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Quantifying Impacts of Climate and Land Use Change on Groundwater Hydrology and Sustainability of the Quaioit River Watershed

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ABSTRACT

Water plays a vital role in our daily activities. As the world's population increases, water demand increases. Water is subject to pressure due to land use and climate changes. Groundwater, tagged as the most reliable alternative resources is in no exemption and must be studied with proper technology for sustainability. SWAT and coupled SWAT-MODLFOW were used to simulate the impact of land use and climate change on the QRW groundwater hydrology and sustainability. The study aimed to: simulate the impacts of land use change using historical change, municipal land use plan, and future demand for land use conversion; simulate the impacts of climate change on groundwater; simulate the combined impacts (LUCC); and provide policy recommendation towards groundwater sustainability. The results of the study show that the SWAT model can adequately simulate the streamflow and efficiently characterize the watershed. The SWAT and SWAT-MODFLOW revealed that urban expansion decreases both the annual recharge of the watershed and the urban areas. A combination of urban, agricultural and grassland expansion, respectively, would increase the groundwater recharge while decreases the urban groundwater recharge. Simulating the 2035 and 2050 climate scenario would both increase groundwater recharge. LUCC1 and LUCC2 (LUCC projections) both increases the groundwater recharge which varies on the individual quantified impacts. Considering the extraction and different demands of water in the watershed, the groundwater recharge and storage can meet the demand for water for the next 15 years. Yet, the study revealed that wet season becomes wetter, while, dry season becomes drier. Under land use and climate changes projections, monthly groundwater supply will abruptly change. It is therefore recommended that a municipal policy should be implemented to protect the groundwater resources against overexploitation. A policy that could mitigate the effect of climate and land use changes on groundwater resources and watershed preservation for sustainability.

Keywords: *Land Use and Climate Change (LUCC), Soil and Water Assessment Tool (SWAT), SWAT-MODFLOW, Streamflow, Watershed Hydrology, Watershed Sustainability, Quiaoit River Watershed (QRW).*

1. INTRODUCTION

World's population grows abruptly resulting in the ever increasing demand of basic necessity with water supply as most needed, yet at least attention. According to Altieri (2016) [1], water, a finite resource, is one of the most integral and important aspects of daily life for every human being—food, clothing, and almost everything else humans interact with involves water. As the demand of food, space, shelter, and other human needs increases as result of population growth, land and water resources are forced to produce more, thus, resulting in degradation. Throughout history, environment degradation has primarily been the push of the efforts to secure improved standards of food, clothing, shelter, comfort, and recreation for the growing numbers of people[2]. In the absence of environmental management and sustainability, it will come a point that such resources will not bring benefit to human but will cause casualties to human societies [10].

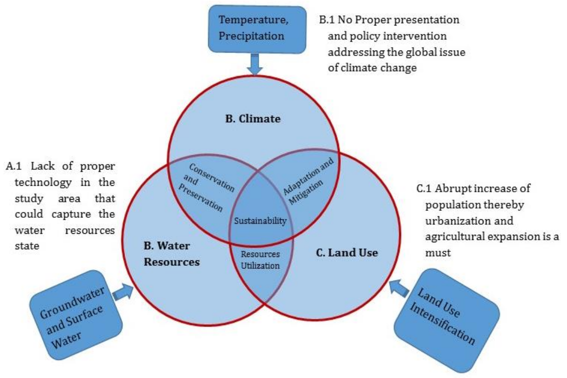

Figure 1. The Conceptual Paradigm of the Study.

The importance of groundwater resource has been already rising due to the increasing demands of human activities, from production to consumption. Groundwater pollution were noted by various studies from different places [6] This observed occurrence are pieces of evidence that groundwater resources are facing problems, thus water resources degradation. To address such issues of groundwater contamination and limiting water supply, groundwater sustainability must be implemented [3]. Capturing the scientific projection of the state and scenarios of groundwater must be taken to take the first step of sustainability. This is to define the real (if not exact, at least approximate) picture of the problem of the resources. Considering climate change and land use, two of the most global concerns nowadays, raises the general challenge of water resources, how to ensure sustainability. Anderson (2014) [2] defined groundwater sustainability as the beneficial use of groundwater to support present and future generations, while, ensuring that unacceptable consequences do not occur.

Quaioit River Watershed (QRW), located in the Northern Philippines, offers resources for the needs of people living along its area. Covering the 1 City and 2 Municipalities, the watershed caters to numerous livelihoods for the various communities.

A Study [8] highlighted the pressure imposed to water supply due to changing land-use and urban development. This high pressure is evident to the doubling of built up area from 391.24 to 743.69 ha, in seven years [2007-2013] due to the drastic increase of population in the area, from 79,960 to 86,555, with projections to becoming 94,848 and 103,833 in 2020 and 2051 [8]. The study [1] also highlighted the decreased of inland water (from 257.95 to 33.50 ha) is due to the increasing extraction of water for agricultural use. The watershed is also facing gradually-changing meteorological characteristics. Another study [6] revealed that the variability of rainfall and temperature of the Province of Ilocos Norte (where the QRW is located) from 1976-2010, the annual temperature was found to increase from 27.1°C to 27.3°C indicating a significant change in the monthly rainfall pattern and a slight change in the peak rainfall pattern. They [6] also observed the annual increase of frequency (0.288 per year) and intensity of tropical cyclone, and an annual increase of rainfall by 92.7 mm. These increases were associated with heavy rainfall, frequent rainfall during wet season and other rainfall pattern changes.

GIS has been shown as a very effective and efficient application to various issues in water resources management. It is widely used in other countries for time and cost-efficient planning. Various GIS software have also been developed and applied for proper compilation and analysis for the best management practices. Soil and Water Assessment Tool (SWAT) known as a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds, and is considered as public domain hydrology model with the following components: weather, surface runoff, return flow, percolation, evapo-transpiration, transmission losses, pond and reservoir storage, crop growth and irrigation, groundwater flow, reach routing, nutrient and pesticide loading and water transfer [7]. SWAT-MODFLOW is an integrated hydrological model that couples SWAT land surface processes with spatially-explicit groundwater flow processes [12].

The goal of this study is set to quantify the impact of land use change and climate change to groundwater resources to adequately serve the possibility of regional scale policy to protect and conserve groundwater resources against the destructive effect of the two

Table 1. Land and climate change (LUCC) scenarios for the model.

Scenario	**Land Use and/Climate Change**			
	AGRL	RNGB	FRST/FRSD	CLIMATE CHANGE
LUC1	5% to URBN			
LUC2	10% to URBN	50% to AGRL	50% to RNGB	
CC1				2035 CCP
CC2				2050 CCP
LUCC1	5% to URBN			2035 CCP
LUCC2	10% to URBN	50% to AGRL	50% to RNGB	2050 CCP

aforementioned global issues. The study considered three main field in the water cycle namely; land use, groundwater, and climate (Figure 1). These factors are essentials to each other. They provide significant role for each other. The study noted the problem of capturing the state of groundwater resources and the groundwater hydrological response of the impact of climate change and land use change in the watershed. The study also introduced some scientific approach to characterize groundwater based on the locally available data required by SWAT and SWAT-MODFLOW application.

Specifically, the study aims to: simulate the impacts of land use change using historical change, municipal land use plan, and future demand for land use conversion; simulate the impacts of climate change on groundwater; simulate the combined impacts (LUCC); and provide policy recommendation towards groundwater sustainability.

2. METHODOLOGY

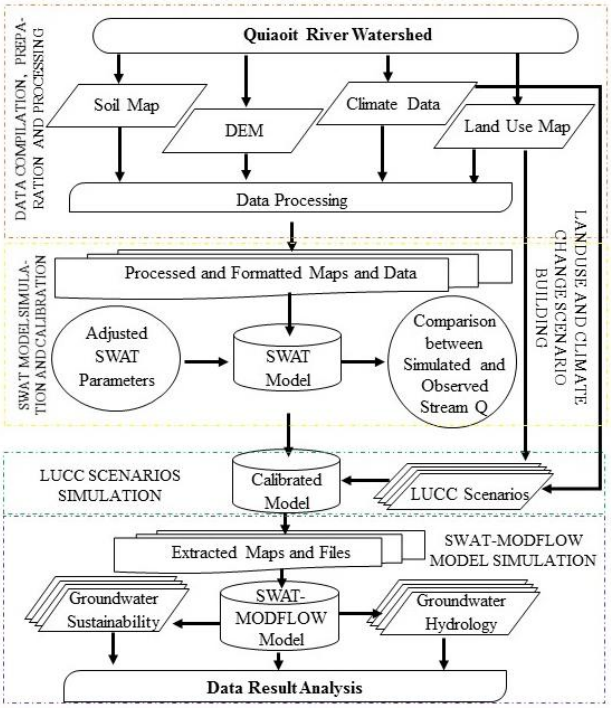

Figure 2. Operational Framework of the Study

The study was conducted in the Quiaoit River Watershed (QRW) located in the Ilocos Region of the Philippines. The watershed has a total land area of 18,960.23 hectares. The area has two pronounced season: wet season (June to October) and dry season (November to April).

The study was divided into various major and consecutive methodologies (Figure 2) namely: Data Compilation, Preparation and Processing; Land Use and Climate Changes (LUCC) Scenario Building; SWAT Simulation and Calibration; LUCC Scenario Simulation; and SWAT-MODFLOW Model Simulation. These various sub-methodologies were discussed on the following sub-sections.

2.1. Data Compilation, Preparation, and Processing

Data collected includes Soil map, Land Use map, Digital Elevation Map (DEM), Meteorological Data, Land Use Map, Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) climate projection in the area and Comprehensive Land Use Plan (CLUP) of the involved Local Government Unit (LGU). These raw data were analyzed, tabulated, and processed based on the required format and needs of the GIS computer application.

2.2. Land Use and Climate Changes (LUCC) Scenario Building

The collected PAGASA climate projections and the LGU’s CLUP was used to developed LUCC scenario. Table 1 shows the LUCC scenarios that was used in the study.

2.3. SWAT Model Simulation and Calibration

The SWAT 2012 model [13] and QSWAT3 v1.1 22 were used in the study.

To ensure that the SWAT model is reliable and a better predictor than the mean, some statistical tools were used to determine the likeliness of the predicted and observed streamflows. The efficiency of the model to simulate hydrologic processes occurs in the watershed was evaluated using the Nash and Suctliffe (1970) equation shown below:

$$NSE= 1-\frac{\sum_{i=1}^{n}(X_{mi}-X_{pi})^2}{\sum_{i=1}^{n}(X_{mi}-X_{m})^2} \qquad (1)$$

where: NSE is the efficiency of the model; X_{mi} is measured value of the stream flow, m3/s X_{pi} = predicted value of the stream flow, m3/s; and X_m = average measured value of the stream flow, m3/s. A value of NSE = 1.0 indicates a perfect prediction, while, negative values indicate that the predictions are less reliable than if one used the sample mean instead [9].

Pearson Correlation R was also used to measure the relationship between the simulated and observed streamflow. A negative relationship proved a poor association between the two variables, while, positive r indicates that the observed and simulation is well associated. Computation of Pearson R was done in Microsoft excel. +1 r value indicates that the model predicted has a perfect relationship with the observed. In this case, the model shows a perfect result with regards to the observed streamflow. Coefficient of Determination

(R^2) was also used to measure how fitted the two variables (between observed from selected sites along river networks and predicted streamflows from simulated SWAT model) with the regression line. The coefficient of determination is the squared value of the Pearson R. A +1 R^2 indicates perfect fitted variable values with the regression line. This simply means that the model is perfectly fitted with the current situation. On the other hand, R and R^2 values that approaches zero indicate a weak relationship and lesser reliable prediction model. Furthermore, Pearson R and the coefficient of determination (R^2) were computed in Microsoft excel.

Root mean-square error (RMSE) was also used to determine the absolute fit of the predicted streamflow to the observed streamflow. An RMSE that is equal to zero is a perfect fit of the model to the observed data. Also, RMSE is calculated using the following formula:

$$RMSE = \sum_{i=1}^{n} \sqrt{\frac{(X_{pi}-X_{mi})^2}{n}} \qquad (2)$$

Table 2 shows the SWAT model parameters adjusted parameters during the calibration for the calibrated model to better capture the current scenario of the watershed in terms of its hydrologic cycle.

Table 2. The SWAT model adjusted during calibration

Parameters	Default Value	Calibration Value
Baseflow alpha factor, Alpha_BF	0	0.05
Curve Number, CN2	-*	+10
Manning's n for the main channel, CH_N2	0.014	0.075
Linear factor, SPCON	0.001	0.01
Exponential Factor, SPEXP	1.5	2.0

** varies by land use.*

These adjusted SWAT parameters give an effective and efficient model to simulate a watershed. Table 3 shows the computed statistical parameters showing the comparison of the observed and simulated values of streamflow in the two stations set in the watershed.

Table 3. Comparison between the simulated and observed runoff volumes at the two stations.

Statistical Parameters	Station 1		Station 2	
	Obs Q	Sim Q	Obs Q	Sim Q
Mean (m3/s)	0.159	0.089	0.301	0.239
R	0.920		0.978	
R^2	0.847		0.955	
NSE	0.328		0.833	
Ttest (P value)	0.092		0.453	
RMSE	0.092		0.084	

Figure 3 presents the calibrated model that demonstrates a clear response of the simulated streamflow to extreme rainfall events resulting in high streamflow discharge. With this statistical and graphical results of the calibrated model, it can be concluded that hydrologic processes in the specific watershed can be modelled realistically using the SWAT model.

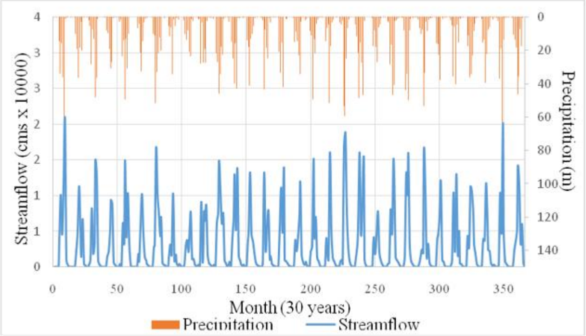

Figure 3. Simulated Streamflow Superimposed with the Weekly Rainfall at the Watershed

2.4. LUCC Scenarios Simulation

After the most efficient and effective model were calibrated, the different scenario developed for the study were simulated using such calibrated model.

2.5. SWAT-MODFLOW Model Simulation

SWAT outputs were again extracted and processed in accordance to the required format that the SWAT-MODFLOW needed. This is to simulated the corresponding Groundwater Hydrology. This groundwater hydrology, through time, will become the basis in conceptualizing the policy for the protection of the groundwater resources of the watershed.

3. RESULT AND DISCUSSION

3.1. Impact of Land Use Change on Groundwater Hydrology

Undoubtedly, land use change can give a state of change of the groundwater hydrology. This is due to the different land use responses to water recharge to groundwater. Table 4 reveals that deep groundwater recharge is affected with such ground surface changes. LU1 scenario decreases the annual rate of groundwater recharge of 0.1624 mm, while, LU2 scenario increases the annual rate of groundwater recharge [11] for the whole watershed of about 0.02527 mm.

While, the rate shows a versatile change for the whole watershed, an annual decrease of groundwater recharge of the urban areas was also observed. LU1 and LU2 decrease the annual rate of urban groundwater recharge of 0.1626 mm and 0.2077 mm, respectively. While, the two affects the rate of recharge on the shallow groundwater, land use changes were also noted to affect the recharge of the deep aquifer.

Table 4. The Groundwater hydrology (mm/year) of the QRW at different land use scenario

Scenario	Watershed Groundwater Recharge (mm/yr)	Urban Groundwater Recharge (mm/yr)	Groundwater Deep Aquifer Recharge (mm/yr)	Groundwater Discharge (mm/yr)
CUR	129,912.6129	3,699.8488	6,495.6365	117,060.3253
LU1	129,912.4504	3,699.6862	6,495.6288	117,060.1693
LU2	129,912.6381	3,699.6411	6,495.6368	117,060.3431

As for the same behavior from the shallow groundwater, the deep groundwater also responses with the two land use changes differently. While, in LU1 decreases by 0.00773 mm in a year, LU2 increases by 0.0267. LU2 almost maintains the annual rate of recharge of the deep groundwater recharge. A great land change was done in land use but the recharge is almost the same for deep aquifer.

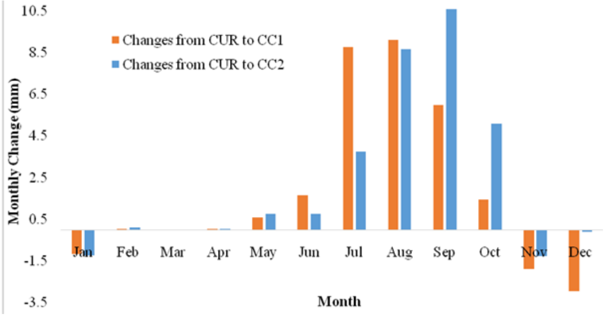

Figure 4. Monthly Trend Analysis on the Groundwater Recharge Changes from Current to the Two Climate Scenarios.

3.2. Impacts of Climate Change on the Groundwater Hydrology

Climate change is expected to change the behavior of the groundwater [4]. Climate change includes the changes in rainfall and temperature. CC1 simulated the 2035 climate projection of the PAGASA, while, CC2 adopts the projected changes of climate by the PAGASA in 2050. Under these scenarios, changes on rainfall and temperature vary through months.

Figure 4 and Table 5 shows the different quantified response of groundwater hydrology at given climate changes. Table 5 shows that deep aquifer increased under both climate scenarios by 1.1 mm and 1.44 mm per year, respectively. CC1 increases the annual recharge by 22.59 mm, while, CC2 increases by 28.88 annual rate of recharge in the watershed.

It should be noted that the groundwater recharge monthly trend behaved differently with the CC2 scenario (Figure 4). Also, a decrease of groundwater recharge occurred from October to

March (0.79, 2.05, 0.75, 0.28, 0.10, 0.04 mm, respectively) and June (5.39 mm). Thus, 57.34% of such decreases the subtotal of the groundwater recharge that occurs during the month of June. Furthermore, the subtotal increase of the groundwater was 38.27 mm. Moreover, 91.12 % of

such increase occurs in July to September (10.94, 14.18 and 9.75 mm, respectively). During the summer period, may (0.31 mm) and April (3.08 mm) were also noted to increase the groundwater recharge under CC2 scenario.

Table 5. The groundwater hydrology (mm/year) of the QRW at different climate scenario.

Scenario	Watershed Groundwater Recharge (mm/yr)	Groundwater Deep Aquifer Recharge (mm/yr)	Groundwater Discharge (mm/yr)
CUR	129,912.6129	6,495.6365	117,060.3253
LU1	129,935.2069	6,496.7671	117,081.8748
LU2	129,941.4897	6,497.0783	117,087.4389

Table 6. The groundwater hydrology (mm/year) of the QRW at different land use and climate change (LUCC) scenario.

Scenario	Watershed Groundwater Recharge (mm/yr)	Urban Groundwater Recharge (mm/yr)	Groundwater Deep Aquifer Recharge (mm/yr)	Groundwater Discharge (mm/yr)
CUR	129,912.6129	3,699.8488	6,495.6365	117,060.3253
LU1	129,912.4504	3,699.6862	6,495.6288	117,060.1693
LU2	129,912.6381	3,699.6411	6,495.6368	117,060.3431

Groundwater discharge (baseflow) (please see Table 4) also increased at the two climate changes. CC1, on one hand, increased groundwater discharge by 21.55 mm per year. On the other hand, CC2 increased groundwater discharge by 27.11 mm per year. While, the yearly trend increased the groundwater discharged, the groundwater discharge behaved differently under monthly trend (please see Figures 4). The majority of the months had an increased groundwater discharge. Under CC1, the months of July to September (8.76 mm, 9.09 mm and 5.96 mm, respectively) were noted to have a great increase in groundwater discharge (please see Table 5). Out of the 27.56 mm subtotal increase of the watershed, 86.41% represented by the increase occurs in the months of July to September. 80.45% of the subtotal decrease of groundwater discharge was noted in the months of November (1.88 mm) and December (2.95 mm). Under CC2, the peak discharge is observed during the months of July to October (discharge change from current scenario as follows: 3.73 mm, 8.66 mm, 10.58 mm, 5.09 mm, respectively). 94.42% of the subtotal of 29.72 mm increase in groundwater discharge occurred in these four months.

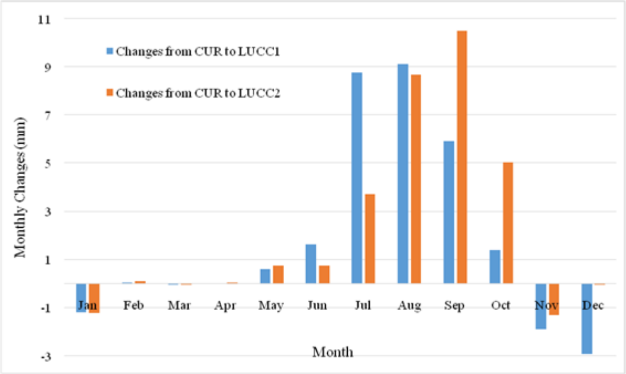

Figure 5. Monthly Trend Analysis on the Groundwater Discharge (Baseflow) Changes from Current to the two Land Use and Climate Scenarios.

3.3. Impacts of Land Use and Climate Change on the Groundwater Hydrology

While, the groundwater discharge and recharge show various quantified values by the individual impact of land use and climate change [11], a combined impact of the two were also investigated. Table 6, responses at two different land use and climate change. In Table 6, an increase of 22.56 mm/year is

quantified due to LUCC1, while, an increase of 28.82 mm per year is also observed due to LUCC2 of the watershed groundwater recharge. The deep aquifer also increased by 1.12 mm per year under Figures 5 and 6 show that groundwater had various LUCC1 and 1.44 mm per year under LUCC2. Furthermore, Figures 6 reveal how the changes occur in monthly rate for every scenario prediction. The decrease has 5.97 mm subtotal on the groundwater discharge under LUCC1. This decrease occurs in the month of January (1.17 mm), March (0.04 mm), November (1.88 mm) and December (2.91 mm). The rest of the months had increased groundwater discharges. The following months, however, have the increased groundwater discharge: February – 0.043 mm, April – 0.32 mm, May - 0.59 mm, June – 1.64 mm, July – 8.76 mm, August – 9.10 mm, September – 5.91 mm, and October – 1.41 mm. While, under LUCC1, increased groundwater discharge had been noted - the months of July, August, and September contributed 86.48 of the subtotal. Under LUCC2, the subtotal of the decreased groundwater discharge is 2.557 mm, while, the increased is 29.61 mm in a year. The months that contributed to the decreased groundwater are the months of January (1.3 mm), December (0.03 mm), January (1.22 mm), and March (0.007 mm). While, 94.40% of the subtotal increase on groundwater occurs in the month of July (3.73 mm), August (8.68 mm), September (10.5 mm), and October (5.05 mm). The yearly increase of groundwater discharge in the watershed is 21.52 mm under LUCC1 and under LUCC2, it is 5.54. Urban groundwater recharge and discharge also noted an increase under land use and climate change scenarios. Under LUCC1, the urban groundwater recharge increased by 2.87 mm per year and urban groundwater discharge have an increase of 2.68 mm per year. Under LUCC2, the urban groundwater recharge was noted to have an increase of 0.0728 mm per year, while, the urban groundwater discharge was noted to have a decrease of 0.043 mm per year.

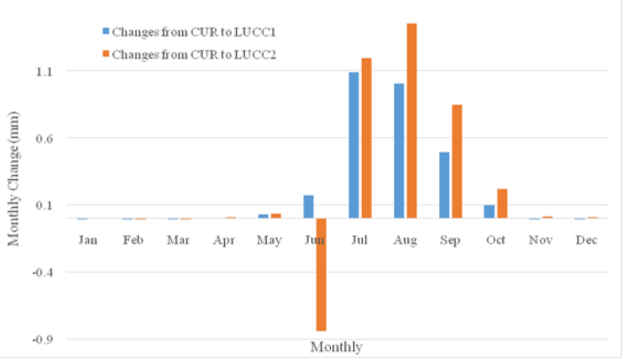

Figure 6. Monthly Trend Analysis on the Urban Groundwater Recharge Changes from Current to the Two Land Use and Climate Scenarios.

Figures 6 show the trend of groundwater recharge on urban areas. Under changing land use and climate, the groundwater recharge had different response throughout the year (please see Table 6). Under LUCC1, groundwater recharge had zero to very little decrease in the month of November to December (0.002 – 0.008 mm) and January to March (0.001 – 0.006 mm). While, the rest of the months noted increased recharge. The months of July to September had the peak groundwater recharge. Under LUCC2, it can be noted that throughout the years, the urban groundwater recharge increases, except in the month of June, which has an abrupt decrease of 0.84 mm per year. It was also observed that the majority (98.13%) of the water recharges of groundwater occur during the months of July to September.

3.4. Implications and Recommend Mitigation of the Impact of Land Use and Climate Change

The impact of land use and climate change on groundwater hydrology significantly varies at different scenarios. The conversion of agricultural land, on one hand, to urban area would decrease the groundwater recharge and may subject urban groundwater to over exploitation of the resources. The conversion of grassland, on the other hand, to agricultural land and forest areas to grassland favors the groundwater with an increasing groundwater recharges that may be used for crop irrigation. Yet, the extensive conversion of forest land to grassland abruptly increases the groundwater discharge that contributed to streamflow discharges. Moreover, the conversion of grassland to agricultural land and forest land to grass land also increases stream sediment yield that resulted in river siltation, reducing the capacity of river networks to drain excess water.

Moreover, the climate change scenarios provided in the study also favors the groundwater resources. It provides greater recharge on both climate scenarios. However, the simulation of the 2035 and 2050 climate scenarios revealed that on the monthly recharge, there is an uneven distribution of changes. While, wet season increases the recharge rate of groundwater, dry season has a decrease of groundwater due to the decrease of rainfall during these months of the year. There are also notes that in future scenarios, some months become drier during wet season. Both climate scenarios also increase dramatically groundwater discharge that contributed to massive stream discharge. These could result infrequent and deeper flash floods to vulnerable areas.

Considering the impact of land use and climate change, retained groundwater resources declined due to higher demand of urban areas and agricultural land, increased groundwater discharge under extensive land use conversion, and over exploitation in urban groundwater areas due to lesser groundwater recharge as affected by the construction of impervious layer of urban areas. While, urban areas increase and groundwater discharge also increases, vulnerable places in the watershed to flash flood will also increase, specifically, in the months of July to October. While, these months have huge amount of water, the rest of the months were noted to have decreasing groundwater resources resulting in being gradually unavailable due to uneven distribution of groundwater recharges.

With these implications of such changes, mitigation must be addressed to reduce the adverse impacts of land use and climate change in the watershed. Based on the results of the simulation, the following are recommended:

Land use conversion. A compliment policy that protects the nature state of the watershed. This is an additional feature of the existing policy that will provide information and educate the involved community on the adverse impacts of deforestation and agricultural expansion. Groundwater may increase yet vulnerable areas on flash floods will frequently be affected.

Urban groundwater may face over exploitation in the near future resulting in being unavailable for human consumption. An urban groundwater recharge facilities or well must be constructed along with the expansion of urban areas.

Climate change. Climate change affects the extent of wet season and dry season. The months of wet season become wetter, while, months during the dry season become drier. Anent to this notion, agricultural pattern must be changed according to the adverse impacts of climate change.

Land use and climate change. While urbanization expand, climate change increases rainfall events. The more water falls in the watershed, the more groundwater discharges in the streams, thereby, increasing the frequency of areas that are vulnerable to flash floods. It may also expand because of increased streamflow. The expansion of river beds that increase the river capacity to hold water is recommended to the involved towns. Moreover, additional stream network is suggested to reduce the flood waters invulnerable areas, especially, in agricultural land and urban areas.

Groundwater sustainability. Land use decrease groundwater, specifically, in urban areas. Climate change enhances groundwater recharges. The result of the study showed that groundwater sustained at the end of the year can meet the demand of water by its habitant. However, in a monthly trend analysis, land and climate change affects the availability of water throughout the year. All scenarios decrease the sustained groundwater almost all or some of the months. It is hereby recommended that a surface water reservoir (e.g. SWIP, Dam) should be constructed to store groundwater discharges that can regulate the adverse impact of streamflow discharge (e.g. flood) and to bring water to the community during dry seasons.

4. CONCLUSION

Groundwater is the most reliable alternative and reliable source of water throughout the year. In recent decades, communities are relying their source of water to groundwater knowing that it has a huge amount of water stored. Because of unavailability of a technology that can simulate the state of the groundwater, early communities were not able to capture the state of groundwater. With the newly built and conceptualized theorem and with the help of the computer technology, groundwater state can now be simulated and visualized. SWAT is a GIS-based software that helps to simulate the impact of human activities and other drivers that brings water stress to the natural water cycle. The study showcased the concept of

SWAT and SWAT-MODFLOW to quantify the impacts of land use and climate changes on the groundwater hydrology and sustainability.

The results of the study showed that SWAT and SWAT-MODFLOW can characterize the groundwater state of the watershed in terms of groundwater recharge and discharge. The simulation revealed that urban and agricultural lands have the least groundwater recharge per unit area. During the comparison, the daily simulated groundwater head had different values as compared to observed groundwater head. The simulated model is accurate for a watershed wide simulation. A specific site simulation must have a daily observation of drawdown and groundwater pump schedule to better simulate a site specific location study.

Land use conversion affects the groundwater recharge and discharge of the watershed. The expansion of urban areas decreased urban groundwater, while, deforestation increased groundwater discharge. Climate change increased groundwater recharge, while, it also increased groundwater discharges. Land use and climate change affect the behavior of the groundwater of the watershed. While, groundwater increased, groundwater discharge also increases having an adverse impact on areas that are vulnerable to flash floods.

With the above constraints of land use and climate change, groundwater sustainability was noted to decline throughout the year. It is hereby recommended to develop and implement policy to protect, conserve, and maintain the natural state of the watershed. These are the following: (1) compliment policy that will educate the community to the adverse impact of land use and climate change; (2) construction of urban groundwater recharge facilities or wells; (3) development of cropping pattern; and (4) construction of surface water reservoir (e.g. SWIP, Dam, etc.).

After all, SWAT and SWAT-MODFLOW models are able to simulate the hydrological processes of the watershed. It can also quantify the impacts of land use and climate change to the groundwater hydrology and sustainability.

AUTHORS' CONTRIBUTIONS

The author of this article had contributed to the body of science by compiling necessary information, documents and problems that were used to the success of this research. This study that was successfully conducted contributed to the Soil and Water Resources Management, Climate Change, Environmental Conservation. This also contribute to groundwater resources conservation and protection to reserve water for sustainability for the future generation and environmental protection.

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REFERENCES

[1] Altieri D., 2016. The Effects of Overpopulation on Water Resources and Water Security. Retrieved from http://fubini.swarthmore.edu/~ENVS2/dan/Essay4.html on January 15, 2019.

[2] Anderson, M. (2014). Groundwater research and management: new directions and re-inventions. In M. Taniguchi and H. Tatsuya (Eds.), *Groundwater as a key adaptation to changing climate and Society, Global Environmental Studies* (pp. 1-16). Springer Japan 2014. DOI: 10.1007 1978-4-431:54968.

[3] De Vries, J.J. (2007). History of Groundwater Hydrology. In J. DELLEUR (Eds.), *The Handbook of Groundwater Engineering-Second Edition.* (pp. 24-63). Taylor & Francis Group, LLC. London New York.

[4] Epting, J., Michel, A., Affolter, A., and Huggenberger, O. (2021). Climate change effects on groundwater recharge and temperature in Swiss alluvial aquifers. *Journal of Hydrology X, 11,* 100071.https://doi.org/10.1016/j.hydroa.2020.100071

[5] FAO (2018). *Soil and Water Assessment Tool (SWAT).* http://www.fao.org/landwater/land/land-governance/land-resources-planning too lbox/category/details/en/c/1111246/. July 16, 2018.

[6] Galacgac E.S., C.G. Acosta, N.R. Alibuyog (2013). Variavility of Rainfall and Temperature in Ilocos Norte, Philippines. *MMSU Science and Technology Journal*. 3(2) ISNN:2012 0060.

[7] Konikow L.F., T.E. Reilly. P.M. Barow and C.I. Voss (2007). Groundwater Modeling. In J. Delleur(Eds.), *The Handbook of Groundwater Engineering Second Edition.* (pp. 816 - 867). Taylor & Francis Group, LLC. London New York.

[8] Manzano V.P. and N.R. Alibuyog (2014). The hydrological Capacity of the Quiaoit River Watershed (QRW). *MMSU Science and Technology Journal Vol. 4 No. 1 – January – June 2014*. ISSN: 2012 0060. Retrieved from

http://research.mmsu.edu.ph/stjournal/vol4_hydrological_capacity_of_qrw.pdf

[9] Nash, J., and Sutcliff, J. (1970). River flow forecasting through conceptual models part I – A discussion of principles. *Journal of Hydrology, 10*(3), 282-290. https://doi.org/10.1016/0022-1694(70)90255-6

[10] National Climate Assessment (2014). *Climate Change Impacts in the United States.* U.S. Global Change Research program 1800 G Street, NW, Suite 9100, Washington, D.C. 20006 USA. https://nca2014.globalchange.gov/

[11] Priyantha Ranjan, S., Kazama, S., and Sawamoto, M. (2006). Effects of climate and landuse changes on groundwater resources in coastal aquifers. *Journal of Environmental Management*, *80*(1), 25-35. https://doi/10.1016/j.jenvman.2005.08.008

[12] SWAT. (2020). SWAT-MODFLOW. Retrieved at https://swat.tamu.edu/software/swat-modflow/#:~:text=SWAT%2DMODFLOW%20is%20an%20integrated,spatially%2Dexplicit%20groundwater%20flow%20processes.&text=A%20user%20interface%20to%20facilitate,been%20tested%20in%20several%20watersheds on September 11, 2020.

[13] Winchell M., R. Srinivasan, M. Di Luzio, and J. Arnold (2013). *ArcSWAT Interface for SWAT 2012 – User's Guide*. Grassland, Soil and Water Research laboratory. USDA Agricultural Research Service. 808 East Blackland Road – Temple, Texas 76502