Estimating Land Use Change Effects on Groundwater Recharge in Nadi and Kabinburi, Thailand

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ABSTRACT

The effect of land use change on groundwater recharge in Nadi and Kabinburi Districts, Prachinburi Province, Thailand was studied by forecasting land use change using the CLUE model and estimating groundwater recharge using the H08 model. The results suggested that compared to the current average groundwater recharge, the groundwater recharge estimates from scenario 1 (changing the miscellaneous areas of mostly wasteland to mixed perennial areas) and scenario 2 (predicting the land use scenario for the next 10 years based on trends of land use change from the past to the present) were greater by 1.46 and 2.25%, respectively. In scenario 1, the increase in forest and mixed perennial areas increased the groundwater recharge by helping to slow down the surface runoff and, thus, increased the chances of water seepage into the soil. However, increasing the perennial area or turning wasteland into mixed perennial area (scenario 1), resulted in an increase in the groundwater recharge that was similar to the results from simulating future land use scenarios in the next 10 years (scenario 2). Therefore, to increase the efficiency of groundwater management and drought relief, the relevant agencies should adopt appropriate land use planning, be encouraged to plant perennials or support mixed farming on wasteland, restore degraded forest areas, and improve the management of water use concurrently.

1. INTRODUCTION

At present, water shortage is a major global issue, with many countries facing this problem (Miyan, 2015; Zhong et al., 2020), especially in developing countries (Sharafi et al., 2021). This problem is influenced by both natural factors and human activities. Human activities, such as land use change that acts as an important catalyst to droughting problems, are worsening rapidly (Owuor et al., 2016). Water resources are extremely important for the survival of all living things (people, animals, and plants). Thailand is one country facing drought problems annually, where the water shortage problem has a profound effect on people's livelihoods (United Nations, 2022). In addition, Thailand is an agricultural country where the main occupation of the people is agriculture. Drought affects agricultural productivity, including the food security of the country (Keshavarz and Karami, 2018; He et al., 2019). One of the major problems that causes a drought to intensify rapidly is land use change without planning or proper management. Unused area greatly affects water resources because there is nothing to cover the soil surface and no plants protecting the soil. Thus, rain affects the soil surface directly, increase the likelihood of surface runoff and reduce the chance of water seepage into the soil (Kumar et al., 2017). These affect both groundwater recharge and the amount of groundwater.

Groundwater is an important water source that helps to add water to surface water sources during the dry season (Niyom, 1992). Most of the rain that falls on the surface will return to the atmosphere due to evapotranspiration, with only 14% becoming groundwater recharge (Fornes and Pirarai, 2014). Thailand has widely used groundwater, from the past to the present, to alleviate the problem of water shortage and to respond to the increasing water demand of the people (Department of Groundwater Resources, 2018). However, factors affecting groundwater recharge have not been studied much in Thailand. Most studies have examined the relationship between streamflow and land use change, for example, Chacuttrikul et al. (2018) projected the streamflow in the land use change situation at Lam Chi Sub-

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watershed, Northeast Thailand, using H08 model, Faksomboon et al. (2019) investigated the land use change of head water area on streamflow, suspended sediment, and water quality in Khlong Lan Watershed, Kamphaeng Phet Province using SWAT model, and Borrabut et al. (2022) studied the effect of land use change on streamflow of Mae Nam Khuan and Nam Pi Sub-watersheds in Nan and Phayao Provinces, Thailand. Therefore, it is not yet clear what factors affect groundwater recharge. Furthermore, there is limited quantitative evidence on how changes in land use affect groundwater recharge.

The selected areas for the current research were the Nadi and Kabinburi Districts, Prachinburi Province, eastern Thailand. The Nadi and Kabinburi Districts are recurring drought-affected and drought-prone areas, respectively. The recurring drought-affected area was the area that experienced drought in agriculture regularly or frequently. It is an area that lacks water for use in agriculture and consumption, affecting the livelihood of the people (Research Institute Developed for Desertification Prevention and Early Warning, 2005). In addition, water demand by the people in this area is continuously increasing. As a result, the amount of surface water and groundwater is insufficient to meet demand. Thus, the drought response plan for the year 2019-2020 was established by the Office for Prevention and Mitigation in Prachinburi Province and one of the drought relief plans was to survey the area that could supply groundwater to help alleviate this problem. Therefore, the Nadi and Kabinburi Districts, Prachinburi Province are very suitable as a relevant study area. The drought problem of the study area may be due to the land use changes that have resulted in an increase in abandoned areas and to increasing people's water demand (Department of Groundwater Resources, 2015), make the water from both surface sources and groundwater not sufficient to meet the demand of the total population.

Therefore, this research simulated the land use change scenario using the Conversion of land use and its effects (CLUE) modelling framework, which is a land use change model (Verburg et al., 1999; Verburg and Overmars, 2009). Afterward, the H08 model, which is an open-source global hydrological model that can consider the interactions between natural hydrological processes and human activities (Mateo et al., 2014; Hanasaki et al., 2018; Hanasaki, 2022), was applied to estimate the impacts of land use changes on groundwater recharge in Nadi and Kabinburi Districts, Prachinburi Province, Thailand.

2. METHODOLOGY

2.1 Study area

The Nadi and Kabinburi Districts (2,611 km^2) in Eastern Thailand, Prachinburi Province, were selected as the study site (Figure 1). To the north, it connects with Nakhon Ratchasima Province, to the east with Sa Kaeo Province, to the south with Chachoengsao Province, and to the west with Nakhon Nayok Province. The Nadi and Kabinburi Districts are constantly experiencing drought.

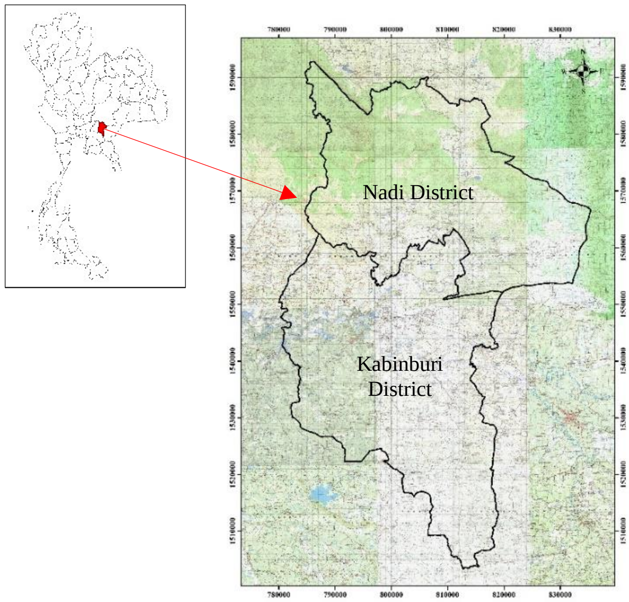

Figure 1. Location of study areas in Nadi and Kabinburi Districts, Prachinburi Province

The research procedures and methods are shown in Figure 2 and detailed as follows:

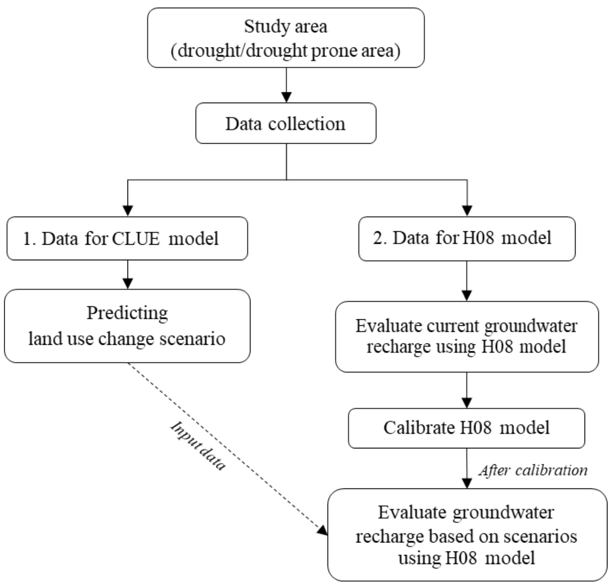

Figure 2. Methodology

2.2 Data preparation for the model

2.2.1 CLUE model

The conversion of land use and its effects modelling framework (the CLUE model) was used to develop the future land use scenario by the boundary of the study area, land use data in 2020 from Land Development Department, elevation and slope data from topographic map, and roads and main streams from topographic map (Verburg, 2015).

Chacuttrikul's findings regarding the impact of land use and climate change on future soil erosion and sediment yield in Northern Thailand indicate that the CLUE model has high performance for simulated land use change scenarios. The results from the CLUE model closely corroborate the land use change data from the actual measurement for over 82% of the total area. However, there are some errors in simulating small areas such as water and urban areas (Chacuttrikul, 2018).

2.2.2 H08 model

H08 model (Hanasaki, 2022) estimating land use change impact on groundwater recharge during 5 years by the Meteorological data (rainfall, air temperature, and relative humidity) were collected from the weather monitoring station of the Thai Meteorological Department and the Royal Irrigation Department for 2016-2020, in daily time scale, boundary from topographic map, land use data in 2020 from Land Development Department, elevation and slope from topographic map, and data regarding artesian wells or groundwater such as well depth and water level in the well from field data collection by the Department of Groundwater Resources. Soil moisture, soil texture, soil depth, and water holding capacity of soil from field data collection. For field data collection, the soil sampling points were chosen based on different land use and soil groups. The soil samples were collected at a depth of 0-30 cm at 11 points, with 3 replications at each sample collection points (total of 33 samples).

In addition, a geographic information system (GIS) was used to prepare the data for the H08 model, including boundary, elevation, slope, and land use data. Data were prepared at 1 arc-minute spatial resolution, or approximately 2 × 2 kilometers. In addition, some soil hydrological data from the field collection were also included in the GIS after analysis in the laboratory.

2.3 Simulation of land use situation based on CLUE model

After preparing the input data, land use situation was created using the CLUE model, which is an integrated land use change model (Verburg et al., 2002; Verburg, 2007; Verburg, 2015). The relationships were analyzed among land use types and factors that affect land use change, such as elevation, slope of the area, slope direction, and distances from communities to rivers and roads.

There were two land use scenarios: scenario 1 changed other agricultural areas (such as floricultural, animal husbandry, and pasture) and miscellaneous areas (such as bare areas and wasteland) to an area for mixed perennial plants to be consistent with the daily life and well-being of the people in the area; and scenario 2 simulated the next 10 years of land use change from the trends in land use change from the past to the present, to forecast the groundwater recharge rate in the near future and plans for water use. As basic data for simulation, both land use scenarios used the GIS, the CLUE model (Dyna version) and land use data in 2020 from the Land Development Department. The CLUE model is an integrated land use change model (Verburg et al., 1999) that can be used to simulated land use change scenarios from land use data in the past along with the data that are related to land use change, including slope data, elevation, distances from roads, and distances from water sources.

2.4 Forecasting effect of land use change on groundwater recharge based on H08 model

Step 1: Assessment of groundwater recharge was based on current land use (in 2020) and climatic data (2016-2020).

Step 2: Calibration of the H08 model was done using the groundwater level data that had been measured by the Department of Groundwater Resources. The model was calibrated by changing the values of the parameters that related to the amount of groundwater and groundwater recharge. In addition, the coefficient of determination (R^2) and standard error of the estimate (SSE) were used to measure the accuracy of the values obtained from the models.

Step 3: Evaluation of the effects of land use change on groundwater recharge using land use data from the CLUE model along with current climatic data.

3. RESULTS AND DISCUSSION

3.1 Land use and land use change

The land use data for the research site between 2008 and 2020 from the Land Development Department showed that the major land uses were forest, perennial, field crop, and paddy field, with areas of 26.45, 16.73, 15.77, and 15.47%, respectively, in 2008 and 29.32, 18.81, 17.91, and 12.42% in 2020, respectively. These figures suggested that land use for the study site had slightly changed. In 2020, the forest area, field crops, perennial, water, and miscellaneous areas increased by approximately 2.79, 2.15, 2.08, 1.47, and 1.18%, respectively. In contrast, paddy field, other agricultural, urban, and degraded forest area decreased by approximately 3.05, 2.43, 1.61, and 1.61%, respectively. The areas with little change were forest plantations and orchards that decreased and increased by only 0.99 and 0.02%, respectively, of the total area (Table 1).

3.2 Forecasting land use change under the two scenarios

Scenario 1 (changing the land use area of other agricultural and miscellaneous areas to mixed perennial) involved approximately 219.6 km^2 or 8.4% of the total area. The relevant maps and land use data are shown in Table 2 and Figure 3(a).

Scenario 2 (trends in land use change from 2008 to 2020) showed that the forest, field crops, fruit trees, perennial plants, water, and miscellaneous areas tended to increase, while degraded forest, forest plantations, paddy fields, other agricultural, and urban areas tended to decrease. This affected land use in scenario 2. The future land use areas under the two scenarios are shown in Table 2 and Figure 3.

Table 1. Changes in land use (2008-2020)

Land use type	Land use in 2008		Land use in 2020		% Change
	km^2	%	km^2	%	
Forest	690.70	26.45	763.52	29.23	2.79
Degraded forest	81.18	3.11	39.15	1.50	1.61
Paddy field	404.05	15.47	324.40	12.42	3.05
Field crops	411.79	15.77	467.88	17.91	2.15
Orchard	42.83	1.64	43.34	1.66	0.02
Perennial	436.89	16.73	491.28	18.81	2.08
Other agricultural areas	231.50	8.86	168.08	6.44	2.43
Forest plantations	32.35	1.24	6.45	0.25	0.99
Urban area	218.33	8.36	176.35	6.75	1.61
Water area	41.41	1.59	79.79	3.05	1.47
Miscellaneous area	20.79	0.80	51.57	1.97	1.18

Table 2. Original land use and future land use under scenarios 1 and 2

Land use type	Land use in 2008		Land use in 2020		Scenario 1		Scenario 2	
	km^2	%	km^2	%	km^2	%	km^2	%
Forest	690.7	26.4	763.5	29.2	763.5	29.2	823.0	31.5
Degraded forest	81.2	3.1	39.2	1.5	39.2	1.5	0.0	0.0
Paddy field	404.0	15.5	324.4	12.4	324.4	12.4	251.3	9.6
Field crops	411.8	15.8	467.9	17.9	467.9	17.9	517.1	19.8
Orchard	42.8	1.6	43.3	1.7	43.3	1.7	53.1	2.0
Perennial	436.9	16.7	491.3	18.8	491.3	18.8	567.3	21.7
Other agricultural areas	231.5	8.9	168.1	6.4	0.0	0.0	75.7	2.9
Mixed perennial tree	0.0	0.0	0.0	0.0	219.6	8.4	0.0	0.0
Forestry plantations	32.3	1.2	6.5	0.2	6.5	0.2	0.0	0.0
Urban area	218.3	8.4	176.3	6.8	176.3	6.8	127.9	4.9
Water area	41.4	1.6	79.8	3.1	79.8	3.1	109.6	4.2
Miscellaneous area	20.8	0.8	51.6	2.0	0.0	0.0	86.8	3.3
Total	2,611.8	100.0	2,611.8	100.0	2,611.8	100.0	2,611.8	100.0

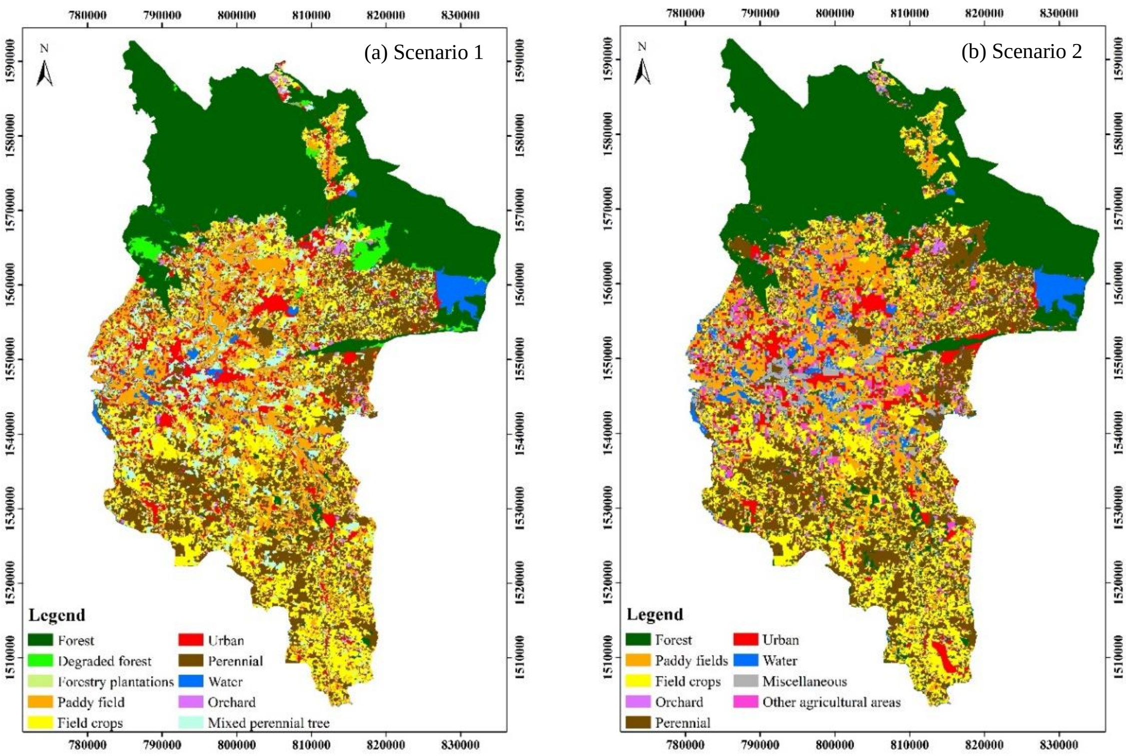

Figure 3. Land use maps: (a) scenario 1 and (b) scenario 2

3.3 Predicting the effect of land use change on groundwater recharge using H08 model

3.3.1 Calibration of H08 model

To calibrate the H08 model, the groundwater data obtained from the actual measurements was compared with the results from the model and used to modify the relevant parameters such as groundwater depth, groundwater yield (Gwyield), the maximum time constant for groundwater runoff per day (Tau), and parameters related to groundwater flow (Gamma). In this study, the Gwyield, Tau, and Gamma parameters were adjusted according to land use in 2020 in the Nadi and Kabinburi districts, with the groundwater depth data of the Department of Groundwater Resources being used as a baseline. The actual measurement groundwater data were recorded during 2018-2020 from two groundwater wells of the Department of Groundwater Resources. The coefficient of determination (R^2) and standard error of the estimate (SSE) were used to measure the accuracy of the values obtained from the model. However, due to the lack of continuity of the measurement groundwater data, only 5 data values per well were available for calibration. The results of the model calibration are shown in Table 3.

For model calibration, the groundwater data from the Kabinburi and Ladtakian wells were compared with the data output from the model. It was found that the R^2 value for the Kabinburi well was 0.97 and the SEE was 0.017, while for the Ladtakian well, the R^2 value was 0.76 and the SEE was 0.012.

Table 3. Results of H08 model calibration

Statistic	Groundwater well	
	Kabinburi	Ladtakian
R^2	0.97	0.76
SEE	0.017	0.012

3.3.2 Effect of land use change on groundwater recharge

The simulations for both land use scenarios using the GIS and the CLUE model indicated that land use change clearly affected the groundwater recharge. The results of the assessment of groundwater recharge for both scenarios (scenario 1 that changed other agricultural areas and miscellaneous areas, such as mixed perennial area, and scenario 2 that predicted the next 10 years of land use based on land use change trends from the past to the present) showed that the average monthly groundwater recharge for the current situation and all scenarios were the highest in October and the lowest in May (Table 4 and Figure 4) and that the groundwater recharge amounts from scenarios 1 and 2 were higher than the groundwater recharge from the current situation. The average groundwater recharge for 5 years of the current situation, scenario 1, and scenario 2 were 7.33×10^{-4}, 7.44×10^{-4}, and 7.49×10^{-4} m^3/s, respectively. The average groundwater recharge amounts of scenario 1 and scenario 2 were greater than the current situation by 1.46 and 2.25%, respectively, due to the decrease in miscellaneous areas (mostly wasteland), the increase in forest area in scenario 2, and the increase in mixed perennial areas in scenario 1. These all helped to cover the surface soil leading to reduced surface runoff, reduced soil erosion, an increased chance of greater penetration of water into the soil, which affected the groundwater recharge and the amount of groundwater (Winter et al., 2003; Graf and Przybylek, 2018). The results of the current study were consistent with the research of Zomlot et al. (2015) that assessed the control factors regarding the spatial distribution of groundwater recharge and found that land use had a profound effect on the rate of groundwater recharge, especially an increase in forest area, because the forest helped to slow down surface runoff and increased the chance of water seepage into the soil. On the other hand, groundwater recharge tends to decrease when the built-up area increases (Ghimire et al., 2021; Ashraf et al., 2022; Salem et al., 2023) or the vegetated land cover decreases (Sajjad et al., 2022; Siddik et al., 2022). The groundwater recharge rate was dependent on land cover, soil properties, surface runoff, and infiltration, which were influenced by land use change (Sajikumar and Remya, 2015; Owuor et al., 2016; Abdelaziz et al., 2020).

Moreover, this research showed the benefits of land use management. If the wasteland were converted into mixed perennial, there is a tendency of increasing groundwater recharge and may help to relieve the drought problem in this study area. The average groundwater recharge is shown in Table 4.

Table 4. Average groundwater recharge

Groundwater recharge (×10^{-4} m^3/s)						
	Current situation		Scenario 1		Scenario 2	
	Min-max	Average	Min-max	Average	Min-max	Average
January	2.20-12.76	7.30	2.20-13.17	7.40	2.27-14.44	7.46
February	2.07-12.83	7.29	2.07-13.25	7.39	2.13-14.55	7.45
March	1.93-12.90	7.28	1.93-13.33	7.38	1.99-14.66	7.44
April	1.85-12.96	7.28	1.85-13.39	7.37	1.89-14.75	7.44
May	1.79-13.01	7.27	1.79-13.45	7.37	1.81-14.84	7.43
June	1.95-13.06	7.29	1.95-13.50	7.38	1.95-14.92	7.45
July	2.24-13.10	7.33	2.24-13.55	7.43	2.30-14.99	7.49
August	2.53-3.13	7.38	2.59-15.06	7.54	2.59-15.06	7.54
September	2.69-13.16	7.41	2.69-13.62	7.51	2.76-15.11	7.57
October	2.75-13.19	7.43	2.75-13.66	7.53	2.83-15.16	7.59
November	2.53-13.03	7.39	2.56-13.68	7.52	2.64-15.20	7.58
December	2.27-12.62	7.31	2.29-13.19	7.43	2.36-14.48	7.49
Average		7.33		7.44		7.49

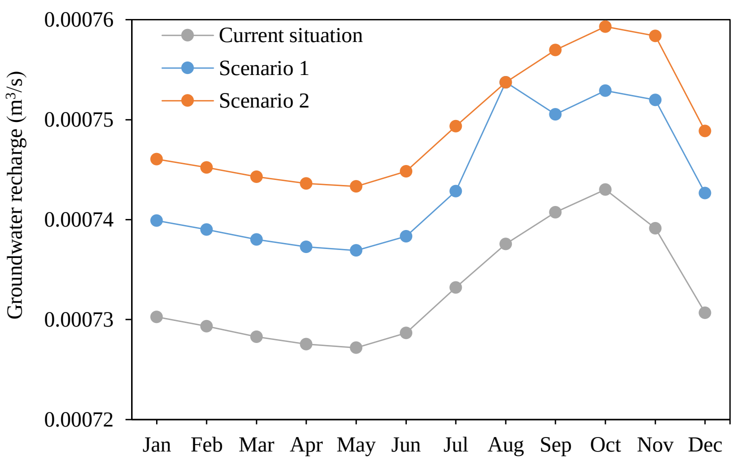

Figure 4. Monthly groundwater recharge for current situation, scenario 1, and scenario 2

4. CONCLUSION

Land use changes between 2008 and 2020 in the Nadi and Kabinburi Districts, Prachinburi Province, showed that the increased areas of forest, field crops, perennials, water, and miscellaneous and decreased areas of paddy fields, other agricultural, urban, and degraded forest areas. In addition, the areas with very little change were forest plantations and fruit tree areas. The major focus of this research was evaluating the impact of land use change on groundwater recharge. The simulation showed that the average monthly groundwater recharge amounts in scenario 1 that changed other agricultural areas and miscellaneous areas, and scenario 2 that predicted the future land use based on land use change trends from the past to the present, were more than the current situation. Changes in land use in the study area, such as increasing land cover or turning wasteland into mixed perennial areas (scenario 1), affected the groundwater recharge in the Nadi and Kabinburi Districts and produced recharge values, close to the results from the simulating future land use scenarios in the next 10 years (scenario 2), which was based on the trends of land use change from the past to present. Therefore, planting more and protecting the forest area, establishing a forest care policy, creating water use plans for both surface water and groundwater, and following the principles of soil and water conservation to prevent the occurrence of surface runoff are increasing the opportunity to replenish the groundwater in Nadi and Kabinburi Districts, Prachinburi Province.

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