Environmental Research 185 (2020) 109440

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Impacts of land-use changes on the groundwater recharge in the Ho Chi Minh city, Vietnam

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ARTICLE INFO

Keywords:
Groundwater recharge
Land-use
SWAT
Dyna-CLUE
Urbanization
HCMC

ABSTRACT

Ho Chi Minh City (HCMC), Vietnam has undergone tremendous transformation in land-use practices in the past few decades. The groundwater-related issues have also been a major concern in the fast-growing southern city of Vietnam. Quantitative prediction of the impact on groundwater recharge due to changes in the land-use pattern of a watershed is crucial in developing sound groundwater management schemes. This study aims to evaluate the impacts of change in land-use patterns on the quantity of groundwater recharge in HCMC. An empirical land-use projection model (Conversion of Land-use and its Effects, Dyna-CLUE) and a hydrological model (Soil and Water Assessment Tool, SWAT) was used for the study.

Three future land-use scenarios of Low Urbanization Scenario (LU), Medium Urbanization Scenario (MU) and High Urbanization Scenario (HU) were developed in Dyna-CLUE focusing on the increase of built-up area to generate land-use maps of HCMC until the year 2100. The land-use maps for all three scenarios were then used in the calibrated hydrological model SWAT to get the future recharge in the near future (2016–2045), mid future (2046–2075) and far future (2076–2100). The recharge was observed to increase in the far future of LU by 10% while reduction of 30% and 52% in annual average recharge was observed in far future of MU and HU respectively. It was, thus, observed that change in built-up area has a significant effect on the groundwater recharge in HCMC.

1. Introduction

Water is a finite, vulnerable and valuable natural resource. According to the United Nations Development Program (UNDP, 2007), Asia is the most vulnerable and scarce freshwater resources area in the world. It has been predicted that freshwater resources will be more scarce in the future due to climate change and increased human demand (Wada et al., 2016; Veldkamp et al., 2017; Boretti and Rosa, 2019). Moreover, the availability of freshwater in terms of quality and quantity will be a major issue. There is lack of infrastructure to utilize freshwater resource which means the use of groundwater will be much more. This means the dependence on groundwater is increasing. It is about 2.78 million trillion gallons of groundwater which is about 30.1 percent of total world's freshwater is estimated for entire planet of Earth (National Geographic, 2010). Groundwater is not only the primary source of drinking water for half of the world's population but also sustains ecosystems in providing water, nutrients and a relatively stable temperature (Tharme et al., 2003; Kløve et al., 2011). Global groundwater resources may be threatened by human development activities and the uncertain consequences of climate change (Treidel et al., 2012).

Groundwater resources can be assessed based on the existing storage capacities, inflow rate into the aquifer systems and outflow rate from the aquifer systems. Groundwater aquifer systems get replenished by groundwater recharge process which is happening predominantly through rainfall-recharge and surface water and groundwater interaction processes. The groundwater recharge processes can be likely influenced by the change in land-use and land cover (LULC) scenarios as the changes can be likely alters the hydrological processes on the earth segment. For example, converting the bare soil cover into more urbanized zones limits the infiltration into the ground thus reduces the recharge rates into the groundwater systems. Groundwater recharge determines the groundwater withdrawal rates in an area for groundwater development and sustainable groundwater resources management (Mohan et al., 2018). There are several methods available for estimating groundwater recharge and they can be broadly classified into physical, chemical, tracer, and numerical modelling methods (Scanlon et al., 2002). The distributed groundwater recharge modelling approach can be conceptual-based or physical-based approaches (Lerner, 1990; Cherkauer and Ansari, 2005; Scibek and Allen, 2006; Batelaan and Smedt, 2007; Yeh et.al, 2007; Wang et al., 2015). Considering the

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https://doi.org/10.1016/j.envres.2020.109440
Received 15 February 2020; Received in revised form 18 March 2020; Accepted 24 March 2020
Available online 31 March 2020

limitations in the fully physical based approach that involves intense datasets and parameterization process while the simplified lumped model approach that limits the variations in the inputs over the space, a semi-distributed approach can be adopted to model groundwater recharge at a catchment scale. A well tested semi-distributed hydrological model which is used for analyzing hydrological components over catchment scale is Soil and Water Assessment Tool (SWAT) (Arnold et al., 2012).

Water resources allocation and planning for the current and future demand will likely be influenced by climate change and land-use change scenarios. The land-use change could happen mainly due to population growth, increasing urban areas, change in agricultural practices and reduction in the net cropped area. These activities in the present and future will likely influence the surface runoff, evapotranspiration and groundwater recharge variations over the spatial and temporal scales significantly (Ansari et al., 2016). There have been many studies that investigated the impact of climate change, land-use change, and mining activities on groundwater recharge (Twine et al., 2004; Hu et al., 2005; Pan et al., 2011; Owuor et al., 2016; Shrestha and Htut, 2016; Techamahasaranont et al., 2017; Trang et al., 2017; Shrestha et al., 2018; Osei et al., 2019; Lamichhane and Shakya, 2020; Shrestha et al., 2020). The application of SWAT model on predicting groundwater recharge due to urbanization or land-use change conditions can be found in Guo et al. (2008) and Zhang et al. (2016). Similarly, another distributed raster-based physical model WetSpass applications in groundwater recharge in response to urbanization effect has been widely studied across the globe (Dams et al., 2008; Tilahun and Merkel, 2009). For instance, Sertel et al. (2019) studied the hydrological water balance for the change in LULC conditions in Buyukcekmece water basin of Istanbul Metropolitan city using SWAT model. They calibrated and simulated the SWAT model for two different scenarios with 1990 and 2006 LULC maps. They found that change in LULC played a significant role in changing the hydrological dynamics in the watershed under the same climatic conditions. They also reported that the water level, groundwater recharge, evapotranspiration and baseflow were highly sensitive to LULC change conditions while soil water was found to be least sensitive. These studies imply that the land-use change will have a significant effect on the catchment hydrological processes and components. Thus, it is vital to study the impact of land-use change on hydrological response to properly manage the water resources systems.

The LULC maps can be generated from the satellite images for the historical and recent times based on the availability of the satellite images. The use of satellite data has become very common as the availability of the satellite images is abundant in recent times. Moreover, the satellite images are widely available with different spatial scales ranging from 250 m to 5 m (Castilla et al., 2014). There have been many studies that have attempted to classify the LULC maps from several satellite data products (Rogan and Chen, 2004; Mishra et al., 2016; Liping et al., 2018; Abdullah et al., 2019). One of the problems with the LULC classification from satellite images is that the cloud cover pixels. The cloudy images are often not suitable to accurately and completely obtain the LULC information from the raw satellite images (Wulder et al., 2016). Sometimes, the classified LULC maps can be obtained from the respective departments in the region so that these maps are ready to use in the hydrological models to simulate the hydrological response of the catchment. As this satellite data information is limited to the historical and current time periods, the generation of such LULC maps are also limited to the historical and current time periods. However, the future LULC scenarios to assess the future hydrological response can be simulated with Dyna-CLUE model (Verburg and Overmars, 2009). The Dyna-Clue model is a dynamic, spatially explicit land-use land cover change model. The application of this model is around many different environments around the world. The most widely applied fields of this model include the simulation of deforestation, land degradation, urbanization, and integrated assessment of land cover change. Therefore, assessing the impact of future climate change and LULC change on hydrological response especially on the groundwater recharge in terms its spatial and temporal distribution is vital for sustainable groundwater management.

Among the Asian Countries, Vietnam's development record in the past 30 years has been remarkable according to World Bank. The GDP growth rate stands at 6.7% in 2017 (World Bank, 2019). Vietnam's population reached about 95 million in 2017 (up from about 60 million in 1986) and is expected to expand to 120 million before tailing off around 2050. The HCMC is the economic center of Vietnam and accounts for a large proportion of the economy of Vietnam. Although the city takes up just 0.6% of the country's land area, it contains 8.34% of the population of Vietnam, 20.2% of its GDP, 27.9% of industrial output and 34.9% of the FDI projects in the country in 2005 (General Statistics Office, Vietnam). According to CCOP-KIGAM (Coordinating Committee for Geoscience Programmes in East and Southeast Asia – Korea Institute of Geoscience and Mineral Resources) collaborative project, the average groundwater water level drops in Hanoi and HCMC has been reported to be 1 m/year and there has been decreasing trend of groundwater levels in many other places of Mekong River Basin due to over-extraction (Vuong et al., 2016). It is evident that HCMC has undergone rapid change and development activities are still on the rise. There has also been a rapid increase in water demand in HCMC. In 2012, the total amount of water supply in the city was about 1.5 MCM/d out of which 44.67% was produced from groundwater (Vuong et al., 2016). There high dependence of groundwater but the recharge has been affected by rapid urbanization. The CCOP-KIGAM project has been mostly targetted on seawater intrusion and land subsidence problems in the Mekong Delta region. However, an assessment of recharge rates due to rapid urbanization, current situation and projected scenarios, has not been specifically studied in HCMC, Vietnam. Therfore it is important to study the impact of LULC change on the groundwater recharge in HCMC to understand the current and future status of groundwater availability for sustainable use of groundwater resources through proper regulation and policy making.

Based on the above discussions, this research aims to quantify the impact of the increase in the impervious built-up area on the groundwater recharge in HCMC. The specific objectives of this research include: i) to model the future land-use change based on three specific scenarios of low urbanization, medium urbanization, and high urbanization scenarios until the year 2100 using Dyna-CLUE model, ii) to predict the future groundwater recharge for the above-mentioned land-use change scenarios in HCMC, and iii) to assess the impact of land-use change scenarios on the groundwater recharge under above-mentioned land-use change scenarios in HCMC.

2. Study area and data collection

2.1. Study area

Ho Chi Minh City, located in on the south end of Vietnam, is one of the largest cities in Vietnam (Fig. 1). It is located from 10° 10′ - 10° 38′ North latitudes and 106° 2′-106° 54′ East longitudes. The city's natural land area is 2095 km^2 (209,500 ha). The HCMC is a municipality where the city has been bifurcated into 24 administrative divisions. Five of the districts, covering the area up to 1601 km^2 are rural while the remaining districts with the area of 494 km^2 are urban. It has the elevation in range of 10–25 m (Fig. 1). The terrain of HCMC can be classified into uplands, lowlands and downtown areas. The upland areas are mostly situated in the northern, north-eastern, and north-western parts of the city. These regions are connected with some hills in the region. The highest hill in this region is Long Binh Hill with the highest elevation of 32 m. The lowlands appear in the southern parts, south-eastern and south-western parts of the city with an altitude of around 1 m. The downtown part of HCMC has the elevation range of 5–10 m (HCMC Geography, 2020).

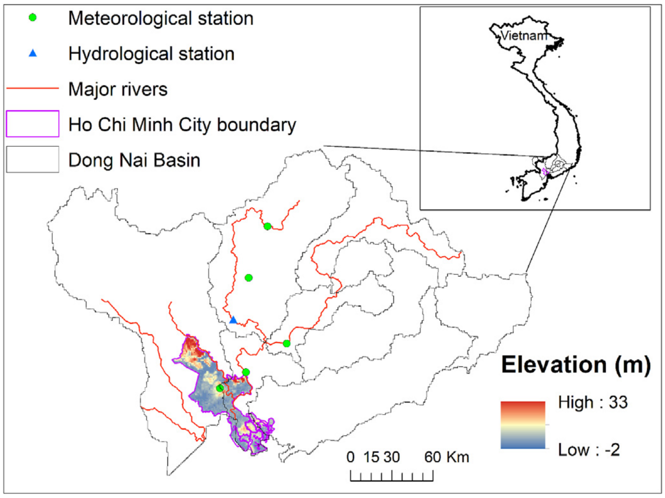

Fig. 1. Ho Chi Minh City with elevation and river networks.

Geology of HCMC consists of two main types of sedimentary formations which include Pleistocene and Holocene formations. The Pleistocene formation mostly covers the northern, north-western and north-eastern parts of the city. On the other hand, the Holocene formation associated with seas, bays, and rivers. The soil types in the HCMC classified into marine alluvial soil, acid sulfate soil, and alkaline soils. The climate in the city can be broadly classified under two distinct seasons which include rainy and dry seasons. The rainy season extends from May to November while the dry season occurs from December to April. The mean annual precipitation is around 2100 mm/year with a spatial variation of 700–3000 mm/year. The mean minimum temperature is 23 °C and the mean maximum temperature is 32 °C. The evapotranspiration varies from 600 to 1350 mm/year spatially. There are 7 different aquifer layers with aquitards in between. The land-use of HCMC is significantly dominated by agriculture in the north, urban settlements in the center and the Can Gio mangrove forest in the south (HCMC Geography, 2020).

The HCMC is located in the downstream of Dong Nai – Saigon river system. This enables the city with a network of rivers and canals systems. The Dong Nai river is draining the water from Lam Vien Plateau with a large basin area of about 45,000 km^2. Thus, this Dong Nai river is the major source of freshwater to the city's water demand. Apart from this Dong Nai river, the river Saigon and the river Nha be are also connected to the HCMC and Dong Nai river. The Saigon river flows along the territory of the city with a stretch of about 80 km in length. The river Saigon has the range in width of 225–370 m and the depth of 20 m. The Nha be river forms at the confluence of Saigon and Dong Nai rivers. The dense network of canals along with these major rivers include Lang The, Bau Nong, Rach Tra, Ben Cat, An Ha, Tham Luang, Cau Bong, Tau Hu, Ben Nghe and so on. These irrigation canals are affected by a diurnal variation of tides that affects crop productions and limits the drainage from the city.

The groundwater potential in the northern part of HCMC is abundant where the groundwater occurrence is associated with Pleistocene sediments. But, in the southern parts of the HCMC, the groundwater is affected by salinity and acidity issues. Therefore, groundwater quality is the main problem in the southern parts of the city. The groundwater is exploited from three-layer which are at 0–20 m, 60–90 m, and 170–200 m respectively. The groundwater withdrawal from the layer 60–90 m is the additional major source of freshwater to the city (HCMC Geography, 2020).

2.2. Data collection

The datasets used in the study include the elevation, land-use, soil,

Table 1
Datasets used in the study.

SN	Data required	Spatial Resolution	Temporal resolution	Number of stations	Time period	Source
1	Digital Elevation Model (DEM)	30 m	–	–	–	ASTER GDEM V2
2	Land cover/Land-use map	200 m	–	–	4 maps- 2000, 2005, 2010, 2015	DoNRE HCMC
3	Soil map	1:5000000	–	–		FAO/UNESCO- digital soil map of the world
4	Rainfall	Point	Daily	7	1978 to 2015	DWRPIS
5	Temperature (Tmin, Tmax) & Evaporation	Point	Daily	2	1975 to 2015	DWRPIS
6	Observed streamflow (m3/s)	Point	Hourly	1	1987 to 2002	DWRPIS
7	RCM: ACCESS-CSIRO-CCAM	0.5°	Daily	–	1975–2099	Collaboration for Australia Weather and Climate Research, Australian Government
8	RCM: CNRM-CM5-CSIRO-CCAM	0.5°	Daily	–	1975–2099	National Center for Meteorological Research
9	RCM: MPI-ESM-LR-CSIRO-CCAM	0.5°	Daily	–	1975–2099	European Network for Earth System Modelling

Note.
DoNRE HCMC: Department of Natural Resources and Environment of Ho Chi Minh City (http://www.donre.hochiminhcity.gov.vn/).
ASTER GDEM V2: Advanced Spaceborne Thermal Emission and Reflection Radiometer (https://asterweb.jpl.nasa.gov/gdem.asp).
FAO/UNESCO: Food and Agricultural Organisation/United Nations Educational, Scientific and Cultural Organisation (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/faounesco-soil-map-of-the-world/en/).
DWRPIS: Division for Water Resources Planning and Investigation for the South of Vietnam. (2008). Annual report on groundwater monitoring. Ho Chi Minh City, Vietnam: DWRPIS.

streamflows, historic climatic datasets such as rainfall and temperature, and projected future climatic datasets of rainfall and temperature based on Regional Circulation Model (RCM) outputs. The spatial and temporal resolutions of the above-mentioned datasets are given in Table 1.

2.3. Historical land-use in Ho Chi Minh city

The land-use of HCMC is significantly dominated by agriculture in the north, urban settlements in the center and the Can Gio mangrove forest in the south. Different industrial activities are ongoing in different parts. The Dong Thap Muoi region in the west is an important agricultural region. The Can Gio mangrove forest is located 40 km southeast of HCMC and the site is an important wildlife sanctuary in Vietnam and UNESCO has listed it as a biosphere reserve. Initially, different land-use types were identified in the study area according to the information available in the land-use maps. These land-use types were consequently subdivided into three groups whereby the first group comprises land-use types for which an aggregated demand is calculated at a national level (e.g. arable land, grassland, permanent crops, and built-up area). The second group includes land-use types for which it is assumed that they remain stable over time as they are not suitable for agricultural or urban purposes or because their alteration is strictly forbidden (e.g. wetlands). The third group contains all other land-use types for which no demand can be calculated based on macroeconomic modelling, but which is rather the result of the net-change of land-use developments within the first category (e.g. recently abandoned land, semi-natural land, forest). But, in this study, the land-use type was grouped into four classes namely: agricultural land, forest, built-up area and water bodies.

The calculated areal coverage of four major land-use types across the years 2000, 2005, 2010, and 2015 in HCMC is shown in Fig. 2a. The area under agriculture has steadily decreased from ~100,000 ha to ~20,000 ha from 2000 to 2015 (Fig. 2a). This is because of the proportionate increase in the built-up area from ~20,000 to ~40,000 during 2000–2015. Moreover, the forest cover has not changed over the years. Currently, more than one-fourth of the total area occupied under forest cover. The proportional percentage of areas occupied by agriculture, built-up areas, forest, and waterbody land-use classes is shown in Fig. 2b. Agricultural areas dominate in the HCMC study area with 41% while water bodies cover by 10%. Forest and urban or built-up areas share the total area with 26% and 23% respectively.

3. Research methodology

The overall methodological framework has been described in Fig. 3. The probable land-use pattern of the city was developed focusing more on the built-up area based on which three future land-use scenarios were developed which are Low Urbanization Scenario (LU), Medium Urbanization Scenario (MU) and High Urbanization Scenario (HU). A land-use projection model Dyna-CLUE was then used to obtain yearly maps until the year 2100 for all the future land-use scenarios. The calibrated and validated SWAT model was supplied with future projected climatic variables such as rainfall and temperature from the RCMs outputs. A linear scaling method was used to bias corret the projected climatic grids with respect to the raingauge stations datasets in the study area. Similarly, the future land-use maps were input into the calibrated/validated SWAT model to simulate future groundwater recharge. The future predicted groundwater recharge for LU, MU, and HU scenarios under near future (2016–2045), mid future (2046–2075) and far future (2076–2100) were analysed in terms of its relative change from baseline groundwater recharge. Furthermore, the risk related to this scenario and alternative measures and adoption practices to minimize the effect of urbanization on groundwater recharge processes are recommended in the HCMC study area.

3.1. Land-use projection using Dyna-CLUE model

The calibration procedure of the Dyna-CLUE model is shown in Fig. 4a. The Dyna-CLUE model simulates land-use change in an iterative method by spatially allotting the national level demands to individual grid cells after stepwise relating the demanded area with the area available for the respective land-use type.

The Dyna-CLUE model takes into consideration scenario-based simulations of the demand for agricultural and urban land, calculated by global economic and integrated assessment models, as well as a local analysis (i.e. logistic regression) of the different possible local driving factors (biophysical, socio-economic) which might determine land-use patterns and their change. Moreover, the combination of a top-down and bottom-up approach allows to spatially allocate demands for different land-use types to individual grid cells.

The conversion sequence for land-use governs the probability of one land-use type changing to the other (Table 2). This is indicated with logical 0 and 1 values where 1 represents the full potential possibility of the conversion from one land-use to another and 0 represents zero possibility of the conversion from a land-use type to other land-use types. Similarly, the conversion elasticity defines the tendency of the land-use type to change to any other category. This value ranges from 0 to 1. The land-use that takes the conversion elasticity value 1 means that it cannot be changed to other land-use types while the land-use takes the value 0 means that it can be easily converted to other land-use types. The intermediate values indicate the relative conversion tendency. In this study, these conversion elasticity values were derived based on the best judgment and practical conditions observed in the HCMC (Table 3).

The Dyna-CLUE model considers five types of input files i.e., land-use demands, location suitability, neighborhood suitability, spatial

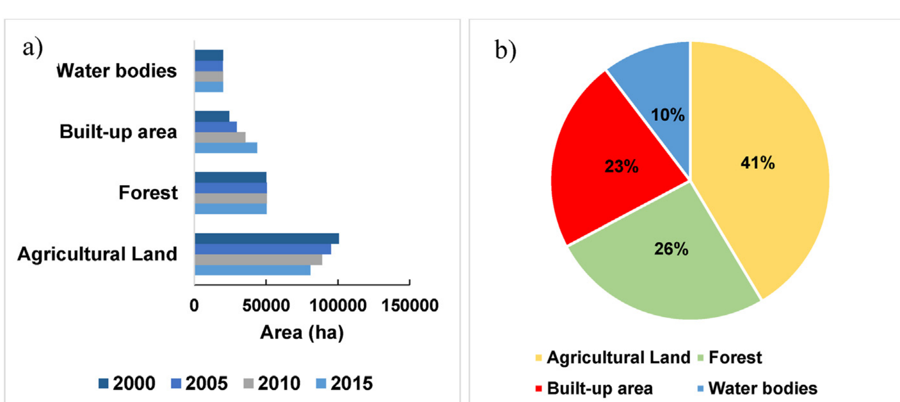

Fig. 2. a) Area of each category of Land-use in 2000, 2005, 2010 and 2015 and b) The percentage of each Land-use category in 2015.

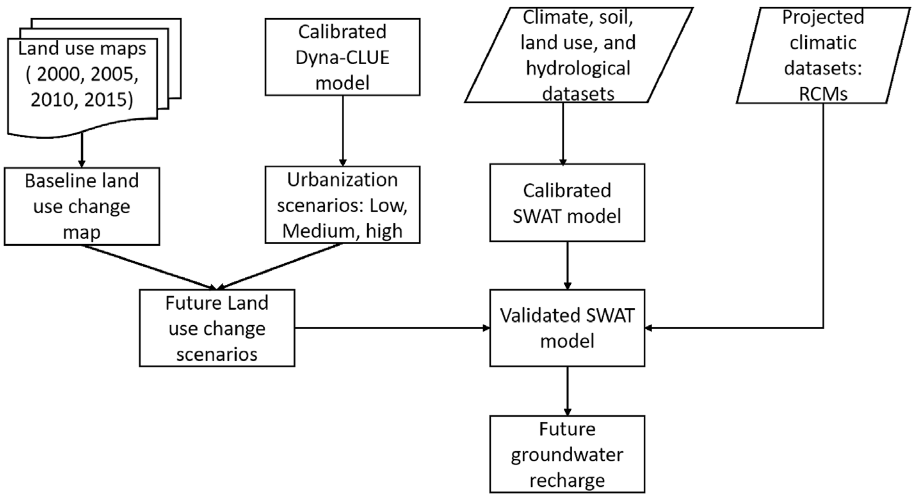

Fig. 3. Overall methodological framework used in the study.

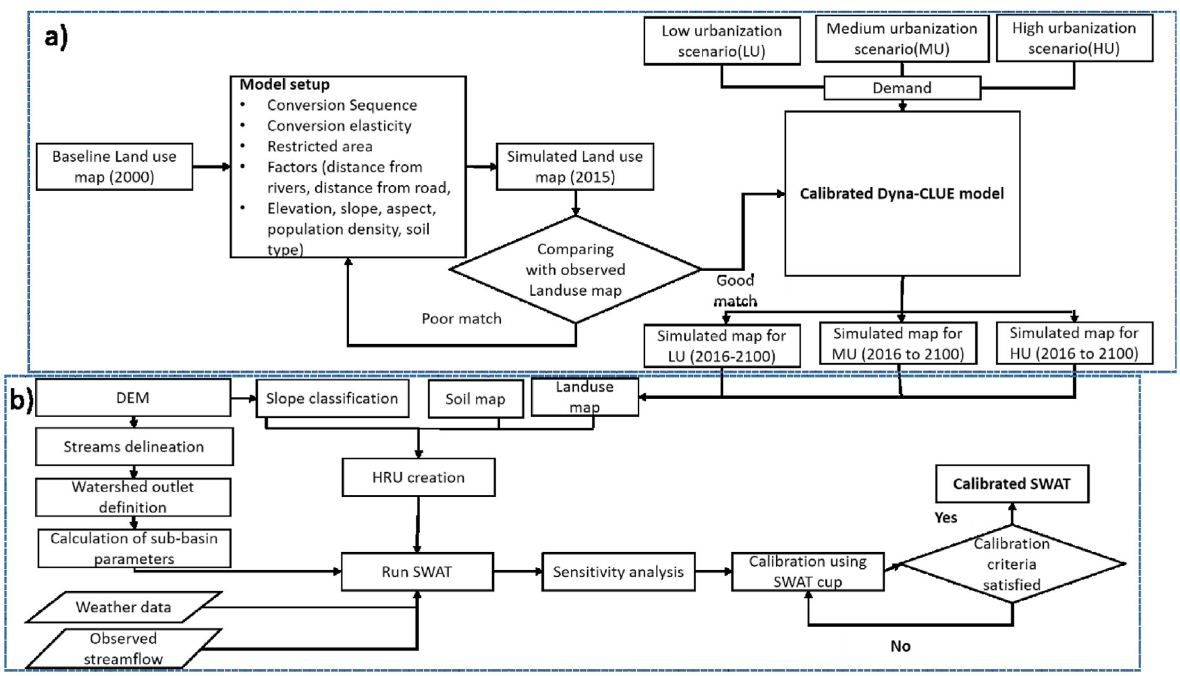

Fig. 4. Model setup and calibration steps for a) Dyna-CLUE and b) SWAT models.

Table 2
Conversion sequence for Dyna-CLUE model in HCMC.

		Future land-use			
		Crop	Forest	Built-up	Waterbody
Present land-use	Crop	1	1	1	0
	Forest	1	1	1	0
	Built-up	0	0	1	0
	Water body	0	0	0	1

Table 3
Conversion elasticity for Dyna-CLUE model in HCMC.

Land-use type	Value	Remarks
Crop	0.3	Lower value as it can be easily changed
Forest	0.8	Close to higher value as it is relatively difficult to change
Built-up	1	Higher value as it is difficult to change
Water body	1	Higher value as it is difficult to change

restrictions and conversion parameters. The stepwise logistic regression method was used for location suitability and neighborhood suitability for each land-use type. The logistic regression was calculated as (Verburg et al., 2009)

$$\log\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \ldots + \beta_n X_{n,i} \tag{1}$$

where $P_i$is the probability of a grid cell for the occurrences of the considered land-use features. $X's$are the driving factors. $\beta's$ are the coefficients which are estimated using logit regression.

It has been observed that higher βvalues indicate a higher value of the variable, while negative βvalues indicate the lower the probability of finding a particular land-use class in that location.

The observed land-use map of 2005 was used as the baseline map and the observed land-use map of 2015 was used for calibration (Fig. 4a). The seven driving factors were considered in this study which are the distance from river, distance from road, elevation, slope, aspect, population density and soil type. Three urbanization scenarios, LU, MU and HU, were simulated using the calibrated Dyna-CLUE model based on the conservation scenario, limited growth rate of urbanization, and rapid growth rate of urbanization situations in HCMC respectively. The LU scenario or conservation scenario was simulated where the agricultural land converted into forest by 1 percent per annum during 2016–2100. Furthermore, the built-up area and water bodies remain constant in this scenario. In MU scenario, the urban growth in built-up area was projected 1 percent per annum during 2016–2100 which is less than 5.3 percent per annum during 2000–2015. Furthermore, the land-use change conversion was allowed from agricultural land to urban while forest and waterbodies remain constant in MU scenario. In HU scenario or rapid urbanization scenario where the urban area grows at 5 percent per annum during 2016–2025, 2.5 percent per annum during 2026–2035, and 1 percent per annum during 2036–2100.

3.2. Hydrological modelling by SWAT

Hydrological modelling was done using SWAT model. The SWAT model was selected in this study to estimate groundwater recharge for HCMC for two reasons. One reason is that it has the capacity to simulate the hydrological components for a large number of years with lesser computational effort. Secondly, the SWAT model can be calibrated even outside of the study area provided the hydrological gauging stations are representing the whole basin beyond the study area limit. The SWAT model is a continuous simulation model that enables daily, and long-term water yields to be modelled from a watershed area. After collection of all the required data, the first step is discretizing a basin into several sub-basins based on the topographical information. The model can then be separated into two major components. The first component models the land phase into hydrologic response units (HRUs) to calculate water yield to the main channel from each sub-basin. The second component is the water routing phase, which is the movement of water through the channel network to the watershed's outlet (Winchell et al., 2010). The HRUs comprises of unique land cover, soil, and slope, in which the simulations are carried out and are combined at the sub-basin level. The hydrology of HRU is determined by using water balance equation which includes precipitation, runoff, evapotranspiration, percolation, and return flow components. Major hydrological processes modelled in SWAT are surface runoff, soil and root zone infiltration, evapotranspiration, soil and snow evaporation and baseflow (Arnold et al., 1998). The model predicts the hydrology at each HRU using the water balance equation (2) given by Neitsch et al. (2011) which is as follows:

$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \tag{2}$$

where SW_t is the final soil water content, $SW_0$is the initial water content on day i (mm), $R_{day}$is the amount of precipitation on day i (mm), $Q_{surf}$is the amount of surface runoff on day i (mm), $E_a$is the amount of evapotranspiration on day i (mm), $w_{seep}$is the amount of water entering the vadose zone on day i (mm) and Q_{gw} is the amount of return flow on the day i (mm).

The calibration procedure of SWAT model using various input datasets and derived datasets is shown in Fig. 4b. For setting up the SWAT model, the elevation map of the area, land-use and soil maps were used which described and represented the basin characteristics. The hydrological and meteorological station data was then used to study and analyze the overall hydrological components of the watershed. The SWAT model was set up using the digital elevation model (DEM) obtained from ASTER with 30 m resolution. The entire watershed was divided into 39 sub-basins and 794 HRUs. The Soil map was obtained from FAO with a resolution of 1:5000000. Fourteen different types of soil were found in the watershed. The HRUs were developed by fixing 5% threshold for each land-use percentage over sub-basin area, soil class percentage over land-use area and slope class percentage over soil area. Five meteorological stations in and around the Dong Nai river basin were used in the study.

The hydrological station used for the study was Phuoc Hoa discharge station and the discharge data was available from 1989 to 2002. Therefore, the calibration period was selected from 1989 to 1999 and the validation period was from 2000 to 2002. The accuracy of the model was tested by checking the fitness of observed and simulated value of flow along with the calculation of statistical parameters like Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), and coefficient of determination (R^2) whose formulations are as follows,

$$NSE = 1 - \frac{\sum_{t=1}^{T} (Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T} (Q_o^t - \bar{Q}_o)^2} \tag{3}$$

$$PBIAS = 100\frac{\sum_{t=1}^{T} Q_m^t - Q_o^t}{\sum_{t=1}^{T} Q_o^t} \tag{4}$$

$$R^2 = \left(\frac{\sum_{t=1}^{T} (Q_o^t - \bar{Q}_o)(Q_m^t - \bar{Q}_m)}{\sqrt{\sum_{t=1}^{T} (Q_o^t - \bar{Q}_o)^2}\sqrt{\sum_{t=1}^{T} (Q_m^t - \bar{Q}_m)^2}} \right)^2 \tag{5}$$

where $Q_m^t$is the simulated streamflow value (L^3/T); $Q_o^t$is the observed streamflow value (L^3/T); $\bar{Q}_m$mean of the simulated streamflow values (L^3/T); $\bar{Q}_o$is the mean of the observed streamflow values (L^3/T); T is the total number of observations.

4. Results and discussion

4.1. Future land-use projection

The projected future land-use maps under LU, MU, and HU scenarios by Dyna-CLUE model are shown in Fig. 5. In LU Scenario, the built-up area was assumed constant while the forest was assumed to increase by 1%. The conversion of the agricultural area will occur to the forest, which is unlikely, but the scenario was developed to study the recharge when the built-up area will not change. The total forest area was 27.86% in 2000, which rose to 32.97% in 2100. This scenario results were relatively in comparison with Shrestha et al. (2018) study on the conservation scenario of land-use change in Songkhram River basin Thailand.

In MU Scenario, the built-up area was assumed to increase at the rate of 1% per annum. By this rate of increase, the built-up area was 28.91% of the total land in 2100 from 13.77% in 2000. The agricultural land was decreased from 50.35% in 2000 to 36.73% in 2100 compensating for the increase in built-up area. The forest was decreased slightly with 27.85% in 2000 to 26.33% to 2100. The amount of area covered by water bodies remained same with 8.01% throughout the period.

In the High Urbanization Scenario, the built-up area was assumed to increase at the rate of 5% per annum from 2016 to 2025, then at 2% per annum from 2026 to 2035 and at 1% per annum from 2036 to 2100. This is a very high rate of increase in the built-up area scenario. The built-up area was assumed to have tremendous growth from just 13.70% of the total area in 2000 to 69.84% in 2100. The forest area could not decrease less than 17.89% of the total area, as it is a mangrove conservation area, which is known as Can Gio. The total forest decreased from 27.76% in 2000 to 20.06% in 2100, which includes the Can Gio mangrove conservation area. The agricultural area also decreased from 50.36% in baseline to 2.09% in 2100.

4.2. SWAT model calibration and validation

The daily observed discharge values at Phuc Hoa discharge station in Dong Nai River were used in the calibration process of SWAT model to get the best estimate of the hydrological parameters of the basin (Fig. 1). The calibration period for hydrological modelling was from

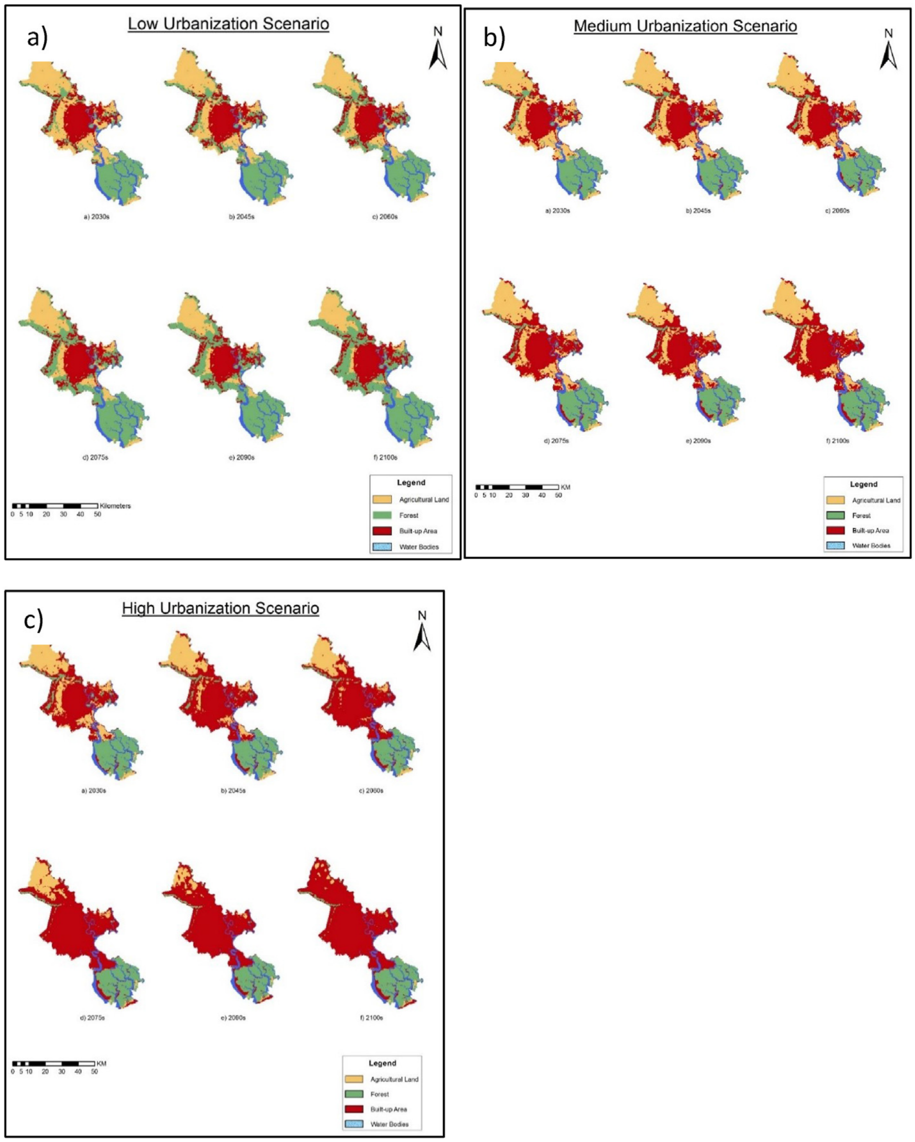

Fig. 5. Future Land-use maps of 2030s, 2045s, 2060s, 2075s, 2090s and 2100s for a) Low Urbanization Scenario b) Medium Urbanization Scenario c) High Urbanization Scenario.

Table 4
Final estimated parameters of SWAT model through the calibration process.

Hydrological parameters in SWAT	Parameter description	Calibrated value	Range	Sensitivity rank
CN2	SCS runoff curve number for moisture condition II	0.012	−0.3 to 0.3	1
GW_DELAY	Groundwater delay time (days)	9.145	0 to 500	2
CH_K2	Effective hydraulic conductivity in main channel alluvium	482.91	0.01 to 500	3
RCHRG_DP	Deep aquifer percolation fraction	0.46	0 to 1	4
GW_REVAP	Groundwater REVAP coefficient	0.183	0.02 to 0.2	5

1987 to 1999 with a warm-up period of 2 years. The validation period was from 2000 to 2002. The calibration sensitivity analysis was done with SWAT-CUP interface to identify the most sensitive parameters to include in the final calibration process. The final estimated parameters of the SWAT model is given in Table 4.

The accuracy of the model was tested by observing the fitness of observed and simulated discharge values with various performance indicators (Fig. 6). The performance indicators such as R^2, NSE, and PBIAS were used during calibration and validation. These values calculated during calibration and validation periods were $R^2 = 0.727$, NSE = 0.727, PBIAS = −0.661, and $R^2 = 0.77$, NSE = 0.76, PBIAS = 5.54 respectively. The calculated performance indicators show a reasonable value suggesting that the model is performing well.

4.3. Impact of land-use change on groundwater recharge

The future projected recharge from the calibrated/validated SWAT model was calculated using the projected future land-use maps from Dyna-CLUE model in HCMC. Furthermore, the projected recharge was calculated based on three time spans namely: near future (2016–2045), mid future (2046–2075), and far future (2076–2100) for each of the land-use scenarios (i.e., LU, MU, HU).

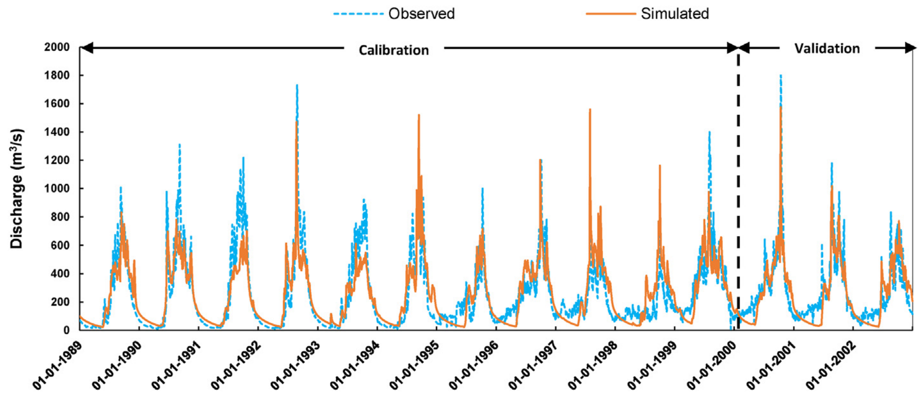

Fig. 6. Observed and simulated discharges at PhucHoa discharge station in Dong Nai River basin during calibration period (1989–1999) and validation period (2000–2002).

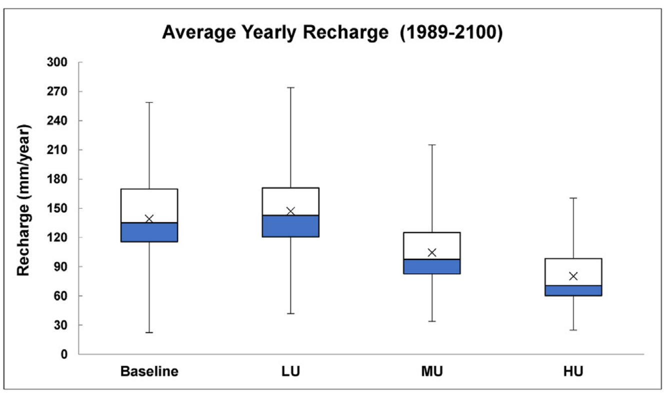

Fig. 7. Average yearly recharge in the Baseline period (1989–2015) compared to the recharge in Medium urbanization scenario (MU), Low urbanization scenario (LU) and High urbanization scenario (HU) from 2016 to 2100 in HCMC.

There was a significant decrease in the average yearly recharge as compared to the baseline period in the high urbanization scenario (HU) while a lesser decrease was observed in the medium urbanization scenario (MU) as compared to the baseline period as shown in Fig. 7. Meanwhile in the low urbanization scenario (LU), a slight increase in the average yearly recharge as compared to the baseline period was observed.

The average yearly recharge in the HU scenario in near, mid, and far future was observed to decrease with the highest relative decrease of 52.15% in the far future as compared to the baseline period. The average yearly recharge in MU scenario in near, mid and far future was also observed to decrease with the highest relative decrease of 34% in the far future as compared to the baseline period. The average yearly recharge in the LU scenario was observed to decrease slightly in the near future while increase in the yearly recharge is seen in the mid and far future with the highest increment of 15% in the far future as compared to the baseline period as shown in Fig. 8.

The aggregated recharge values of near, mid and far future periods for LU, MU, and HU scenarios during the wet season (May to November) are presented in Fig. 9. The calculated recharge values during near, mid, and far future values were showed a decreasing trend for each of the land-use scenarios (i.e. LU, MU, and HU). However, it was observed that a gradual increase in the predicted recharge for LU scenario from near future towards far future. The lowest recharge was predicted for the HU scenario during far future. This is because the increase in the built-up areas in HU scenario is relatively higher than MU and LU scenarios thus, the predicted recharge was also lower compared to LU and MU scenarios (Fig. 9).

5. Conclusions

Three land-use scenarios were developed in order to analyze its impact on groundwater recharge. Dyna-CLUE model was used to project the change in land-use while the amount of change was assumed. The first scenario that was developed is the low urbanization scenario which is an optimistic scenario where the built-up area was assumed to remain the same. This scenario results were more aligned in comparison with Shrestha et al. (2018) study. The second scenario that was developed was the medium urbanization scenario where slowed down urbanization from the current rate of 5% per annum was assumed. The third scenario that was developed was the high urbanization scenario, which is a pessimistic scenario. The distribution of each land-use class was then projected until 2100 annually. Based on the changed land-use, the SWAT model was used to estimate the future recharge in the three scenarios that were developed. The recharge was observed to increase by a maximum of 15% of the annual average in the low urbanization scenario while it was observed to reduce by a maximum of 30.21% of the annual average in medium urbanization scenario. In the high urbanization scenario, the majority of HCMC is expected to be covered in built-up area which will have a significant impact on the groundwater recharge in HCMC with a maximum decrease of 52.15% in the average annual recharge in far future. Thus, a significant impact on the groundwater recharge was observed in HCMC due to changes in the impervious built-up area. Therefore, a rigid regulation on land-use planning in terms of high urbanization in the future should be followed in HCMC to minimize the effect of high urbanization on the groundwater recharge and other environmental consequences.

Author statements

The corresponding author is responsible for ensuring that the descriptions are accurate and agreed by all authors.

The first author carried out the modelling experiments and drafted the paper.

The second author contributed in the analysis of research results and improved the paper.

The third author designed the model and the computational framework and analysed the data.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

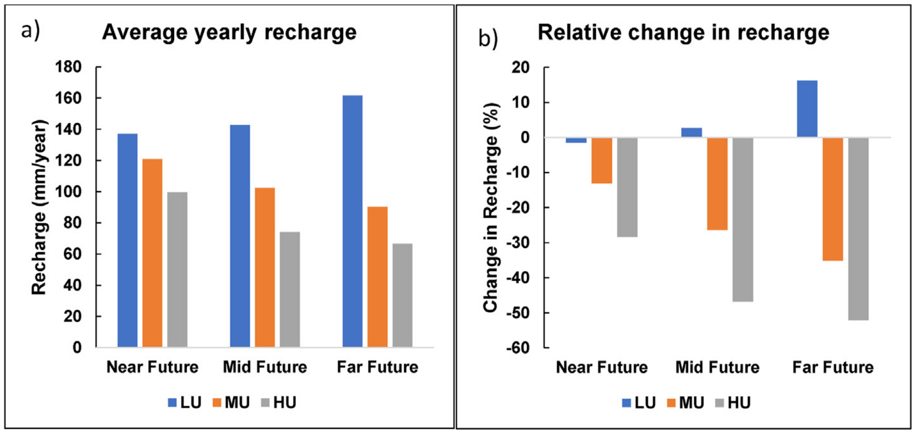

Fig. 8. a) Average yearly recharge b) Relative change in yearly recharge compared to the baseline period (1989–2015) in Medium urbanization scenario (MU), Low urbanization scenario (LU) and High urbanization scenario (HU) from 2016 to 2100 in HCMC.

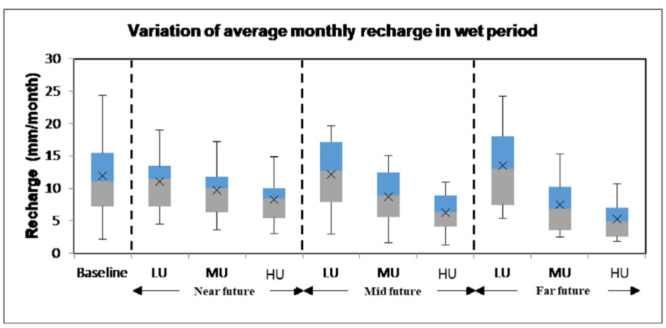

Fig. 9. Variation in average monthly recharge in wet period (May to November) in near future (2016–2045), Mid future (2046–2075) and far future (2076–2100) for Low urbanization scenario (LU), Medium urbanization scenario (MU) and High urbanization scenario (HU) in HCMC.

Acknowledgments

This study was conducted under the project "Mapping groundwater resilience to climate change and human development in Asian cities" (CRRP 2018-01MY-Shrestha) supported by the Asia-Pacific Network for Global Change Research (APN). The authors would like to express sincere thanks to the Division of Water Resources Planning and Investigation for the South of Vietnam (DWRPIS) for providing the required data for this research.

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