GEOSPATIAL ANALYSIS OF LAND USE CHANGE AS AFFECTED BY GROUNDWATER HYDROLOGY USING SWAT-MODFLOW MODELING

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ABSTRACT: Comprehensive planning on land use change and water resources development to maximize human consumption is important for meeting the demand of the increasing competing consumers. However, there is a need for physically-based modeling tools to assist with identifying successful water management strategies, especially groundwater hydrologic responses. This research presents the newly-coupled SWAT-MODFLOW model that allows application at Quaioit River watershed in northern Philippines, specifically in quantifying the agricultural expansion on the land use plan of *Paoay* town as affected by the groundwater hydrology was explored. The study showed the impact of conversion of potential undisturbed land areas suitable for crop production with groundwater use. The SWAT-MODLFOW model showed that the area had groundwater recharge ranged from 69 to 350 m^3/d with varying hydraulic head from 96 to 40 masl at the observation grid cells of the area. Geospatial analysis on the impact of land use change, particularly on agricultural expansion due to groundwater hydrology where groundwater discharge, water yield, deep percolation, total soil water and lateral flow were considered. Results revealed that conversion of undisturbed land to agricultural land reduced the quantity of water underground; groundwater discharge decreased by 1%-2.15%. Same trend was observed on groundwater lateral flow that significant decreased by 5.51%-7.23%. The SWAT-MODFLOW model was an indispensable tool for use by agricultural and biosystems engineers and other professional in the updating the comprehensive land use plan of any towns or cities, incorporating the conjunctive use of surface and groundwater resources toward a sustainable supply of water resources to the community.

1. INTRODUCTION

Often there is a hostile competition within a single river basin from the municipal, agricultural, industrial, environmental, and recreational sectors over the use of the limited supply of surface water and groundwater. Groundwater in rural areas is mostly vulnerable as the transfer of surface water rights to urban areas increases dependence on groundwater resources, leading to a decrease in groundwater levels and overall groundwater storage (Knapp and Baerenklau, 2006). Also, removing surface water irrigation decreases seepage from earthen irrigation canals and deep percolation from applied surface water irrigation, thereby removing a source of groundwater and leading to additional groundwater storage depletion. In such a complex water resources network, wherein both surface water and groundwater resources are managed conjunctively to satisfy all social sectors, physically-based distributed hydrological models can be used to quantify water availability under current and future conditions and determine appropriate integrated water management policies. Hydrological models typically are developed based on (i) surface runoff models that consider groundwater in a simplistic manner, such as the *Hydrologiska ByrånsVattenbalansavdelning* (HBV) (Bergstrom and Forsman, 1973; Bergstrom, 1992), the

Sacramento Soil Moisture Accounting Model (SAC-SMA) Burnash et al, 1973, TOPMODEL (Beven and Kirkby, 1979), the Variable Infiltration Capacity (VIC) (Liang et al, 1994), the Hydrologic Modeling System (HEC-HMS) (William and Peters, 1995), the Soil and Water Assessment Tool (SWAT) among others and just lately is the new coupled SWAT-MODFLOW model (Chenn et al, 2019; Park and Bailey, 2017).

Based on the simulation studies (Arceo et al, 2018) in two watersheds, changes in climate and land cover, including increased precipitation and conversion of range/brush land to forest, affected the present hydrologic balance of a watershed. Given the current condition of the test watersheds, an increase in precipitation tended to significantly increase surface runoff, which could cause serious erosion, sedimentation of the reservoirs, depletion of soil nutrients, and even flooding in low-lying areas within the watershed. Furthermore, increase in forest cover decreases surface runoff, increases evapotranspiration, and decreases base flow. The flux in base flow is significant for the test watersheds as they provide water for irrigation and domestic use in the area. The impacts of land cover and climate changeson hydrologic responses are non-uniform from one watershed to another. A sound watershed management scheme can have potential benefits to improve water availability and reduce flood-risks downstream. However, quantifying groundwater hydrologic responses have not considered and needs further investigation.

Within river basins, water resources competition often exists between agricultural, municipal and industrial sectors, particularly in semi-arid regions where surface water and groundwater are managed conjunctively to sustain urban areas and food production. There is a need for physically-based modeling tools to assist with identifying successful water management strategies in these basins. This paper presents an updated version of SWAT-MODFLOW that allows application to large agro-urban river basins in semi-arid regions of Quaioit River Watershed (QRW).

The study aimed to quantify the impact of land use change (agricultural expansion) to groundwater hydrology of the QRW using SWAT and SWAT-MODFLOW. Specifically, the study aimed to: (1) simulate and calibrate a model for streamflow and other hydrologic processes of the watershed using the Soil and Water Assessment Tool (SWAT); (2) to characterize the groundwater state of the watershed using SWAT-MODFLOW; (3) evaluate the effectiveness and efficiency of SWAT-MODFLOW model to simulate groundwater hydrology link to SWAT model and (4) quantify the impact of agricultural expansion to groundwater discharges and other groundwater processes.

2. MATERIALS AND METHODS

2.1. Research Framework of the Study

To better understand the step by step of the study, the research framework is presented in Figure 1. The study involved computer applications that can simulate the projected impact of land use change, particularly agricultural expansions in the study area. First work to be done is to collect raw data needed in the simulation e.g. meteorological data, land use map DEM and soil map. It is further analyzed and prepared into proper format as required by ArcGIS-ArcSWAT application. These processed maps and data were used to simulate streamflow runoff using SWAT model. It is further calibrated using reliable statistical tool. Simulated data developed by SWAT model were then used as input to the coupled SWAT-MODFLOW model to quantify and characterized groundwater hydrology responses to different land use change scenarios.

2.2. Data Gathering and Compilation

Data needed in the study were gathered and compiled into proper format required by the subsequent geospatial analysis. Spatial data required by the model include digital elevation model (DEM), land use map and soil map. These data were used to delineate the watershed boundary, generate the stream network, and the hydrologic response unit (HRU), which is the basis unit of the SWAT model. The SAR DEM with 90 by 90 m resolution was used in the study. Land use mapping expose the pattern of land use and provide basis for characterizing landscape and understanding land management practices. Land use map that was used in the study were classified into land use classes recognize by the SWAT database. Soil map is a geographical representation showing diversity of soil diversity of soil types and/or soil properties in the area of interest. Like Land use, soil map will be classified generally that recognizable by the SWAT database. The weather data, which include rainfall, maximum and minimum temperature, relative humidity, solar radiation and wind speed were compiled as text file as required by SWAT model (Jimenez and Galeo, 2016).

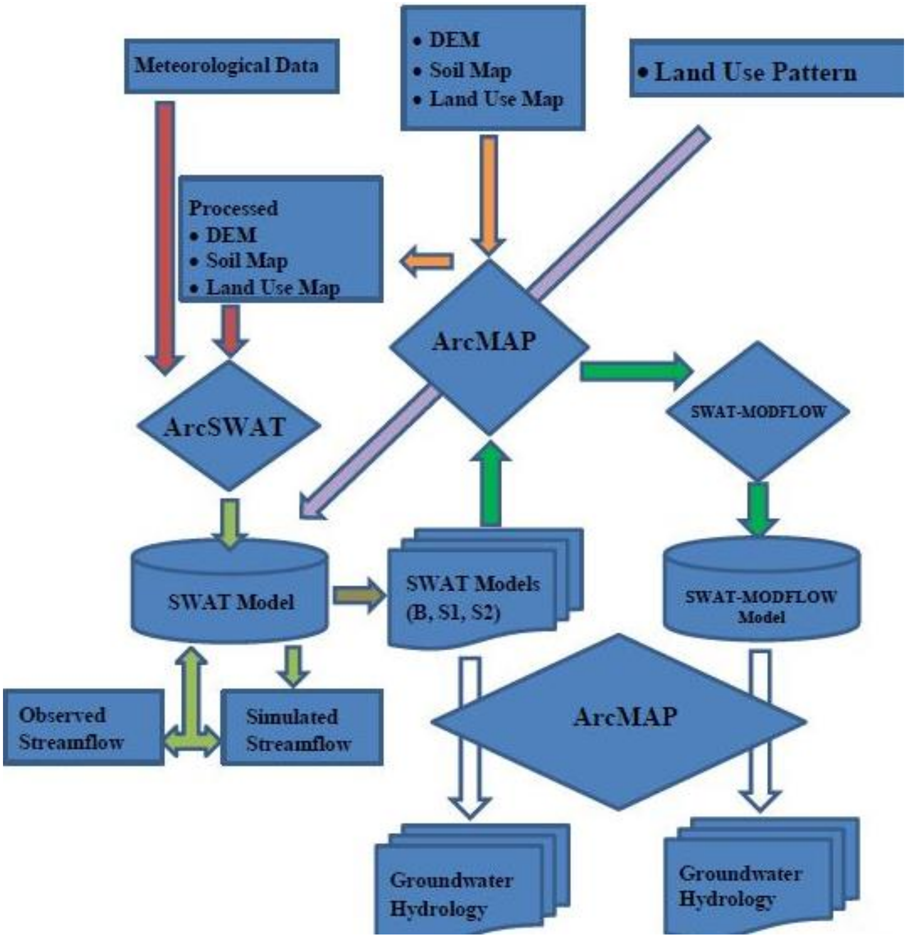

Figure 1.Process framework of the study.

2.3. SWAT–MODFLOW Model

The SWAT-MODFLOW is a newly coupled hydrologic model that combines the land surface and stream hydrologic processes of SWAT and the groundwater hydrologic processes of MODFLOW to provide a comprehensive coupled hydrologic model for watershed systems [9]. Transport of contaminants in this coupled system also can be simulated by including the RT3D (Reactive Transport in 3 Dimensions) model into the MODFLOW groundwater routines. The processes simulated by each model are shown in Figure 2 using some general assumptions of basic groundwater flow conditions. Processes simulated by SWAT are shown with green text, those simulated MODFLOW in blue text, and those simulated by RT3D (if desired; in red text). SWAT performs operations for land surface hydrology, soil hydrology, and surface water hydrology; MODFLOW performs operations for groundwater hydrology and interactions between groundwater and surface water. Data needed in the SWAT-MODFLOW model were the outputs that were simulated in basic SWAT model such as HRUs, river flows and sub-basins. These were used to create and process linkages and other needed data for the simulation was readily available provided by SWAT-MODFLOW interface. It includes MODFLOW input files, swatmf_link.txt and mapping files (linking text files). It also includes executable files which contained the simulation procedure with other needed data for the simulation were readily available provided by SWAT-MODFLOW interface. It included MODFLOW input files, swatmf_link.txt and mapping files (linking text files). It also included executable files which were contained in the simulation procedure.

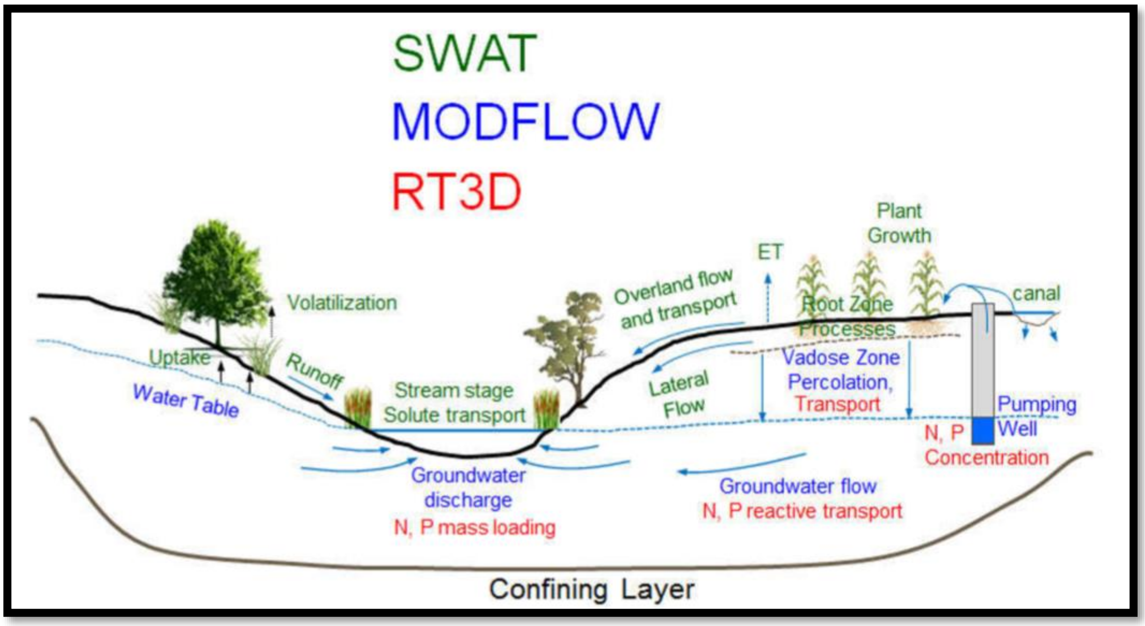

Figure 2.Framework of SWAT-MODFLOW modelling (Park and Bailey 2017).

2.4. Evaluation of Land Use Change

Land use change was based on the Comprehensive Land Use Plan (CLUP) of the 2 biggest localities within the boundary of the watershed, the Batac City and the town of Paoay. To exposed and project the futuristic consequences of intensive land use change in the watershed towards food productions, evaluated land use change was used to simulate the different state of groundwater hydrology in the area. Table 1 shows the formulated land use change scenarios at two stages. Scenario 1 shows the two combination effects of converting Range to Brush land and Forest land into Agricultural land about 25% of their total area in the watershed. Scenario 2 the same with the later scenario; it is just increased by 50% of their total area.

3. RESULTS AND DISCUSSION

The Quiaoit River Watershed (QRW) has a total land area of 17,362.76 hectare covering Batac City and Municipality of *Paoay, Currimao, Banna and Sarrat*, Ilocos Norte (Figure 3). About 61% of the total watershed area was located within the city and the second largest contributor of its area and almost covering its downstream is the municipality of Paoay, which contributed 18% from the total area of the QRW, about 44.48% of the total area of the municipality It summits as high as 520masl. The watershed falls within Latitude 17° 07' North and Longitude 120° 32' to 120° 28' East. The area is about 18km to Laoag City, the province capital; 225km to the regional center (San Fernando, La Union), and about 472 km to Metro Manila (Arceo et al, 2018; Jimenez and Galeon, 2016).

Table 1. Scenario development on land use changes for SWAT-MODFLOW.

SCENARIO	CONVERTED FROM	CONVERTED TO	PERCENTOF THE TOTAL AREA (%)
Scenario 1	Range to Brush Land	Agricultural Land	25%
	Forest Land	Agricultural Land	25%
Scenario 2	Range to Brush Land	Agricultural Land	50%
	Forest Land	Agricultural Land	50%

3.1. Calibration of SWAT Model

The simulated streamflow runoff using SWAT model was further calibrated to validate the effectiveness of the model. The r value and the Nash and Sutcliff Coefficient (NSE) were used to test the adequacy of the model. Calibrated streamflow of the stations in figure 6 gathered from the Crop Research Laboratory of Mariano Marcos State University were requested as foundation of the calibration. Table 2shows the varying values of correlation, r and NSE with respect to stations. Correlation r values ranged from 0.63 to 0.93 which proves that as the simulated streamflows increases, observed streamflows also increase, and vice versa. NSE values were ranges from 0.34 to 0.87 which NSE values indicated that the model is better predictor than the mean. This means that SWAT model simulated was efficient and effective to simulate the relationship of the water behavior to land conversion (Arceo et al, 2018; Jimenez and Galeon, 2014). Figure 4 shows the response of streamflow peaks (calibrated and simulated) during heavy rains.

3.2. Groundwater Characterization of QRW

To perform groundwater simulation using SWAT-MODFLOW, various essential files are needed (Figure 5). Data needed in the SWAT-MODFLOW are data that are simulated in SWAT will be used as hydrologic response units (HRUs), river and sub-basins. These files were created and processed linkages to grid files such as: (a) swatmf_dhru2hru.txt - relates HRUs to DHRUs; (b) swatmf_dhru2grid.txt- relates DHRUs to Grid Cells; (c) swatmf_grid2.dhru.txt- relates Grid to DHRUs; and (d) swatmf_river2grid.txt- relates Grid to DHRUs of the QRW study area.

Initial simulation of SWAT-MODLFOW model shows that groundwater recharge ranges from 69m^3/d up to 350m^3/d (Figure 6). It is also noticed that the watershed has a groundwater hydraulic head of 96.1 up to 140.4masl (Figure 6) along the vicinity of the watershed which varying geographical characteristics. It also show the variation of groundwater head of the watershed at different observation cell of the watershed (Figure 7). Upstream location shows higher head while lower areas have smaller head. It is also noticed that due to time groundwater head is decreasing throughout the watershed.

Table 2. Statistical indicator during calibration using SWAT model.

STATISTICAL PARAMETERS	CORRELATION, r	NSE
STAT 1	0.63	0.34
STAT 2	0.76	0.41
STAT 3	0.93	0.87
STAT 4	0.75	0.64
STAT 5	0.91	0.71

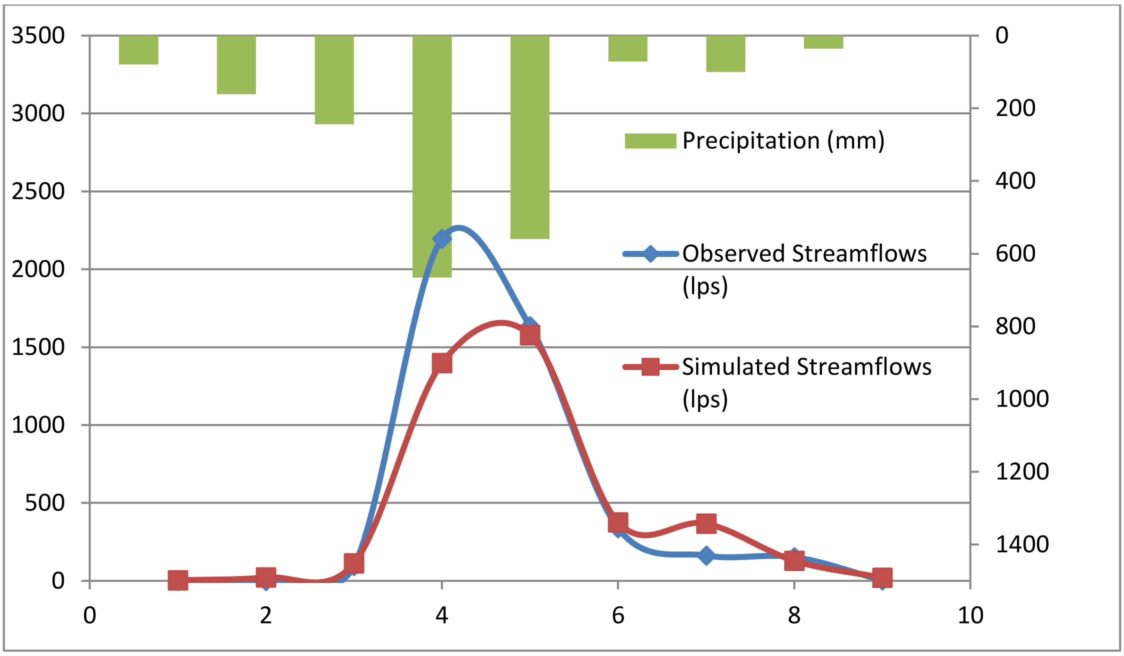

Figure 4.Response of streamflow runoff to peak rainfall using SWAT model.

3.3. Quantifying the Impact of Agricultural Expansion to Groundwater Responses

This aims to display the impact of land use change, particularly on agricultural expansion, to groundwater hydrology responses. Groundwater discharge, water yield, deep percolation, total soil water and lateral flow were considered in the quantifying effect. Results show that conversion of undisturbed land to agricultural land decreases the quantity of water underground (Figure 6). In Table 3 shows that groundwater discharge decrease by about 1% at Scenario 1 and 2.15% decrease at Scenario 2. Same as through with lateral flow that shows significant decrease at the 2 level of conversion, 5.51% to 7.23%, Scenarios 1 and 2, respectively. With the study of [11] Manzano and Alibuyog (2014), the estimated total capacity of about 336,100.8m^3/day of the QRW where the simulated groundwater responses adequately, considering the hydraulic connection of the groundwater from the Quiaoit River to its adjoining areas that can be irrigated using shallow wells (Figure 7).

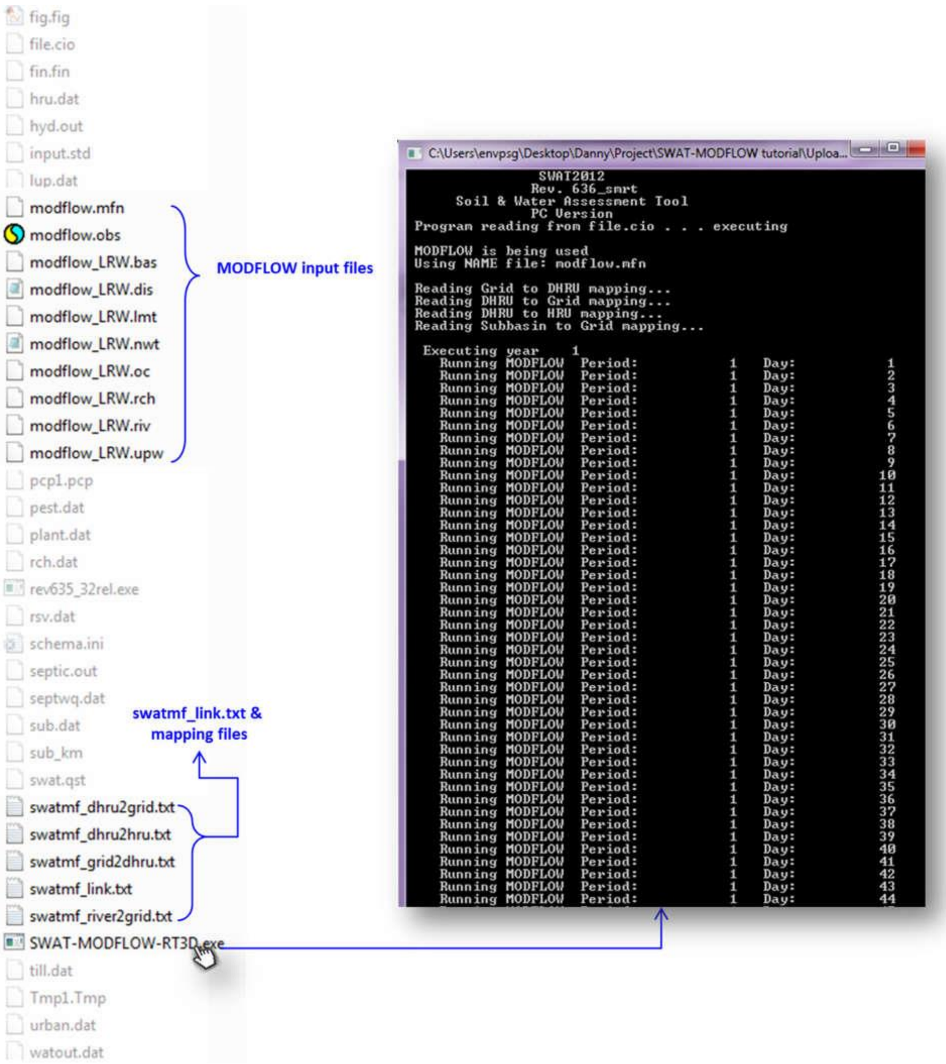

Figure 5. Essential files needed in running SWAT-MODFLOW simulation.

The model was run for the 2005–2014 periods and by tested against groundwater elevation and streamflow discharges at monitoring wells and stream gages, respectively, located throughout the basin. The results of the coupled SWATMODFLOW model are adequate as regards to simulating streamflow and groundwater elevation hydraulic heads. The existing model can be useful for management purposes, qualifying the water resources managers toquantify spatial groundwater vulnerability in the studied QRW or other similar watersheds. However, such investigation needs further hydrogeological characterization and well logs in the study area on more groundwater hydrology parameters and improved irrigation coding of the SWAT-MODFLOW model.

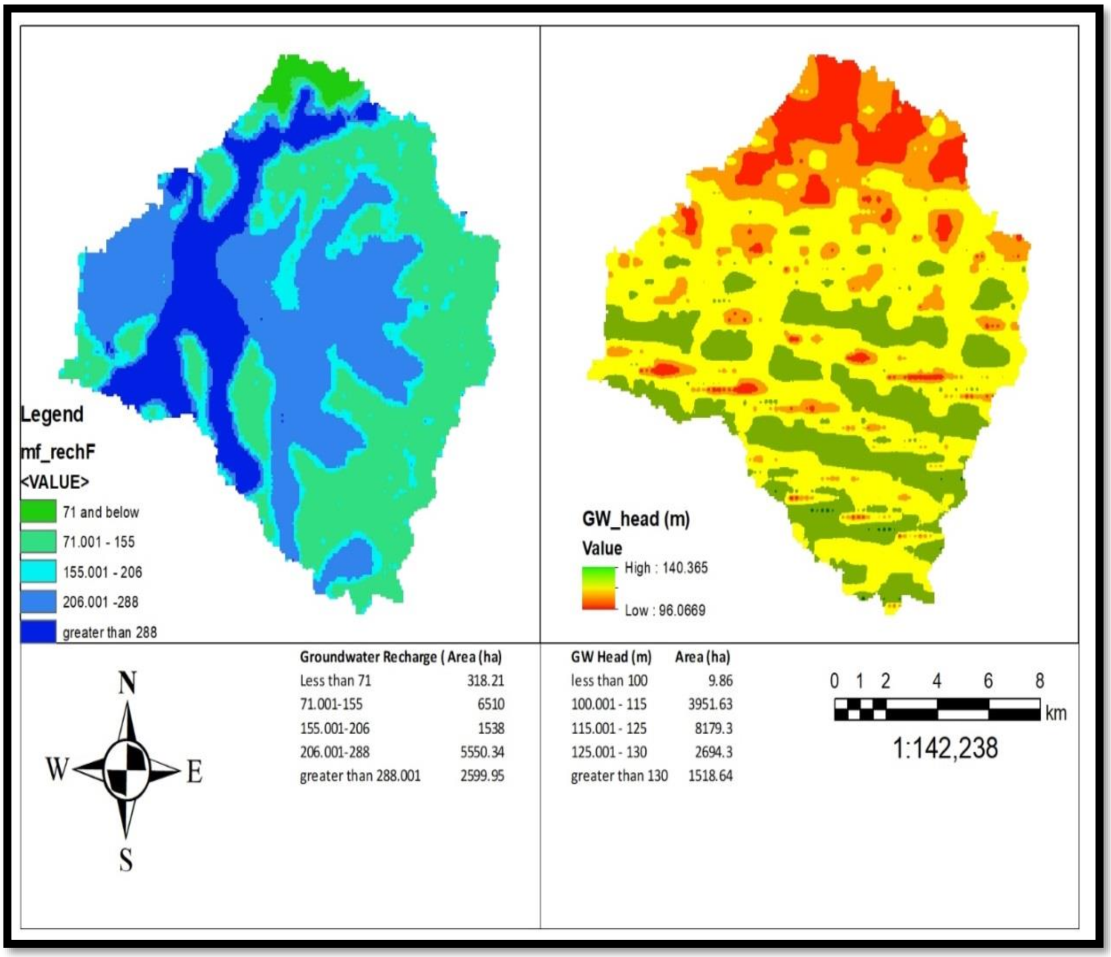

Figure 6.Simulated groundwater recharge spatial coverages and groundwater hydraulic Head of the Quiaoit River watershed using SWAT-MODFLOW.

Table 3.Groundwater hydrology response at different scenarios.

GROUNDWATER PARAMETER	BASELINE	SCENARIO 1	PERCENT CHANGE (%)	SCENARIO 2	PERCENT CHANGE (%)
Groundwater Discharge (mm)	897,944.05	888,942.87	1.00	878,638.25	2.15
Water Yield (mm)	1,876,751.23	1,876,650.92	0.01	1,876,650.92	0.01
Percolation (mm)	947,740.30	938,302.01	1.00	919,781.96	2.95
Total Soil Water (mm)	156,786.30	156,790.25	0.00	156,786.30	0.00
Lateral Flow (mm)	30,773.18	29,079.06	5.51	28,548.28	7.23

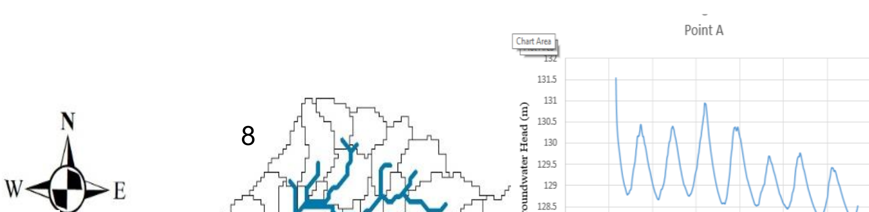

Figure 7.Simulated groundwater recharge at different groundwater head time series of aquifer at observation points of the Quaioit River networks using SWAT-MODFLOW.

4. **CONCLUSI**ON

The coupled SWAT-MODFLOW model was successfully applied in the QRW to quantify land use changes and groundwater hydrologic responses at differing scenarios. The results of the coupled SWAT-MODFLOW model are adequate with regards to simulating streamflow and groundwater recharge and hydraulic heads. The existing model can be useful for management purposes, qualifying the water resources managers to quantify spatial groundwater vulnerability in the area.

Moreover, the study shows the impact of judicious land use changes, though it does not consider the usage of water in the watershed considering the huge increase of crop production. It is recommend that a follow-up study should be done to quantify the effect of agricultural expansion to groundwater hydrologic responses considering the huge requirements of water for irrigation considering groundwater as the second most reliable water source in the watershed for agricultural and other uses. Such irrigation coding program of SWAT-MODFLOW is recommended for further computer programming development and evaluation and can be applied in other similar watersheds.

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