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ORIGINAL ARTICLE

The Impact of Climate Change on Groundwater System Under Conjunctive Use in the Upper Central Plain, Thailand

Chokchai Suthidhummajit[1*], Sucharit Koontanakulvong[2]

[1] Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University. Bangkok, Thailand

[2] Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University. Bangkok, Thailand

[*]E-mail: chokchai.s@gmail.com

***Abstract*:** The Upper Central Plain Basin of Thailand has high potential for social and economic development. However, in the drought year, water storage in the dams is inadequate to allocate for agriculture and caused water deficit in many irrigation projects. Farmers need to find extra source of water by pumping the groundwater. Besides, this area will probably be affected from climate change phenomena, which may cause significant decrease of the water storage in the dams and will cause further water shortage in the future. The objectives of this study are to characterize of groundwater system under conjunctive use and to analyze the impact of climate change by using the MODFLOW model to simulate the groundwater flow. The study used the bias-corrected MRI-GCM data and groundwater model to project the future climate condition and to assess the impact on groundwater system. The study investigated the climate change impact towards the groundwater system and sw-gw conjunctive use ratio compared with the past in the drought years.

Keywords: climate change, impact, groundwater system, conjunctive use, the upper central plain

1. Introduction

The Upper Central Plain Basin of Thailand has high potential for social and economic development. It is also high-volume source of agricultural products, especially rice. However, in the drought year, water storage in the dams is inadequate to allocate for agriculture, and caused water deficit in many irrigation projects. Farmers need to find extra source of water by pumping the groundwater. This area will probably be affected from climate change phenomena, which will cause significant decrease of the water storage in the dams and may cause further shortage in the future.

The objectives of this study are to characterize the groundwater system under conjunctive use and to analyze the impact of climate change.

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2. Study area

Upper Central Plain is in the northern part of Chao Phraya Plain covering the areas of Uttaradit, Sukhothai, Pitsanulok, Kampangphet, Pichit, and Nakornsawan Provinces. Total area is 47,986 square kilometers or 29,991,699 rais. Average height is approximately 40-60 meters above mean sea level. The areas consist of sediments which were changed from erosion and decay of rock, then accumulate and generate as plain, terrace, and swamp. Fig. 1 shows topography and boundary of the study area.

The climate of the Upper Central Plain is under the influences of monsoon winds i.e. southwest and northeast monsoon. From the meteorological point of view the climate of Upper Central Plain can be divided into three seasons, i.e., summer (mid-February to mid-May), rainy season (mid-May to October), and winter (November begin to mid-February). The study area is composed of 5 basins that are Lower Ping Basin, Lower Yom Basin, Lower Nan Basin, Upper Sa-Grae-Grang Basin, and Upper Chao Phraya Basin, as shown in Figure. 1.

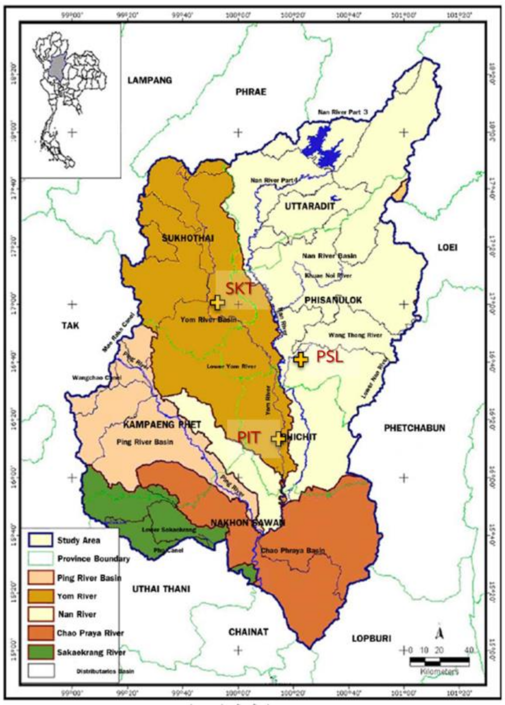


Figure. 1 Upper Central Plain Basin

3. Methodology

The groundwater system can be described in term of river recharge, land recharge, groundwater storage change, groundwater pumping, flow of boundary and leakage between aquifer. To characterize of groundwater system under conjunctive use and to analyze the impact of climate change, there are two steps in this study, i.e., first step is to modify the groundwater model (Koontanakulvong, et. al, 2006) by including the effect of the future climate in term of groundwater recharge rate from climate data and seven groups of soil data series, and to investigate the groundwater system in the present period (1993-2003), second step is to simulate the climate change impact towards groundwater system by using the recharge relationship derived from the part 1 and the projected bias corrected the MRI GCMs climate data (Koontanakulvong, et al., 2011) in two future time frames, i.e., near future (2015-2029) and far future (2075-2089) periods. The revised groundwater model (MODFLOW) was applied to assess the impact of climate change on the groundwater system in the study area and to find the impact on sw-gw conjunctive use ratio in average of three periods and in the drought years (like 1999, 2020 and 2082).

The water year is defined by the reservoir storages of Bhumibol Dam and Sirikit Dam. There are 4 types of water year, i.e., 1) wet year, the storage is more than 12,500 MCM, 2) normal year, the storage between 8,500 and 12,500 MCM, 3) dry year, the storage between 4,200 and 8,500 MCM and 4) drought year, the storage is lower than 4,200 MCM. The future water year refer to the rainfall and dam storage projections done by Chaowiwat , 2013.

3.1 Groundwater model

Groundwater model, used to understand the groundwater system, in this study is MODFLOW (the USGS's three-dimensional (3D) finite-difference groundwater model). MODFLOW is considered an international standard for simulating and predicting groundwater conditions and groundwater/surface-water interactions. The three-dimensional movement of ground water of constant density through porous earth material may be described by the partial-differential equation.

$$\frac{\partial}{\partial x}\left[\mathbf{K_{xx}}\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[\mathbf{K_{yy}}\frac{\partial h}{\partial y}\right]+\frac{\partial}{\partial z}\left[\mathbf{K_{zz}}\frac{\partial h}{\partial z}\right]+\mathbf{W}=\mathbf{S_s}\frac{\partial h}{\partial t} \quad (1)$$

where

K_{xx}, K_{yy} and K_{zz} are the values of hydraulic conductivity along the x, y, and z coordinate axes (space function).

h is the potentiometric head (hydraulic head).

W is a volumetric flux per unit volume representing sources and/or sinks of water, where negative values are water extractions, and positive values are injections. It may be a function of space and time (i.e. W = W(x, y, z, t)).

S_s is the specific storage of the porous material (space function).

t is time.

3.2 Recharge equation

From the water budget analysis in the soil layer, the simple water budget is

$$P = ET+\Delta S+R_{off}+D \quad (2)$$

where

P is precipitation:

ET is evapotranspiration:

ΔS is change in water storage in soil column:

R_{off} is direct surface runoff: and

D is drainage out of the bottom soil which is equivalent to recharge (R)

From the above relation, the recharge can be approximated simpler by using following equation (Krüger, Ulbrich and Speth, 2001):

$$R = P-ET-Q_0 \quad (3)$$

Equation (4) can be written again as follow:

$$R/P=a_i*(P-ET)/P +b_i \quad (4)$$

where

a_i and b_i are constants and can be found by using goodness fit test for each soil group.

Q_o= R_{off} = runoff outflow (assumed zero in monthly scale).

P is precipitation, and ET is evapotranspiration and can be calculated by equation of temperature (T) (Singh, 1992):

$$ET = c*T+d \quad (5)$$

where c and d are constants and can be found by using goodness fit test for each month (Suthidhummajit and Koontanakulvong, 2015).

Recharge function

The rates of groundwater recharge in each soil group zone from the step above were calculated by the developed relationship (Suthidhummajit and Koontanakulvong, 2015) between recharge and amount of monthly precipitation minus monthly evapotranspiration per precipitation (Equation 4),

3.3 Groundwater use

The total number of shallow wells in the study area in 2003 has been 78,114 with a ratio of agricultural to domestic consumption-well of 1:3 (Koontanakulvong S., et. al, 2006) and an average daily domestic consumption of 0.71 m^3/well, amounting to a total domestic consumption from wells of 15 million m^3/year in 2003. The major groundwater use in this area is for agriculture. Since the crop pattern is seasonally planned, the agricultural stress-period used in the model is also based on the climatic conditions. Agricultural well records often do not exist and the pumping behavior is unknown, for this reason, the investigation results about the actual water use pattern, farmer's behaviors and constraints, i.e. harvest terms, groundwater pumping hours, pumping rates, maximum water drawdown, etc., in the Plychumpol

Irrigation Project area in Phitsanulok Province has been used to estimate the groundwater use for agriculture. The major pumping statistics retrieved from the survey which concluded that the average pumping capacity per well is 41 m^3/hour, whereas the average pumping rate per well is 79 m^3/day inside the irrigation project, and 76 m^3/day outside (Bejranonda, Koontanakulvong, Koch, Suthidhummajit, 2007). The historical annual record of the wells in each province during 1993-2003 was converted to a growth rate of the well concentration for the future. As mentioned, besides the seasonally agricultural water use, the latter depends also on the surface water supply available during the time which is linked to the actual storage of two main upstream reservoirs (Koontanakulvong, et. al, 2006), i.e., the Bhumibol and Sirikit reservoirs which provide surface-water and irrigation water to this area. The water demand, the conjunctive use ratio (described by the ratio of groundwater use and surface water use) compared with the water demand and water situation from 1993-2003 as shown in Table 1. In average, the conjunctive use ratio was 9% to 25%. In drought years, the conjunctive use ratio was highest (23-25%) and the lowest was in wet year (9-11%).

Table 1 The water demand and the sw-gw conjunctive use ratio in water year during 1993-2003

Year	Water demand (MCM)	SW Supply (MCM)	GW Supply (MCM)	CJ-ratio (%)	Water year
1993	3,108	2,445	421	17	Dry
1994	3,217	2,443	551	23	Drought
1995	3,020	2,575	287	11	Wet
1996	4,043	3,517	302	9	Wet
1997	3,898	3,222	524	16	Normal
1998	3,290	2,457	540	22	Normal
1999	3,628	2,882	715	25	Drought
2000	3,670	3,072	560	18	Normal
2001	3,843	3,074	333	11	Wet
2002	3,811	3,404	336	10	Wet
2003	4,311	3,858	336	9	Wet

4 Results and discussion

4.1 Groundwater model calibration

Groundwater flow model (MODFLOW) was used to simulate groundwater flow conditions in the area during the period 1993-2003. Input data included river water level, observation groundwater level, and well abstraction used from the former project (Koontanakulvong, et. al., 2006). The layer aquifer conceptual model and model grid design were shown in Figure 2. In this study, the model was calibrated compared with observation data using recharge equation derived (Koontanakulvong and Suthidhummajit, 2015). Model calibration and verification were performed in steady state as well as in transient state. Following the seasonal crop pattern, the seasonal stress period was used in the calibration of two years of recorded historical groundwater levels. Calibration in transient state has been carried out, using the 1993-2003 historical water levels, whereby groups of specific storage have been calibrated. Results of calibrated model (in Figure.3) show that simulated values were closed with observed data and the root mean square calibration error is 3.70 m and a mean error of 0.97 m in steady-state mode. In transient state, a root mean square calibration error is 5.11 m and a mean error of 2.85 m. The verification model, using two years of groundwater level monitoring data (2004–2005), has been performed, resulting in a root mean square error of 5.95m and a mean error of 3.84 m.

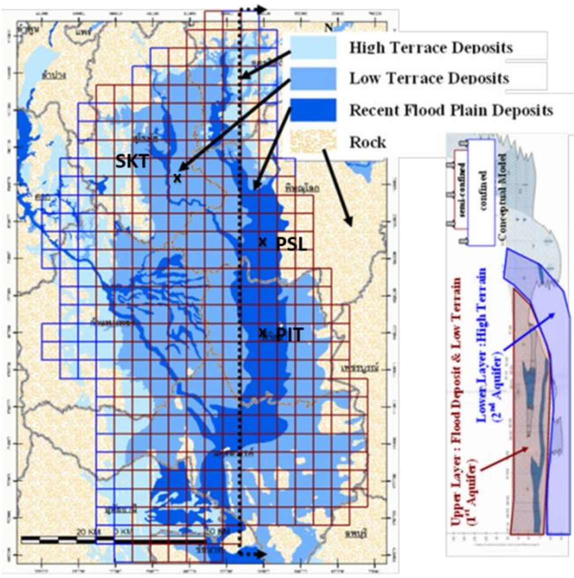
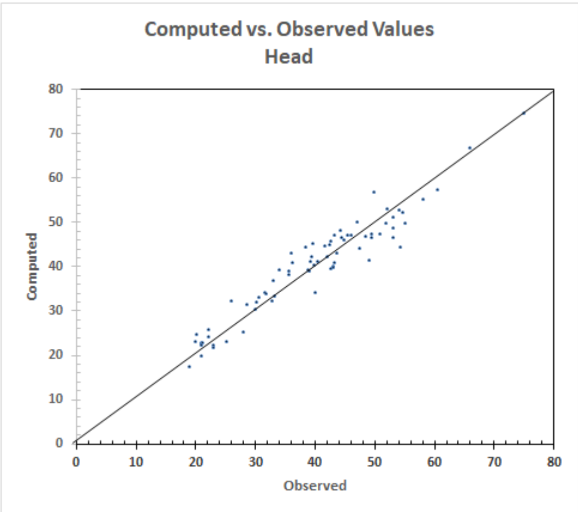
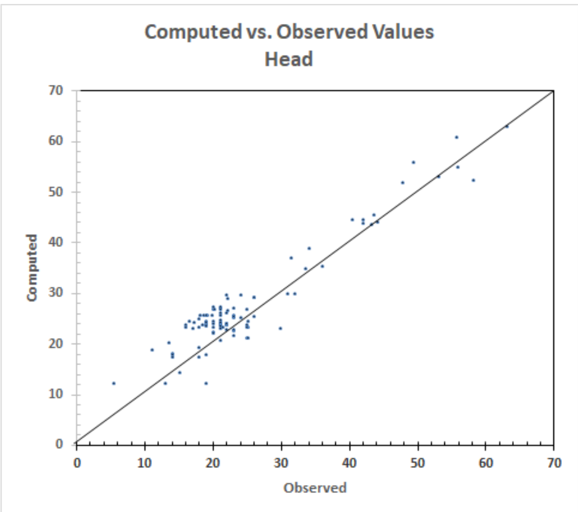


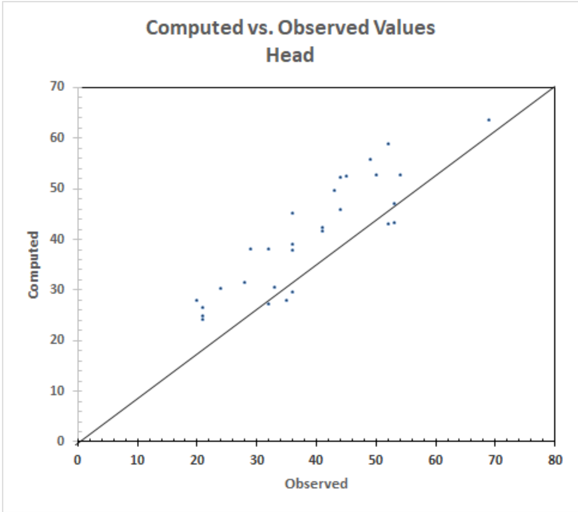
Figure.2 Layer aquifer's conceptual model and model grid design



a) steady state



b) transient state



c) verify state

Figure.3 Computed vs. observed values in steady state, transient state and verify state

4.2 Groundwater system

From the results of groundwater flow simulation, the groundwater system can be expressed from flows extracted to inflow-outflow-storage. ~~From the water budget~~ In dry season when farmers used groundwater, the main out flow are pumping and river discharge (see Figure 4). Storage change in 1st layer is minus and needs supply from 2nd layer. In the 1st layer, the average land recharge was small (25 MCM) and was lower than the discharge to the river (-102 MCM). The average groundwater pumpage was 325 MCM which is high and needs to receive water from 2nd layer. For the 2nd layer, the average land recharge was nearly 0 MCM. The average groundwater pumpage was 38 MCM. The flow in boundary and flow out boundary were 37 MCM, 27 MCM and 30 MCM, 1 MCM in 1st layer and 2nd layer, respectively, and the interaction flow between 2 layers was 64 MCM from 2nd layer to 1st layer.

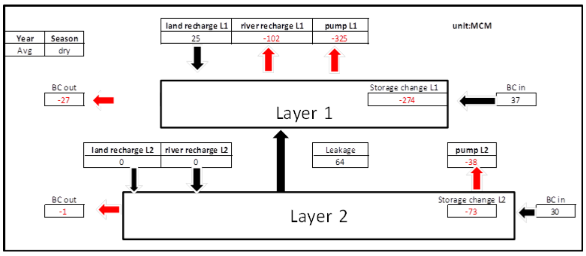


Figure.4 The groundwater system in dry season in 1993

The 1st aquifer is the main aquifer where farmers pumped water for their paddy field. From the model, the flow of groundwater system of 1st layer in seasonal and annual basis are shown in Table 2. It can be seen that the main input is from land recharge while the main outputs are pumping and river recharge. The average land recharge was 1.1, 0.137 and 1.237 MCM/season/day in wet season, dry season and annual respectively. The river recharge worked differently from land recharge. It recharged to aquifer in wet season (0.35 MCM/season/day) but it received water from aquifer in dry season (-0.56 MCM/season/day). The amounts of 0.35, -0.56 and -0.21 MCM/season/day were in wet season, dry season and annual respectively. The average groundwater pumpage was high, nearly 1.8 MCM/season/day in dry season, hence, the average groundwater storage change decreased to 1.5 MCM/season/day in dry season and this was the reason that the average groundwater level in dry season in this area decreased too.

Figure 5 shows the flow of groundwater system with representative groundwater levels in dry season at represented locations at present period and each water year. It can conclude that in dry season and drought year, the groundwater storage decreased from normal year 126 and 366 MCM, respectively. The representative locations of gw level in this study are in Sukholthai (SKT), Pisanulok (PSL) and Pichit (PIT), which were selected from the high change in gw level as shown in Figure 1. The gw level in dry season of SKT, PSL and PIT in drought year was 43.7, 40.8 and 28.8 m MSL, respectively.

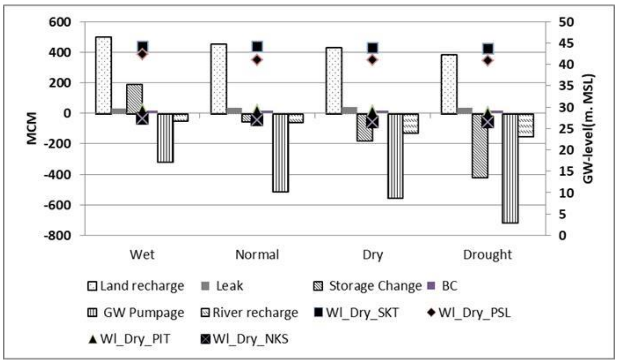


Figure 5 The annual flow of groundwater system (aquifer 1) and gw level at represented locations in the present period and each water year

Table 2 The seasonal flow budget of groundwater system in the 1999 (drought year at present period)

Time Period	Drought year(1999):MCM		
season	wet	dry	annual
River recharge	20	-170	-150
GW_Storage change	235.05	-654.82	-420
Land recharge	343	45	388
GW_Pumpage	-154	-561	-715
Flow in BC	37	37	73
Flow out BC	-27	-27	-55
From Layer 2	17	22	39

Remark: "-" represents a decreasing value

4.3 Impact of climate change on groundwater system and sw-gw conjunctive use

The impact from climate change was shown in Figure 6 where the land recharge will decrease in the periods of both near future and far future periods compared with the past due to the increase of evapotranspiration (temperature). The ratio of average recharge rate in near future and far future periods compared with the present is 0.42, and 0.50 respectively.

The seasonal change of groundwater system in the near future and far future (in Table 3), impacted from the climate change condition, shows that the average groundwater pumpage will increase to 503 MCM in near future and it will reduce to 500 MCM in far future which will slightly decrease from the near future. The annual river recharge will reduce to -21 MCM and -4 MCM in the near future and far future. For all of these results, the groundwater storage change will be -217 MCM and -215 MCM in near future and far future periods respectively. When focused in dry season, the river recharge will reduce to -58 MCM and -44 MCM which means that the groundwater recharged to the river will reduce in dry season and this will effect on the surface water storage in dry season.

Figure 7 shows the flow of groundwater system with groundwater level in dry season at SKT and PSL in drought year in present, near future and far future periods. In this area, the critical of gw level is not lower than 15 m from ground surface. It can conclude that the groundwater storage in the drought events (like 2020 and 2082) in near future and far future will decrease from 1999 at 209 and 319 MCM, respectively. The gw-level in dry season at SKT and PSL point in 2020 dry season will be lower than in 1999 at 5.8 and 1.49 m, respectively. The gw-level in dry season at SKT, PSL and PIT point in 2082 dry will lower than in 1999 at 9.3, 2.53 and 2.95 m, respectively. The gw-level in dry season of drought events (like 2020 and 2082) will be lower than in 1999 as a result of higher pumping. When considered among the representative points, SKT is the lowest gw-level as a result of the hydro-geological setting. SKT is in the high terrace deposit area which has lower potential yield than PSL and PIT, and they are in the flood deposit area as shown in Figure 2. In near future, the gw-level in drought year of SKT is critical because it will be lower than 15 m. below ground surface so pumping should be stopped in this area in the future.

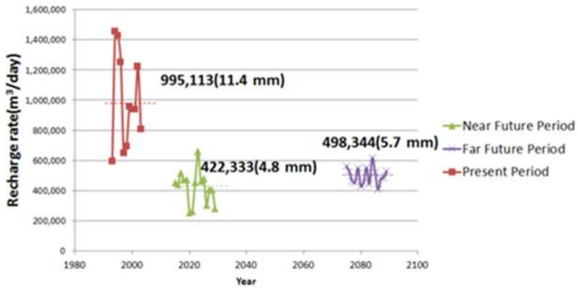


Figure 6 The average groundwater recharge rate from projected future climate data

Table 3 The seasonal and annual change of groundwater system in 2020 (drought year in the near future)

Time Period	drought year(2020):MCM		
season	wet	dry	annual
River recharge	11	-106	-94
GW_storage change	90	-719	-629
Land recharge	175	66	241
GW_pumpage	-247	-578	-825
Flow in BC	37	37	73
Flow out BC	-27	-27	-55
From Layer 2	21	11	31

Remark: “-” represents a decreasing value

Table 4 The seasonal and annual change of groundwater system in 2082 (drought year in the far future)

Time Period	drought year (2080):MCM		
season	wet	dry	annual
River recharge	15	-119	-104
GW_storage change	68	-808	-739
Land recharge	209	51	261
GW_pumpage	-176	-765	-941
Flow in BC	37	37	73
Flow out BC	-27	-27	-55
From Layer 2	11	15	26

Remark: “-” represents a decreasing value

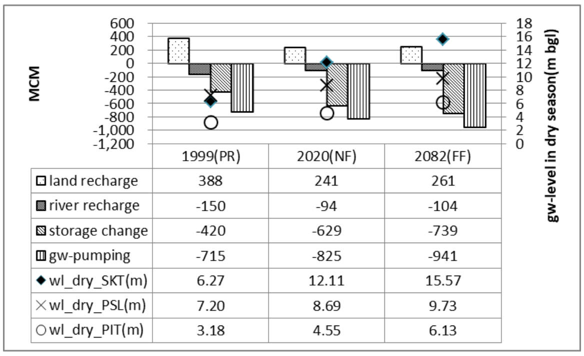


Figure 7 The annual flow of groundwater system (aquifer 1) and gw-level in dry season of SKT and PSL in the drought years (like 1999, 2020 and 2082)

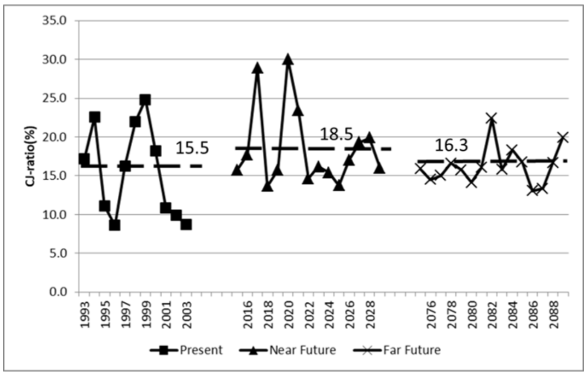


Figure 8 The conjunctive use ratios in the present, near future and far future periods

The conjunctive use ratios in the future are demonstrated in Figure 8, and the mean conjunctive use ratio in annual basis will increase in near future and far future to 18.5% and 16.3% respectively, which means that there will have more groundwater use due to more water shortage situations in the near future and far future. Table 5 shows the water demand, surface water supply, groundwater pumping, water deficit and CJ ratio at the represented drought year in present (1999), near future (2020) and far future (2082). The water demand in 2020 and 2082 are higher than in 1999 at 1,112 and 2,572 MCM, respectively. The surface water supply in 2020 is lower than in 1999 at 107 MCM, and in 2082 is higher than in 1999 at 1,037 MCM. The groundwater pumping in the drought years (like 2020 and 2082) are higher than in 1999 at 110 and 226 MCM, respectively. Although, the pumping in 2020 and 2082 are higher than 1999, but the water demand in 2020 and 2082 are much higher than in 1999 that why the water deficit in 2020 and 2082 will be higher than in 1999.

Table 5 The water demand, sw-supply, gw-supply, water deficit and CJ ratio in drought years

	Drought year (MCM)		
	PR(1999)	NF(2020)	FF(2082)
water demand	3,628	4,740	6,199
sw-supply	2,882	2,775	3,919
gw-supply	715	825	941
deficit	31	1,140	1,340
CJ-ratio	0.25	0.30	0.24

5. Conclusions and recommendations

For the groundwater system in present period, the main input is from land recharge and the main outputs are river recharge and pumping. The average land recharges were 1.1, 0.137 and 1.237 MCM/season/day in wet season, dry season and annual basis respectively. The river recharge works differently from land recharge, i.e., it recharged to aquifer in wet season(0.35 MCM/season/day) but it received water from aquifer in dry season(-0.56 MCM/season/day). The amounts of 0.35, -0.56 and -0.21 MCM/season/day were in wet season, dry season and annual basis respectively. The average groundwater pumpage was high nearly 1.8 MCM/season/day in dry season, thus, the average groundwater storage change decreases to 1.5 MCM/season/day in dry season. This was a reason that the average groundwater level in dry season in this area decreased. Groundwater is used in the dry year more than in the wet year. The sw-gw conjunctive use ratio was highest (23-25%) in drought year and the lowest was in wet year (9-11%).

The impact from climate change can be seen from the change of groundwater system in the near future and far future. The land recharge will be less due to higher temperature and more groundwater pumping needed due to higher irrigation demand which will induce more use of groundwater and lower the groundwater level. The average groundwater pumpage will be 503 MCM in near future and it will be 500 MCM in far future (or slightly decrease from the near future). The river annual recharge in annual basis will decrease to -21MCM and -4 MCM in near future and far future. The groundwater storage change will decrease to -217 MCM and -215 MCM in near future and far future period, respectively. When focused in dry season, the river recharge will be -58 MCM and -44 MCM which means that less groundwater will be recharged to the river in dry season and this will have minus effect to surface water storage in dry season. When focused in drought year, the groundwater storage change and the gw-level of dry season in represented point in the drought years (like 2020 and 2082) will more decrease than in 1999. The conjunctive use ratio in the future will increase in both near future and far future due to the increase in groundwater use. As a result of the higher water demand in the drought years (like 2020 and 2082), there will be more water deficit than in 1999 with higher groundwater pumping.

With the restrictions on this area that it is difficult to construct a new large dam, hence the demand side management should be considered and applied to this area such as increasing water productivity (better water control, cultivation area control, improved production processes) to reduce water deficit to zero. It is recommended that potential groundwater in this area should be studied in more detailed for future groundwater management.

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