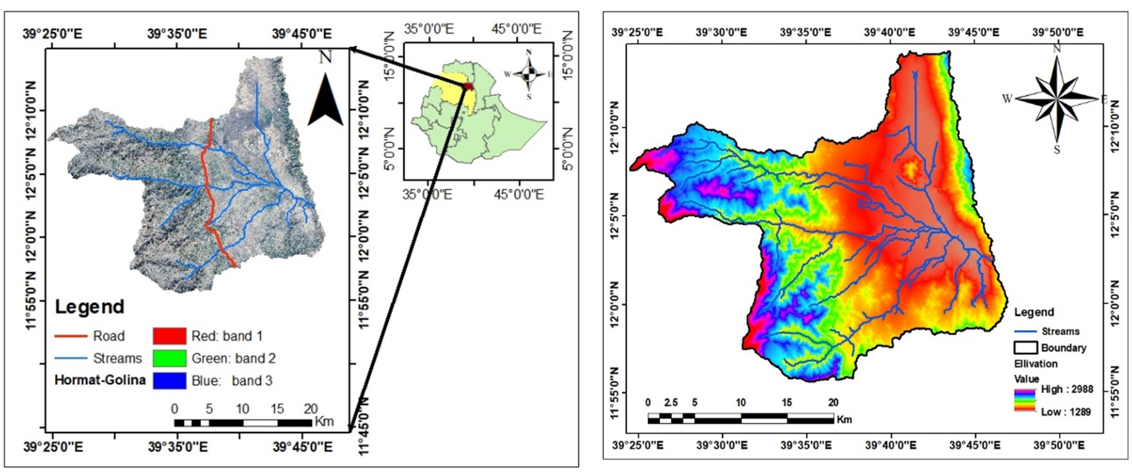


Figure 1: Location map and Drainage of the study area.

During the rainy season, all streams and ravines convey significant volumes of sediments 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 average annual temperature of 21.6^{o}c. The sub basin average annual rainfall is estimated to be around 756.85 mm and potential evapotranspiration of 1669.6 mm during the study period between 2000 and 2019.

Recharge Modeling Approach

The coupled WetSpass and MODFLOW was applied to assess the groundwater recharge of the Hormat-Golina sub basin. The data interchange between MODFLOW and WetSpass is guaranteed until the recharge rates and hydraulic heads have stabilized. The first simulation was started with WetSpass model using different input data. The calculated groundwater recharge was then used as input for MODFLOW for groundwater head simulation.

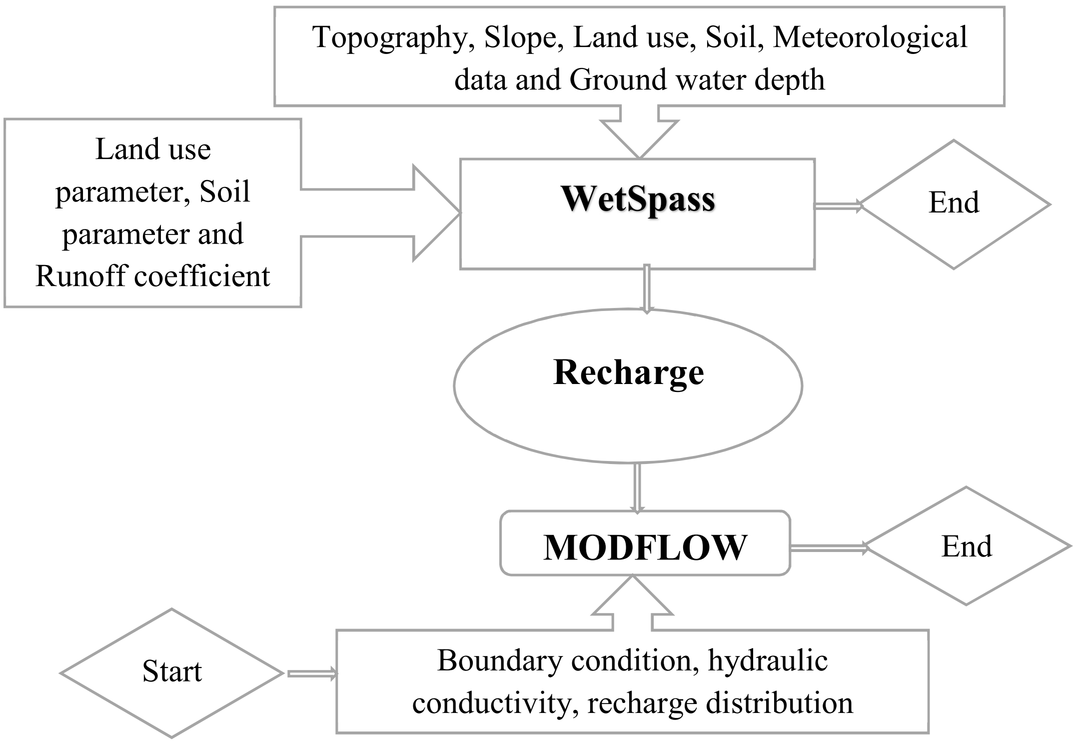


Figure 2: Recharge assessment approach.

WetSpass allows the calculation of surface runoff, actual evapotranspiration and groundwater recharge for seasonal periods by solving the water balance equation cell by cell for successively, the vegetated area, bare soil, open water, and impervious surfaces [9]. For a vegetated area, the water balance is calculated according to the following equation [10];

$$\mathbf{P = I + Sv + Tv + Rv} \qquad \text{Eq 5}$$

where P is average seasonal precipitation, I interception fraction, Sv surface runoff, Tv actual transpiration and Rv groundwater recharge, all with the unit [LT^{-1}].
The interception (I) is firstly calculated. It represents a constant percentage of the annual precipitation value. It depends, mainly on the type of the vegetation. Second, the relationship between precipitation amount, precipitation intensity, interception, and soil infiltration capacity ware used to determine surface runoff (S). There are two stages to estimate surface runoff. firstly, calculate the potential surface runoff (Sv-pot) as follows:

$$\mathbf{S_{v-pot} = C_{sv}(P - I} \qquad \text{Eq6}$$

where Csv is a surface runoff coefficient for vegetated areas; it depends on vegetation, soil type, slope and groundwater saturated areas, P is the average seasonal precipitation [LT^{-1}] and I is the interception fraction [LT^{-1}]. Secondly, S is calculated by considering the differences in seasonal precipitation intensities in relation to soil infiltration capacities [10].

$$\mathbf{S = C_{HOR}S_{v-pot}} \quad \text{Eq7}$$

where CHOR is a coefficient parameterizing seasonal precipitation which contributes to the Hortonian overland flow[11] (Batelaan & De Smedt, 2007). It considers the effective precipitation contributing to runoff.
The evapotranspiration is calculated from 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:

$$\mathbf{T_{rv} = cE_0} \quad \text{Eq8}$$

where Trv is the reference transpiration of a vegetated surface [LT^{-1}], E0 is the potential evaporation of open water [LT^{-1}] and c is the vegetation coefficient which can be calculated as the ratio of reference vegetation transpiration to the potential open-water evaporation [10].
WetSpass computes evapotranspiration in vegetated area by considering the root depth and the tension saturated height when the groundwater is above the root depth otherwise the evapotranspiration is computed as a function of water content. Finally, the groundwater recharge for the vegetated area is calculated by considering the result of the water balance:

$$\mathbf{Rv = P - Sv - ETv - Es - I} \quad \text{Eq9}$$

where R is the groundwater recharge, P is precipitation, Sv is surface runoff, ETv is actual evapotranspiration and I is 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 the 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]:

$$\mathbf{ET}a = avETv + asEs + aoE0 + aiEi \quad \text{Eq 10}$$

$$\mathbf{Sa = vSv + asSs + aoRo + aiRi} \quad \text{Eq 11}$$

$$\mathbf{R\,a = vRv + asRs + aoRo + aiRi} \quad \text{Eq12}$$

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.

WetSpass input data

Grids of topography, slope, soil texture, and seasonal grids of groundwater level, land use, and meteorological data (precipitation, wind-speed, temperature and potential evapotranspiration) are among the input data. The land use and soil are connected to the model by their attribute tables [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 the same coordinate projections and lateral extents using the resample tool in ArcGIS because the determined recharge by WetSpass is utilized for the groundwater flow model MODFLOW. For the processing of meteorological data (Precipitation, evapotranspiration, temperature and wind speed), the period 2000–2019 is chosen with an average value for each seasonal time step, i.e., the winter /dry/ and summer /wet/ seasons corresponding to the periods October to May and June to September, respectively. This period corresponds to the groundwater flow model calibration during the steady state. The input files for land use, soil texture, and runoff coefficient, which were generated as parameter tables, were also prepared in a database file format (dbf).

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	Temperature (summer & winter)	National meteorological agency
5	Precipitation (summer & winter)	National meteorological agency
6	PET (summer & winter)	Estimated by using R-programming
7	Wind speed (summer & winter)	National meteorological agency
8	Depth to groundwater	Direct measurement from existing boreholes
9	Soil parameter, runoff coefficient and Land use parameters	WetSpass user guide

The average seasonal precipitations were computed for seven metrological stations. It was calculated from a daily precipitation data measured for the period 2000 to 2019 for 20 years. The inverse distance weighting (IDW) approach is used to produce the spatial precipitation. 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 334.6 mm for the winter with mean of 297.03mm (Figure. 3a) and from 350.6 mm to 586.8 mm for the summer with 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 Hormat Golina sub basin was 756.85mm.

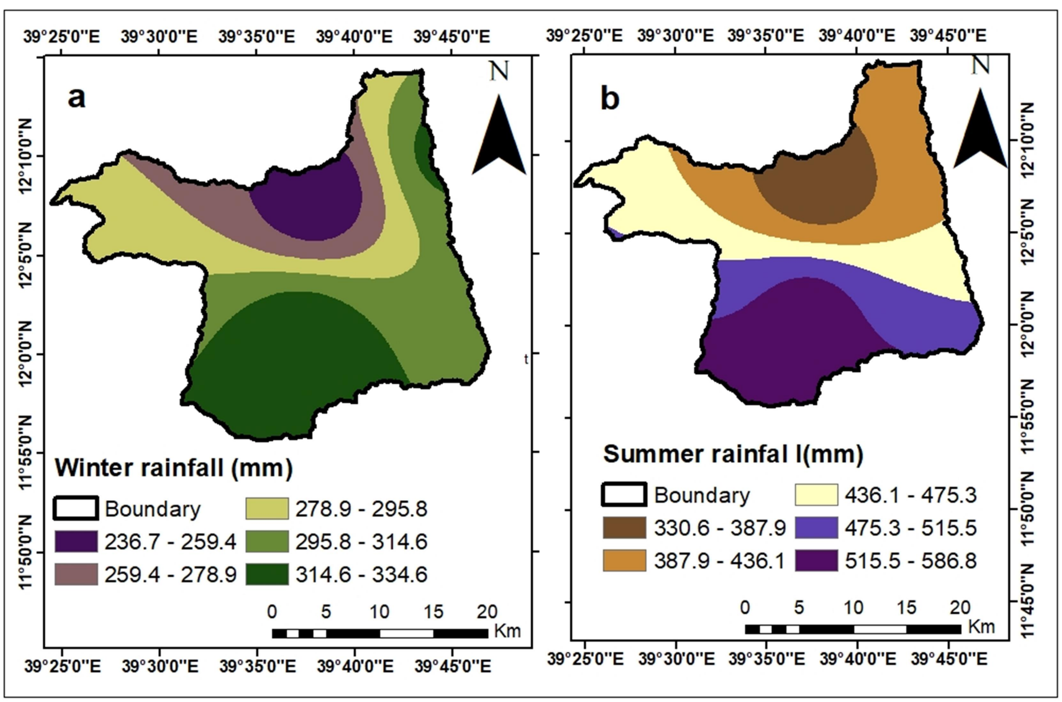


Figure 3. Rainfall distribution map of Hormat-Golina sub basin

The PET was computed using the Hargreaves equation due to a lack of data (Hargreaves and Samani, 1982), which is justified in semiarid area 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 (Allen et al., 1998), as an alternate method for predicting PET. The average monthly PET was calculated during the period 2000-2019 for seven (7) station using monthly average temperature values. The highest value (1076.7 mm) is recorded during the dry season /winter/ season (October to May). The minimum and maximum values of 1020.7mm and 1076.7mm with a mean value of 1048.8mm for winter /dry/ season (*figure* 4a) while the minimum and maximum values of 590.4mm and 620.6mm with a mean value of 620.6mm for the summer /wet/ season (*figure* 4b).winter /dry/ season (*figure* 4a) while the minimum and maximum values of 590.4mm and 620.6mm with a mean value of 620.6mm for the summer /wet/ season (*figure* 4b).

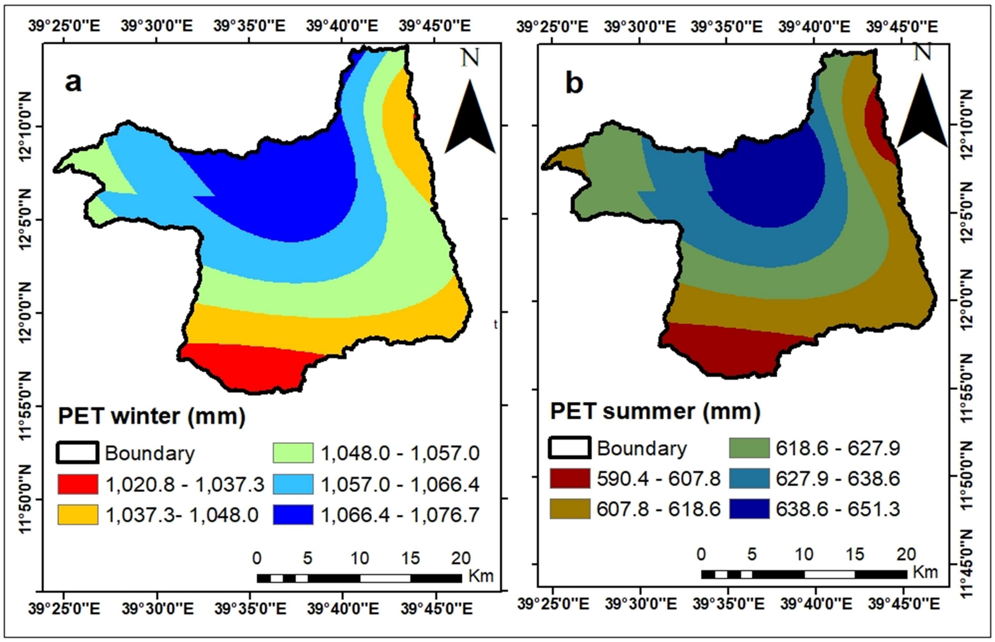


Figure 4: Potential evapotranspiration of Hormat Golina sub basin

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 temperature for the dry season /winter/ was 18.6°C to 21.6°C (*figure* 5a) with a mean value of 20.4°C whereas the minimum and maximum temperature of the summer /wet/ season ranges from 20.1°C to 24°C (*figure* 5b) with a mean value of 22.5°C.

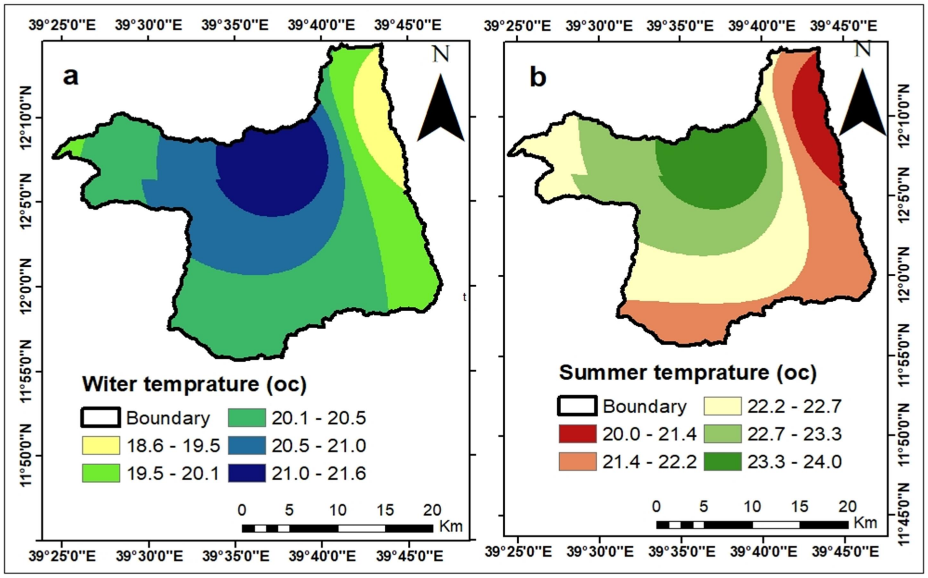


Figure 5: Average temperature of Hormat Golina sub basin

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

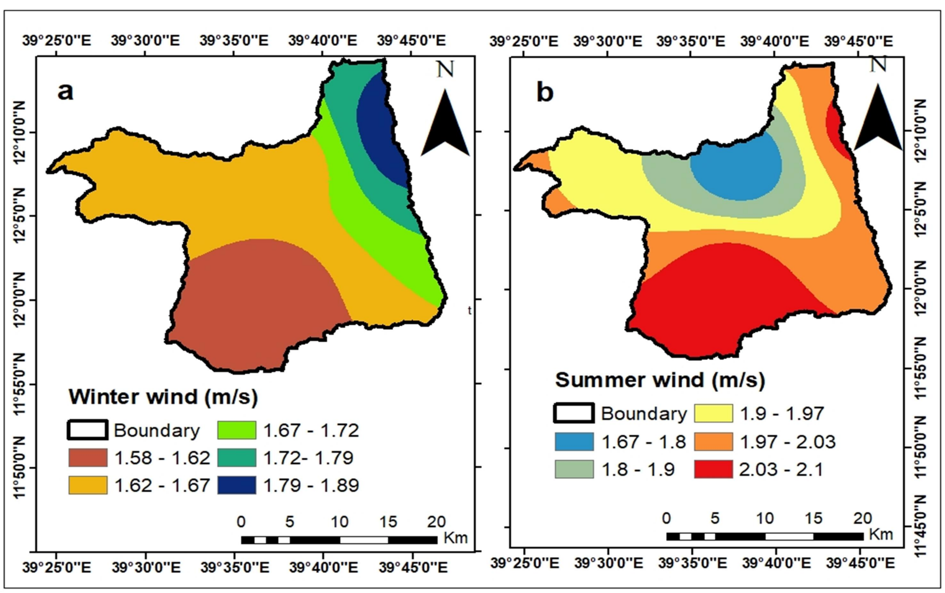
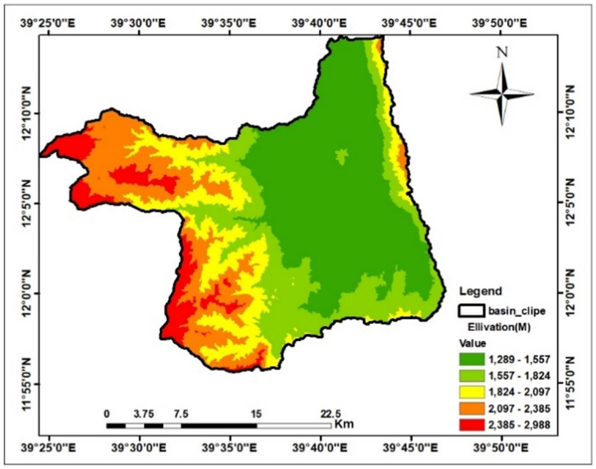


Figure 6: Average wind speed of Hormat Golina sub basin

The Alaska satellite facility (ASF) data set was used to create elevation and Slope map of the study area. The ASF provides Digital Elevation Model with a resolution of 12.5*12.5m (DEM). The sub basin 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 for determining the watershed hydrological features. It is categorized according to the degree of steepness, which ranges from 0 to 43^0. The value 0^0 represents gentle/lowland, while the value 43^0 represents steep/escarpment.



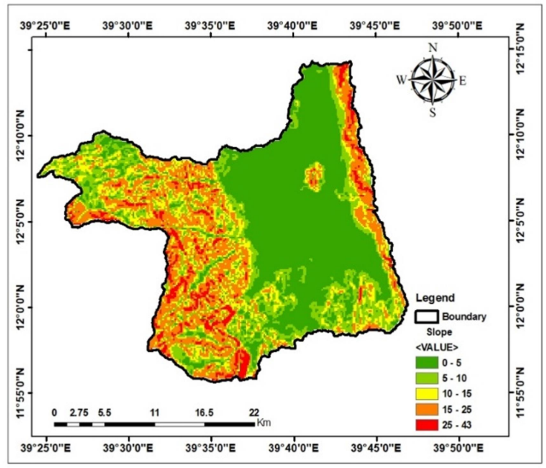
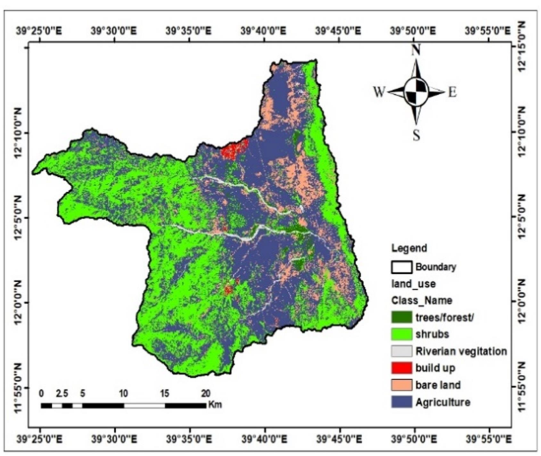


Figure 7: Elevation of the area **Figure 8**: Slope of the area

The land use grid was prepared from Landsat 8 products by supervised land use classification by using bands from 1 up to 7. As indicated by the figure (figure 9) the dominant land use of the sub basin was agriculture which accounts 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%.



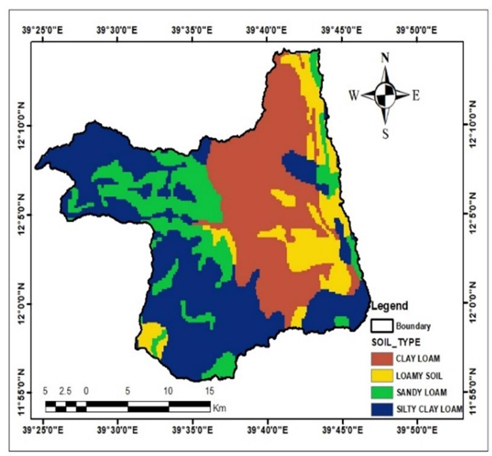


Figure 9: land use of the area **Figure 10**: Soil map of the area

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

Development of groundwater flow model

Visual MODFLOW 2005 software was used to create the groundwater flow model. 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.

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 were collected from 34 boreholes, which were then imported into MODFLOW using the import tool. For the aim of model calibration, observation wells were added to the model. This work required the usage 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 1558044 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 heads 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.

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

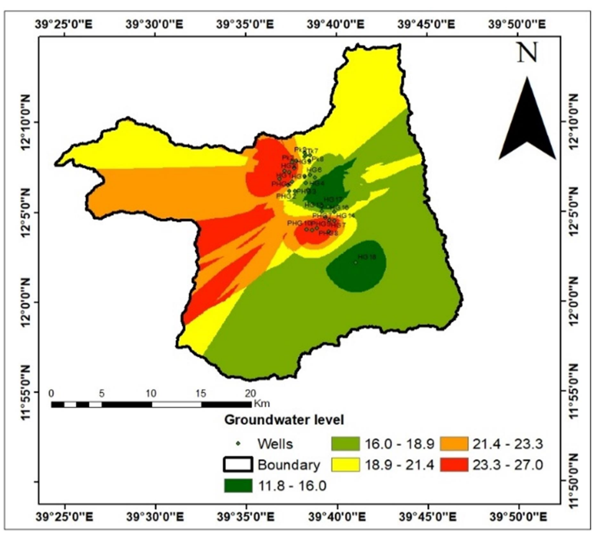


Figure 11: Groundwater level

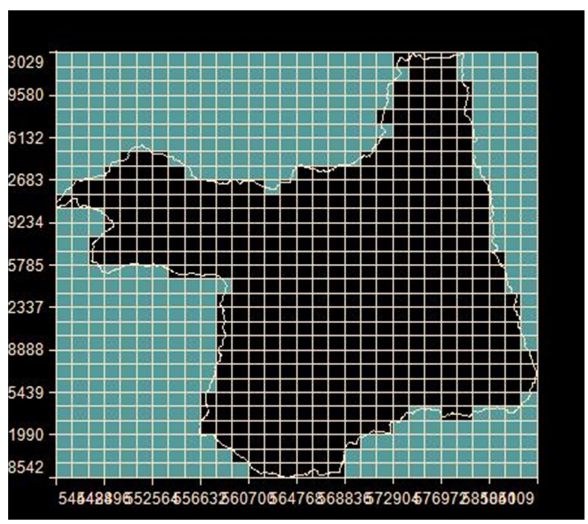


Figure 12: Discretization of the area

RESULTS AND DISCUSSION

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 was 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

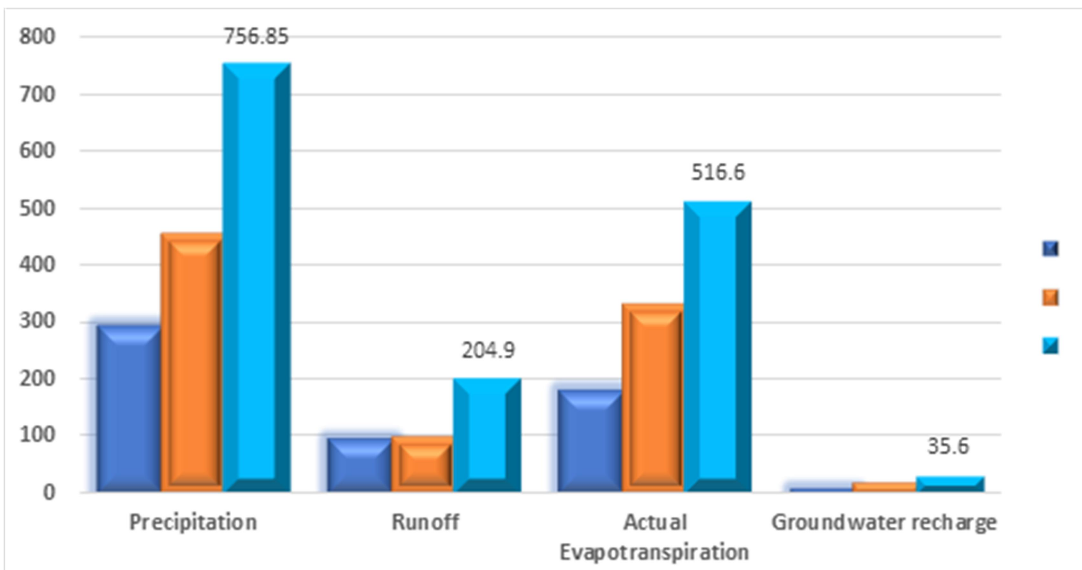


Figure 13: Comparison of precipitation with model simulated runoff, actual evapotranspiration, and recharge for winter (October-May), summer (June-September), and annual averages.

Groundwater recharge

The result shows an average recharge of 12.8, 22.8, and 35.6 mm was simulated for winter, summer and yearly basis respectively. The minimum and maximum values are 6.4 and 18.0mm for dry /winter/, -0.65 and 126.72 mm for wet /summer/ and 6.6 and 140.70mm yearly. Hence, 35.6 mm of annual recharge water are 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 km2), the average annual recharge (35.6 mm) is equivalent to $2.5*10^7 m^3 year^{-1}$.

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

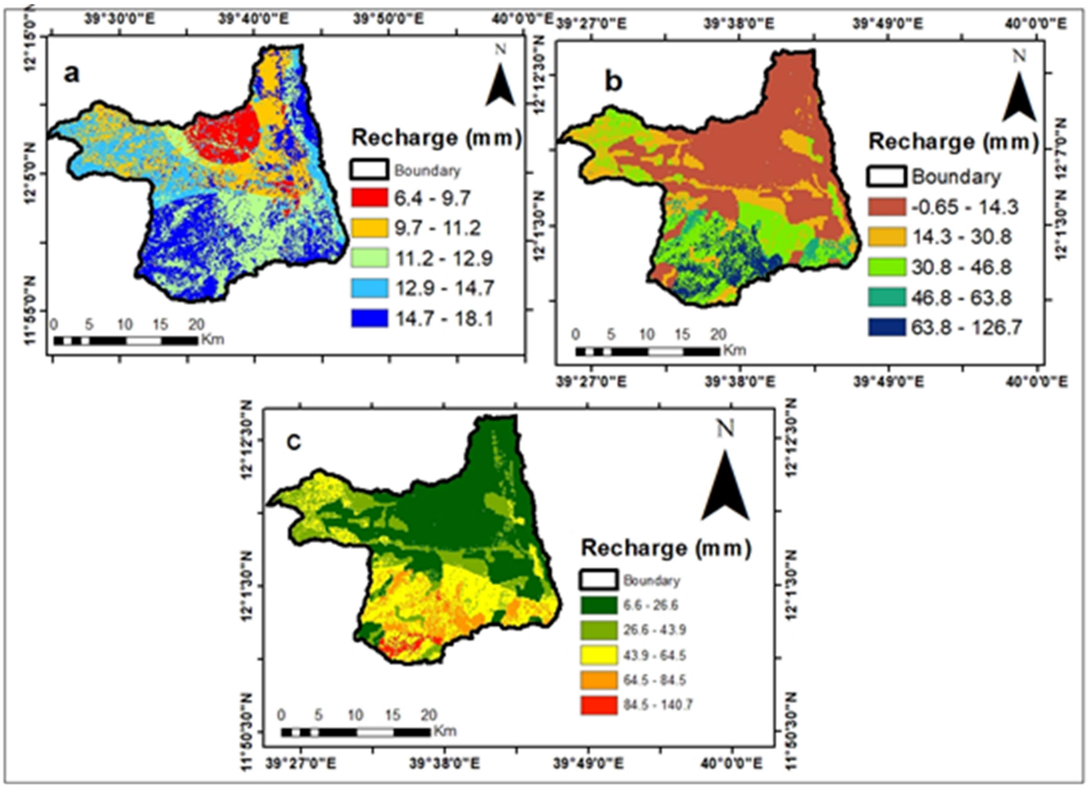


Figure 14: Ground water recharge map of Hormat Golina sub basin

Water balance components

The simulated results from 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, 334.9 mm for the winter /dry/ and summer /wet/ season respectively.

The minimum and maximum values of dry season evapotranspiration was 111.6mm and 284.6mm (*figure* 15a) and also for the wet season minimum and maximum value ranges from 210.8mm to 489.4mm (*figure* 15b). Considering the area of the sub basin (698.25 km2), the average annual evapotranspiration (461 mm) is equivalent to $3.22*10^8 m^3 year^{-1}$. Due to active solar radiation, greater surface temperatures, and dry winds in the watershed, evapotranspiration plays a crucial role in water losses.

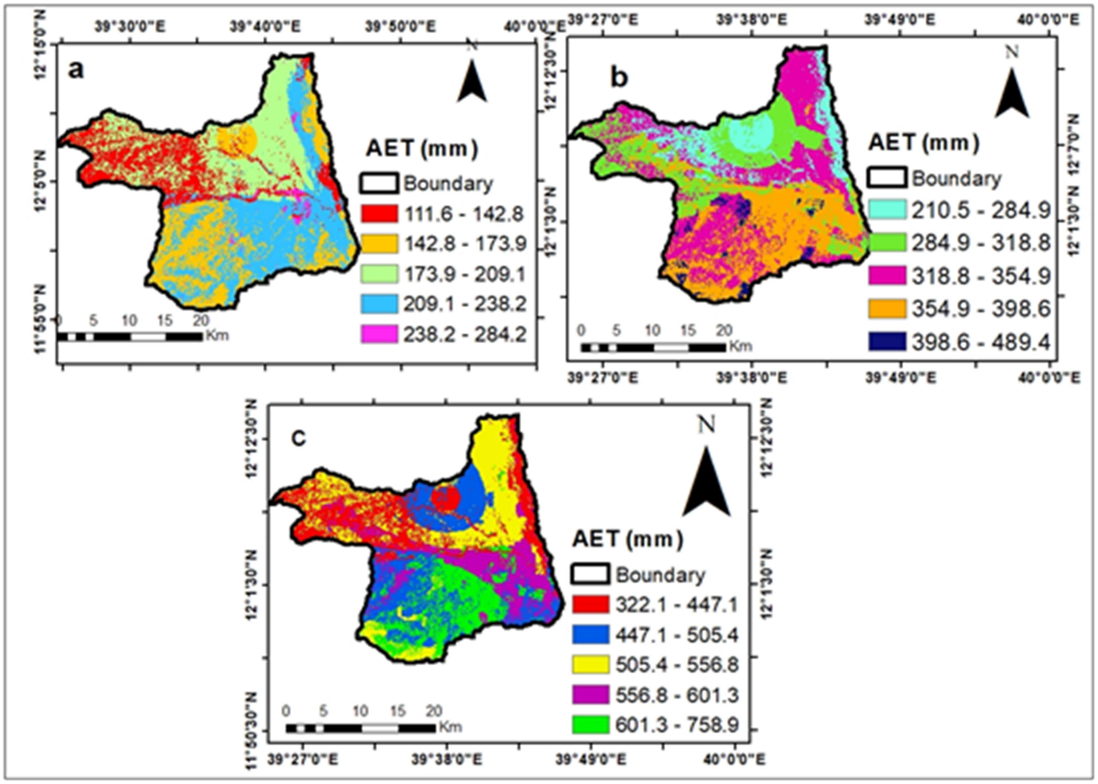


Figure 15: Actual evapotranspiration from Hormat Golina sub basin

Spatially explicit annual and seasonal values of surface runoff simulated by the model are presented in *Figure* 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 long dry season was found 28.8 to 160.7mm with mean of value of 100.6 mm respectively (*Figure* 16a), and the annual surface runoff ranges from 62.5 to 343.1 mm year-1with mean value of 204.9 mm year-1 which accounts 27% of the total long-term mean annual precipitation 756.85 mm on the entire watershed as shown in (*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 km2), the average annual surface runoff (204.9 mm) is equivalent to $1.43*10^8$ $m^3 year^{-1}$.

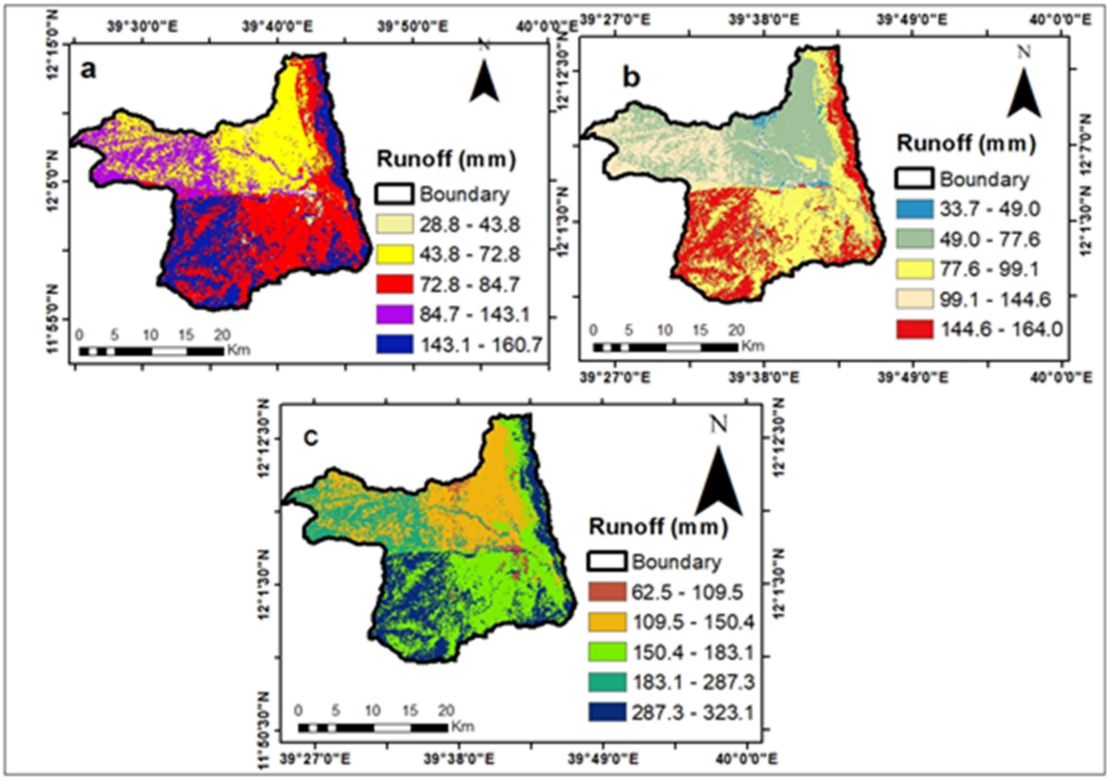


Figure 16: Surface runoff from Hormat Golina sub basin

Groundwater Head (hydraulic head) distribution with respect to stress

The groundwater head in Hormat-Golina Sub-basin had analyzed by different stress periods (Dry season, wet season and annually). After calibration, the model had completed in different stress periods. the model result (*Figure* 17a), shows the groundwater head due to dry/winter stress period (recharge) was varied from 11.24 m in the Eastern parts to 31.73m in the Northwestern parts of the Sub-basin. While in the wet season /summer/ stress period (recharge) (*figure* 17b) the groundwater head was varied from 9.53m in the Eastern and 29.89m in the north western parts of the sub basin and also from the *figure* (*figure* 17c), shows the groundwater head due to the annual stress period /recharge/ was varied from 10.26 m in the eastern and 31.02 m in the north western parts of the sub basin. From the simulation result there is change in the groundwater head by 1.71m in the eastern and 1.84 m in the northwestern parts of the catchment in dry and wet stress periods whereas there is groundwater head change between annual and seasonal stress periods /recharges/. The groundwater head between dry stress period and annual stress period varied from 0.98 m in the eastern and 0.71m in the northwest parts of the sub basin and the groundwater head between wet and annual stress period was varied from 0.73m in the eastern and 1.13.m in the northwestern parts of the sub basin.

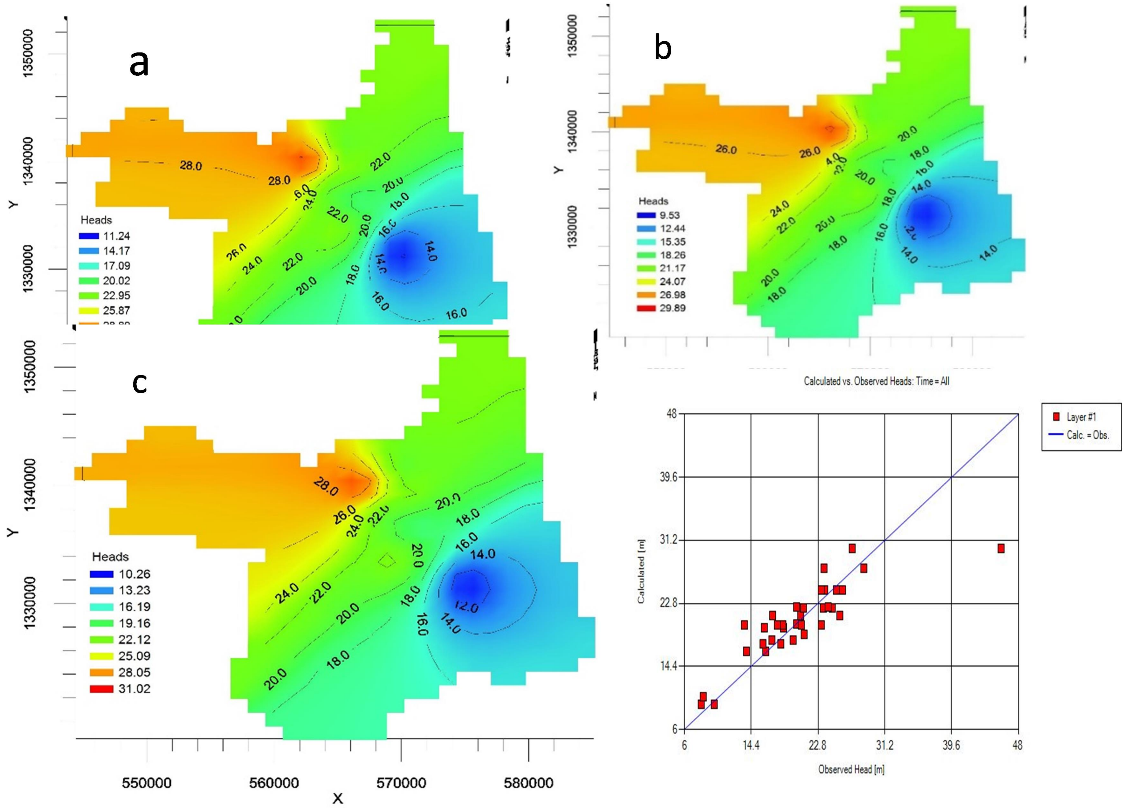


Figure 17:- Groundwater head with respect to stress (recharge) a) winter /dry season/ b) summer /wet season c) annually

The validation result indicated a reasonably match between simulated and observed heads with 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)

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

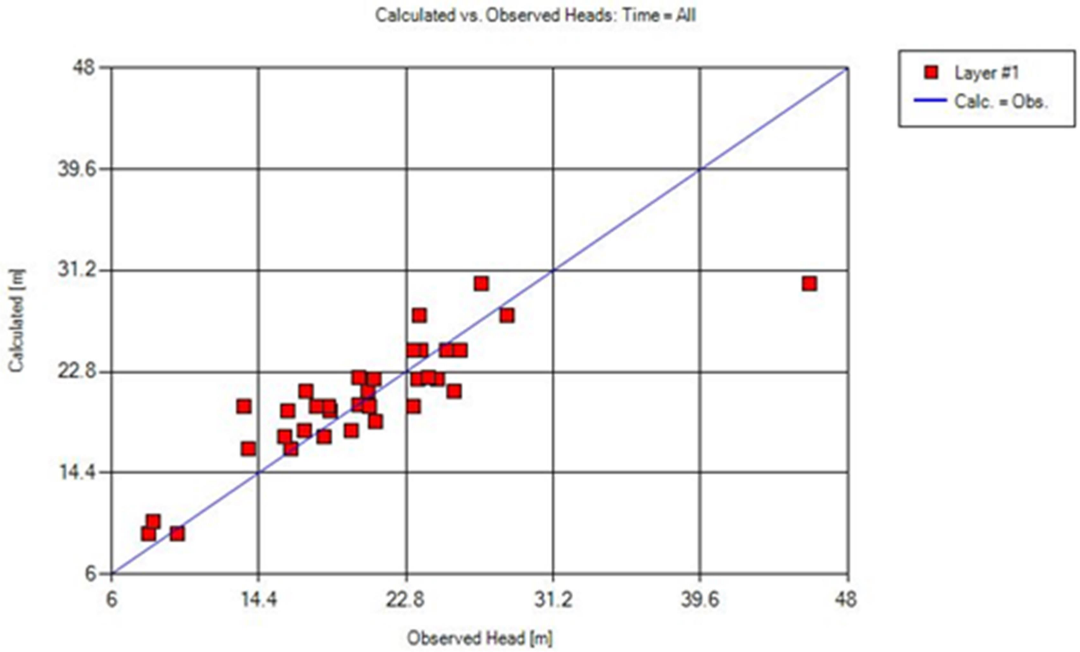


Figure 18: The scatter plots of simulated versus observed

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

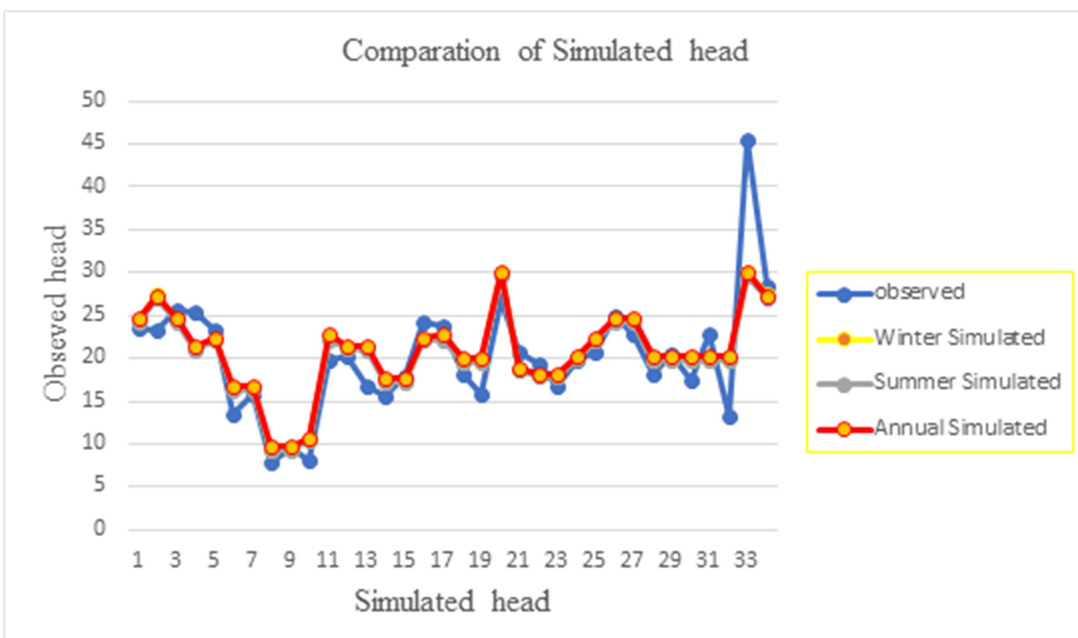


Figure 19: Comparison between the observed and simulated heads of different tress periods

CONCLUSION

Coupled WetSpass and MODFLOW was used to assess the groundwater recharge of 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 component of the watershed hydro- meteorology, land use, soil texture, topography and slope of the area has been investigated.

Based on the model output, the annual groundwater recharge in Hormat-Golina is 6.6 and 140.7 mm as a minimum and maximum value with a mean of 35.6 mm, which represents 4.7% of the total annual rainfall. 64% (22.8mm) of the recharge is occurred in summer (Jun to September) and the rest 36% (12.8mm) of recharge percolate in winter (October to May). The minimum and maximum values of annual Actual evapotranspiration of Hormat-Golina sub basin are 342.1mm and 758.9 mm with a mean value of 516.6 mm which accounts 68% of total rain fall (756.85mm). 64% (334.9mm) was found in the wet and the rest 36% (183.7 mm) occurred in 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 annual precipitation (756.85mm). 51% (104.3 mm) of runoff occurred in wet season and the remaining 49% (100.6 mm) was 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.

REFERENCES

[1] A. Salem, J. Dezső, and M. El-Rawy, "Assessment of groundwater recharge, evaporation, and runoff in the Drava Basin in Hungary with the WetSpass Model," *Hydrology*, vol. 6, no. 1, p. 23, 2019.

[2] UNESCO, "duplicateWater for People, Water for Life," *World Water Dev. Rep.*, p. 36, 2003.

[3] O. M. Saether, P. de Caritat, and D. N. Lerner, "Groundwater recharge," *Geochemical Process. Weather. Groundw. Recharg. Catchments*, pp. 109–150, 2020, doi: 10.1201/9781003077916-4.

[4] S. Tweed, M. Leblanc, I. Cartwright, G. Favreau, and C. Leduc, "Arid zone groundwater recharge and salinisation processes; an example from the Lake Eyre Basin, Australia," *J. Hydrol.*, vol. 408, no. 3–4, pp. 257–275, 2011, doi: 10.1016/j.jhydrol.2011.08.008.

[5] S. K. Izuka, D. S. Oki, and J. A. Engott, "Simple method for estimating groundwater recharge on tropical islands," *J. Hydrol.*, vol. 387, no. 1–2, pp. 81–89, 2010, doi: 10.1016/j.jhydrol.2010.03.034.

[6] Xu, G. Huang, H. Zhan, Z. Qu, and Q. Huang, "Integration of SWAP and MODFLOW-2000 for modeling groundwater dynamics in shallow water table areas," *J. Hydrol.*, vol. 412–413, pp. 170–181, 2012, doi: 10.1016/j.jhydrol.2011.07.002.

[7] S. S. Rwanga and J. M. Ndambuki, "Approach to Quantify Groundwater Recharge Using GIS Based Water Balance Model: A Review," *Int. J. Res. Chem. Metall. Civ. Eng.*, vol. 4, no. 1, 2017, doi: 10.15242/ijrcmce.ae0317115.

[8] S. S. Rwanga, "A Review on Groundwater Recharge Estimation Using Wetspass Model," *Int. Conf. Civ. Environ. Eng.*, pp. 156–160, 2013.

[9] N. Ghouili, F. J. Horriche, M. Zammouri, S. Benabdallah, and B. Farhat, "Coupling WetSpass and MODFLOW for groundwater recharge assessment: case study of the Takelsa multilayer aquifer, northeastern Tunisia," *Geosci. J.*, vol. 21, no. 5, pp. 791–805, 2017, doi: 10.1007/s12303-016-0070-5.

[10] Batelaan and F. De Smedt, "WetSpass: A flexible, GIS based, distributed recharge methodology for regional groundwater modelling," *IAHS-AISH Publ.*, no. 269, pp. 11-18b, 2001.

[11] O. Batelaan and F. De Smedt, "GIS-based recharge estimation by coupling surface-subsurface water balances," *J. Hydrol.*, vol. 337, no. 3–4, pp. 337–355, 2007, doi: 10.1016/j.jhydrol.2007.02.001.

[12] O. Batelaan and S. T. Woldeamlak, "ArcView interface for WetSpass, user manual," Version 19-5-2004, Vrije Universiteit Brussel, Brussels, Belgium, 2004.

[13] G. Y. Lu and D. W. Wong, "An adaptive inverse-distance weighting spatial interpolation technique," *Comput. Geosci.*, vol. 34, no. 9, pp. 1044–1055, 2008.

[14] M. Al Kuisi and A. El-Naqa, "GIS based spatial groundwater recharge estimation in the jafr basin, jordan - application of wetspass models for arid regions," *Rev. Mex. Ciencias Geol.*, vol. 30, no. 1, pp. 96–109, 2013.