Climate change impact on water availability in the Toluca Valley in Mexico

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Chapter 1 Introduction

Global climate change is one of the greatest challenges facing humanity today. In fact, climate change is a "normal" part of the earth's own evolution (Elshemy, 2013), with the earth's climate always shifting between cold ice ages and relatively wet and warm interglacial periods. However, since the second Industrial Revolution, with the continuous emission of greenhouse gases, the process of climate change has been accelerating, and the global temperature has shown a significant trend of increase. That is to say, climate change can be divided into two aspects, one is natural climate change, and the other is climate change brought by human activities.

Climate change can change all kinds of meteorological factors, such as solar radiation, temperature, rainfall, and so on. These factors are important components or driving factors of the hydrological cycle, so climate change will have a significant impact on the hydrological cycle process. To continue, changes in the hydrological cycle will lead to many changes in some brunches of the water resources domain. The total amount of water resources, the amount of surface water and groundwater resources, river flow, the frequency and intensity of extreme hydrological events, water quality, and water ecology will all be affected due to the hydrologic cycle changing. So climate change will have a significant impact on water resources. The impact spans a wide range of spatial scales, including both global and regional scales.

In general, climate change will have the following effects on water resources. Adverse impacts of climate change may include aggravated uneven distribution of the global water resources in temporal and spatial scale, increase in the frequency and intensity of extreme hydrological events, deterioration of water quality in lakes and reservoirs, and decrease in water availability. These changes are not the same in all regions, and the effects of climate change may be quite different in different regions. For example, Asadieh's study shows that the frequency of floods tends to increase in areas near the Arctic Ocean, while in semi-arid areas near the equator, flood frequency tends to decrease, and drought frequency tends to increase (Asadieh and Krakauer, 2017). The different hydrologic cycles and climate change factors in different regions will bring great uncertainty to the change of water resources. Therefore, the change of water resources caused by climate change is a complex process, which is full of uncertainty and unknown to human beings.

Water is the source of life, the basis of production, and the need for ecology. Human basic necessities are inseparable from the support of water resources. So sustainability of water management is important for us and for future generations. The change in water resources caused by climate change brings great challenges to water resource management. In recent decades, floods and droughts have occurred frequently. More and more people around the world are living under water deficit. Clearly predicting future water resource changes and exploring the causes of water resource changes can provide strong data support for the formulation of sustainable water resource management policies. Therefore, it is very essential to analyse and study the impact of climate change on water resources.

At present, there have been many studies to explore the trend of water resources changing under climate change scenarios. There are two main research methods. One is to predict the evolution trend of water resources in the future by analysing the existing long-term series of observation data using statistical methods. The second is to simulate future changes in water resources through hydrological models combined with future projections of climatic variables (e.g., precipitation and temperature) under climate change. This method builds a hydrological model according to the physical process of the hydrological cycle based on the current situation and simulates water resources with climate projection data.

Toluca Valley is located upstream of the Lerma River in Mexico, near Mexico City, the capital of Mexico (Figure 1). The valley has an average elevation of about 2,500 meters above sea level, so although in the temperate zone, the climate is relatively cold. The Lerma River runs through the valley and is the main water source for the Toluca Valley. Since the 1950s, as Mexico City urbanized and ran short of water, groundwater has been abstracted in the Toluca Valley to secure the capital's water supply. In Mexico City, one of the world's most densely populated cities, water demand is high, and the Toluca Valley, one of the main sources of water supply, has gradually observed groundwater levels drop. Arguably, the Toluca Valley's water resources are under high pressure at the current stage. The worse thing is that according to global climate projections, rainfall is decreasing in central Mexico, where the Toluca Valley is located. That means the Toluca Valley may be under greater water pressure in the future. Therefore, assessing the impact of climate change on water resources in the Toluca Valley is critical to sustainable water management.

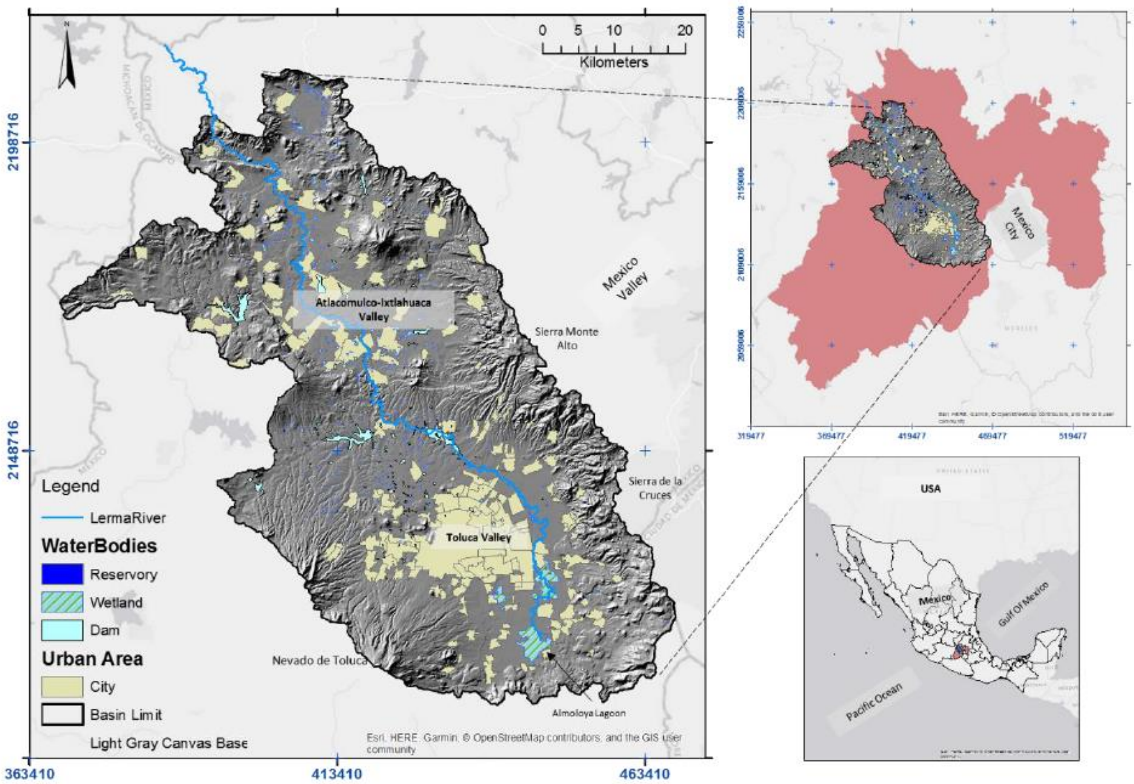

Figure 1. The location of Toluca Valley

So far, although we have a basic understanding of climate change trends in the global water cycle and water resources, we do not know the climate change trends in the Toluca region and how such trends will affect water resources in the Toluca region. This is the first knowledge gap we have.

Water availability is the available water resources that can be utilized for various uses (e.g., drinking water supply, irrigation, and industrial use) without significant harm to the ecosystems. Water availability volume has some differences with water resources volume. Water availability cannot be represented by streamflow easily and related to sustainable developing objectives, reservoir operation rules, well-pumping schemes, etc. And for a region that is under a lot of water pressure and has a very high water demand, we need to understand the amount of water availability locally in order to develop a sustainable development strategy. In other words, we need to figure out how much water will be available in the future for ecological security, future development, and all the requirements which need to be guaranteed. This is one of the most urgent issues for water management in the Toluca valley today.

Chapter 2 Objective and research questions

Objective:

To analyse the trend and changes in water availability under the climate change situation using a comprehensive catchment hydrological model.

Specific objectives:

1) To set up and calibrate hydrological model, assess water resources in the Toluca Valley, and evaluate uncertainty of the hydrological model for simulating water resources.

2) To simulate hydrological model and assess water resources in the future climate change condition in the Toluca Valley.

3) To analyse the water use from existing reservoirs in the current and future climate change conditions.

Research questions:

How is water resources distribution over the basin, and how is it changing in the simulation period?

How can the uncertainty of SWAT model and climate change be represented?

How is water resources distribution in the future, and how is it changing among different climate change scenarios and current condition?

What is the difference of existing reservoirs water use among climate change scenarios and current condition?

Chapter 3 Literature review

3.1 Climate change

Climate change is a “normal” phenomenon. At any time in history, the climate has constantly been changing (Elshemy, 2013). Natural changes in the climate lead to colder ice ages and warmer periods on Earth, which always alternate. At present, the earth is in a warm interglacial period. But since the second Industrial Revolution, with the continuous release of greenhouse gases, the rate of ice loss has accelerated, which is the phenomenon of global warming(Council, 2008). In other words, climate change includes not only the natural climate change of the earth but also the climate change caused by human activities.

3.2 Climate change impact on the hydrology and water resources

As the Fifth Assessment Report of the Intergovernmental Panel on Climate Change shown, climate change on the atmosphere and surface has been observed and grown significantly during recent years (Stocker, et al., 2013). Many components included in the hydrological cycle are affected by climate change, such as precipitation (Giorgi, et al., 2019), evaporation (Helfer, et al., 2012, Johnson and Sharma, 2010), transpiration(Li, et al., 2020), soil water storage(Liu, et al., 2019), and streamflow (Asadieh and Krakauer, 2017, Milly, et al., 2005).

Giorgi et al. (2019) discussed climate change impact on precipitation on the global scale by analyzing climate projections for the 21st century including global and regional climate models (GCM and RCM model). They found precipitation has a significant response to climate change, and results from different models analysis are similar. The main responses are precipitation intensity increasing, while the frequency of precipitation events decreasing, and extreme drought and the duration of dry period increasing. Climate change does have an effect on evaporation, but the effect is not straightforward, but a compound one, and the trend is not yet clear. But what is certain is that the magnitude of change in evaporation is not very large, relative to the change in precipitation. Li et al. (2020) simulated transpiration and evaporation change in the future in the semi-arid Loess Plateau, China, by Hydrus-1D model, and they found that transpiration and evaporation both have a decreasing trend in the future and that the effects on transpiration from climate change are greater than evaporation. For the climate change impact on soil water storage, Liu et al. (2019) found a significant decline in soil water storage occurs from 2003 to 2014 in the southeast US. With most components affected by climate change, streamflow, which is also affected by those components, also changes a lot under climate change conditions. Asadieh and Krakauer (2017) assess the global change in average and extreme streamflow in the 21st century. And they found that climate change has significant effects on streamflow, and the frequency of extreme flow events (drought and flood) increases significantly. Another highlight they found is that regions near the Arctic Ocean will have increasing streamflow trends and flood chance, while arid subtropical areas will have decreasing streamflow trend and increasing drought chance.

As above said, climate change has a significant influence on the hydrological cycle. And these effects operate on almost all the components in the hydrological cycle, not only surface water cycle but also groundwater cycle(Green, et al., 2011). With the components of the hydrological cycle changing, the water resources issue is bound to change along. Climate change impact on many brunches of water resources, such as water yield (Hu, et al., 2020, López-Moreno, et al., 2011, Zhang, et al., 2018), extreme hydrological events (Hirabayashi, et al., 2013, Kundzewicz, et al., 2014, Mann and Gleick, 2015), water quality (Marce, et al., 2010, Michalak, 2016), and water resources management (Giupponi and Gain, 2017, Obeysekera, et al., 2011), etc.

Zhang et al. (2018) reviewed key papers on assessing climate change and human activities' impact on water yield and proposed a new framework to evaluate these impacts. They emphasized the huge impact of climate change on water yield, and this impact is critical to sustainable water resources management. Many specific researches related to climate change how to effect water yield in one specific catchment were produced. López-Moreno et al. (2011) also did similar research in a different basin, the Ebro basin, which is a representative river in the Mediterranean area. They found that although declining water yield is mainly caused by human consumption of water, climate change aggravates water stress and makes water resources management harder.

In the field of water quantity, climate change does not only affect water yield, which is on behalf of average water quantity in one catchment but also affects the occurrence and amount of extreme hydrological events. Hirabayashi et al. (2013) assessed the flood response to climate change in the global scale and they found that with global warming the flood risk is increasing. From their results, in Southeast Asia, Peninsular India, eastern Africa and the northern half of the Andes, the frequency and intensity of flood increases with little uncertainty. Kundzewicz et al. (2014) evaluated IPCC SREX reports in global and specific region scale. They agreed the increasing flood risk in global scale, but meantime they had to admit that the linkages between global warming and flood risk are not clear for scientists. The confidence of recent analysis, which showed flood risk increasing caused by climate change, is low. In fact, from both observation data and projected data, the flood risk is increasing, but we cannot identify the force driver of this trend. Whether the flood cycle exists and its cause is one of the unsolved problems in the current hydrology (Blöschl, et al., 2019). In terms of drought, another type of extreme hydrological event, Mann and Gleick (2015) figured out that climate change caused by human activities is exacerbating California's drought.

Water resources is essential to economy and society, and this importance is not only about water quantity but also water quality. Climate change also has impact on water quality. Michalak (2016) stated that although there is evident showing tight linkage between climate change and water quality change, the study of projection and causing analysis of water quality evolution is still at the beginning stage. Marce et al. used case studies to provide evidence on the impact of climate change on water quality in reservoirs and lakes.

3.3 Simulating climate change impact on water resources by physically hydrological model

As noted above, climate change will have significant impacts on water resources and these impacts are not easy to analyze because of the uncertainty from climate change and the hydrological cycle processing. So, for water resources management assessing water resources changing caused by climate change is essential. There are two main assessment methods projecting the future trend of water resources caused by climate change. First one is to use historical long-term data to analyze the trend of water resources, which is a kind of mathematics method. Statistics analysis and data-driven model are usually applied for this method (Madsen, et al., 2014). Another method is using physically hydrological model to simulate the water cycle based on the meteorological input from climate projection, which can be seen as a physical way (Erler, et al., 2019, Xu and Singh, 2004). Compared with first mathematics method, hydrology model simulating can explain more details about the process how climate change affects hydrology cycle to water resources and also can assess uncertainty from climate change and hydrological cycle to some extent.

So far, many scholars have used various hydrological models to simulate the impact of climate change on water resources in basins of different scales on different continents. Hamududu and Ngoma (2020) evaluated climate impacts on water availability in Zambia by simulating with a water balance model, and the conclusion is the water resources which can be supplied will decrease by 13% at the end of this century because of temperature and rainfall changing (Hamududu and Ngoma, 2020). Tan et al. constructed a SWAT (Soil and Water Assessment Tool) model to evaluating climate change impacts on water resources under CMIP5 RCP scenarios in the Kelantan River Basin, Malaysia (Tan, et al., 2017). They found precipitation and stream flow will have a significant increasing in future dry season, while water yield will decrease from wet season, and they verified the SWAT model had a good performance in tropical area. Zhang et al. assessed water resources availability change caused by climate change in Manning River basin, Australia using XINANJIANG model (Zhang, et al., 2019). They found that runoff will increase in wet season and decrease in dry season in one hydrological year, and the main driver of this hydrological response is precipitation change. While Mourato used SHETRAN model to evaluate climate impacts on water availability in some Mediterranean Watersheds. In conclusion, they found that the annual runoff in southern Portugal will fall sharply by between 13 and 90 percent at the end of century (Mourato, et al., 2015). Shadkam et al. used the variable infiltration capacity (VIC) model to separate the impacts on inflow to Iran's Urmia Lake from climate change and water resources development (Shadkam, et al., 2016). The results indicated inflow change is caused by 60% from climate change and 40% from water resources development. Seiller et al. analyzed thirteen lumped hydrological models performance of forecasting water resources trend caused by climate change in several watersheds in Québec, Canada (Seiller, et al., 2017). And they analyzed uncertainty coming from calibration metrics through these simulations. The conclusion is that different hydrological models have different robustness to the objective selection and calibration metrics. My research will use the SWAT model for simulation. Therefore, the articles and details of the evolution of water resources under different climate change conditions by different scholars in recent years are listed in Table 1.

3.4 Literature review of study area

As above mentioned, the study area is located in one of the most populated and developed parts of Mexico. Because it is the central basin of water supply for the capital, it also meets the needs of local industry and population, the research on water in Toluca Valley is very extensive.

It can be seen from the literature review that the Lerma River basin upstream aquifer has been overexploited, although the Ixtlahuaca-Atlacomulco aquifer is not taken into account in the 2018 Federal Official report. On overexploitation, a study conducted by Esteller & Diaz-Delgado (2002) analyzed the effects of overexploitation on major rivers, wetlands, and land subsidence, and found that the period during which the water level of the aquifer pipette fell to

3.5 / year was studied for the reduction of wetland surface and ground fractures in the subjects involved in the withdrawal of troops from 1968-1996 (Esteller and Diaz-Delgado, 2002).

Martinez et al. (2015) analyzed the water resource vulnerability of the study area and investigated the water supply vulnerability of Mexico City, including the Toluca Valley of Ixtlahuaca Atlacomulco (Martinez, et al., 2015). Climate change impacts, infrastructure, environmental and social management factors were included in the study to obtain vulnerability indicators. The results show that these two aquifers are the most vulnerable compared with other water sources in Mexico City. Lopez et al. (2019) used multiple analysis criteria to study and analyze springs in basins that need immediate protection (López, et al., 2019).

Table 1 Literature review of using SWAT model evaluating climate impacts on water resources

Topic & author	**Study area**	**Study period**	**Main conclusion**	**Model accuracy**
(Agarwal, et al., 2015)	Koshi River Basin	Calibration: 1990-2000 Validation: 2001-2008 Simulation: 2020s, 2055s, and 2090s	The fluctuation of projected hydrological components is large. The maximum of discharge increasing during spring is 23% and 25% in 2055s and 2090s, respectively.	Calibration: NSE 0.82;R^2 0.84; Validation: NSE 0.83;R^2 0.85;
(Tan, Ibrahim, Yusop, Chua and Chan, 2017)	Kelantan River Basin, Malaysia (12134 km^2)	Calibration: 1975-1989 Validation: 1990-1999 Simulating to 2075	Precipitation and stream flow will have a significant increasing in future November to January. Water yield will decrease from June to October. The SWAT model had a good performance in tropical area.	Calibration: NSE 0.75;R^2 0.8; Validation: NSE 0.63;R^2 0.64;
(Bhatta, et al., 2019)	Tamor River Basin (4377 km^2)	Calibration: 1999-2005 Validation: 2006-2008 Simulating to 2080s	River discharge is expected to decrease under climate change scenarios in the study area.	Calibration: NSE 0.85;R^2 0.85; Validation: NSE 0.89;R^2 0.90;
(Chunn, et al., 2019)	Little Smoky River Watershed, Canada (11494 km^2)	Calibration: 1996-2007 Validation: 1986-1995 Simulation: 2010-2034	SWAT-MODFLOW to simulate climate change impacts on surface water and groundwater, and assess the interaction between them. They found more fluctuations of GW-SW exchanges are expected in the future, especially in the upper basin.	Calibration: NSE -;R^2 0.37; Validation: NSE -;R^2 0.62;
(Rivas-Tabares, et al., 2019)	Cega-Eresma-Adaja, Spain	Calibration: 2004-2010 Validation: 2011-2014	They assessed water balance and water demand in CEA basin from 2000-2014 using SWAT. They also give some specific measures related to agriculture, which should be considered in sustainable water resources management.	Calibration: NSE 0.84;R^2 0.86;

				Validation: NSE 0.82; R^2 0.85;
(Yuan, et al., 2020)	Maumee River Basin, US (16394 km^2)	------	This paper introduced one optimizing method for selecting climate change model to simulate climate impact on water resources, which is based on the water resources changing response to precipitation and temperature changing.	------
(Ercan, et al., 2020)	Upper Neuse Watershed, US (1373 km^2)	Calibration: 2005-2008 Validation: 2009-2011 Simulation: 2046-2065, 2081-2099	They quantified water balance changing caused by climate change in on small watershed in North Carolina. They found under high emission situation, water yield will increase up to 157% at the end of summer.	Calibration: NSE 0.55-0.73; R^2 0.62-0.76; Validation: NSE 0.57-0.73; R^2 0.59-0.74;
(Marin, et al., 2020)	Forested watershed less than 1000 km^2	Review	This paper reviewed the previous work on climate change impacts on water resources in small scale basin (less than 1000km^2). They found a significant decreasing trend of discharge and surface flow, especially at the end of this century. They also summarized the limitations of SWAT model are from uncertainty of climate change data and related to the period of calibration and validation.	------

Chapter 4 Methodology

4.1 General approach

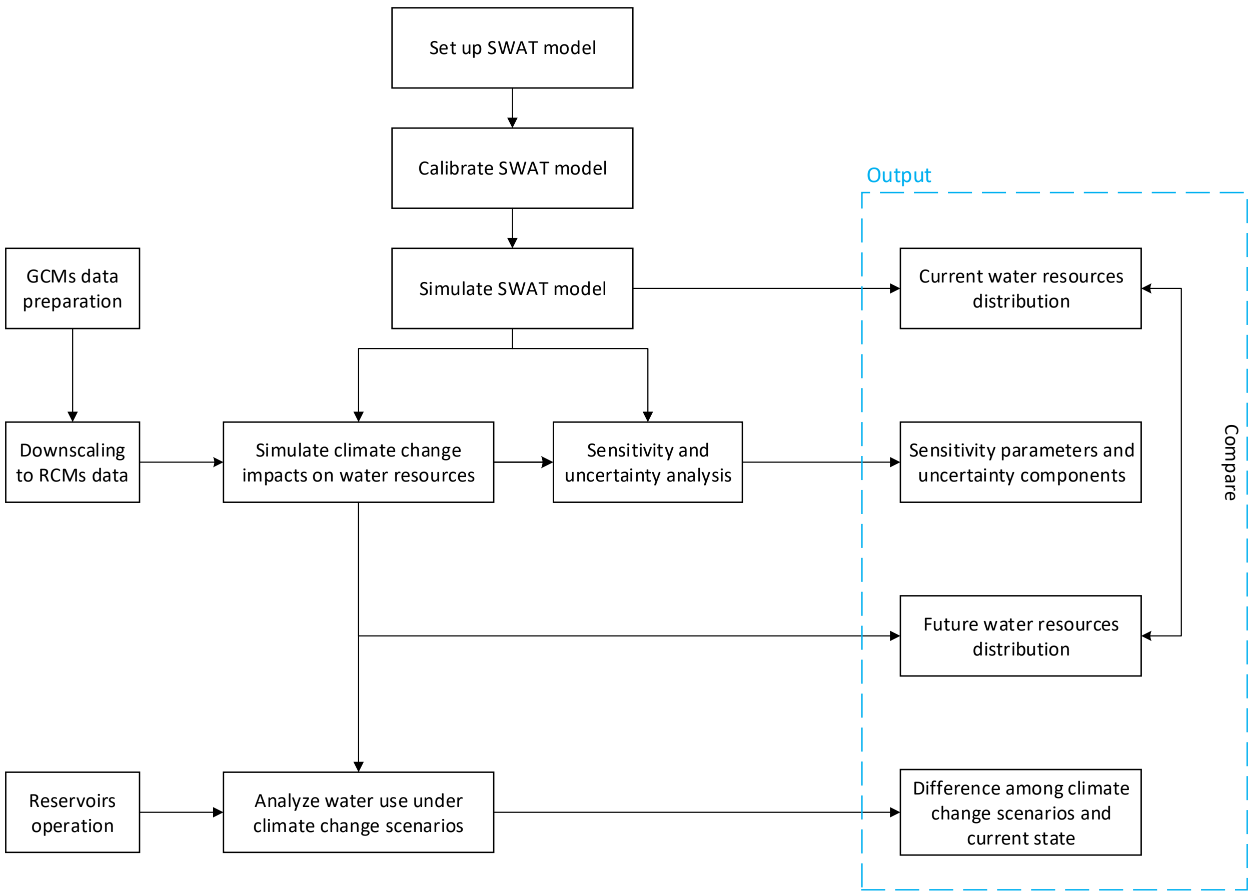

Figure 2. The flow chart of general approach in this research

For achieving the overall objective and specific objectives based on the background and information from the literature review, the research can be divided into three phases. The first phase is setting up and calibrating a model to simulate the hydrological process in Toluca Valley. Another content in the first phase is doing sensitivity and uncertainty analysis of the hydrological model. This phase aims for the first two research questions, which answers will provide current water resources distribution and water resources on how to change in the simulation period and the typical uncertainty source and how uncertainty to represent. The second phase is simulating future water resources in climate change scenarios by the constructed model in phase 1. This phase aims for the second and third research questions, which answers will give water resources in the future with climate change and the difference of water resources from the current situation, and will assess the uncertainty of climate change impacts on water resources. The final phase is using flow data from simulating results in phase 2 to calculate the water use of two existing reservoirs and comparing the available water amount with the current situation. This phase aims for the last one research question, which answers will provide the difference of reservoirs water availability among climate change scenarios and the current situation. The total flowchart is shown in Figure 2 above. And the specific methods and tools to solve every research problem are represented in Table 2.

Table 2. The methods and tools used to solve research questions

Research questions	Methods	Tools
Current water resources distribution and changing trend	Physically rainfall-runoff hydrological model	SWAT
Uncertainty represent of climate change and hydrological model	Sensitivity & uncertainty analysis	SWAT-CUP
Future water resources distribution in climate change scenarios	Downscaling GCMs model Physically rainfall-runoff model	LARS-WG weather generator/ LOCA SWAT
Assessment of existing reservoirs water use	Existing reservoirs operation rules	-

4.2 Calibration and uncertainty analysis of SWAT model

I will use a physical hydrological model to assess the water resources distribution in my research. Compared with empirical model and conceptual model, physical model is based on physical process. Physical model is generally seen as mechanistic or white box model (Devia, et al., 2015). Finite difference equations represent the hydrological processes. Physical model includes parameters which has realistic meaning to describe the real world and is based on spatial distribution. Most of physical hydrological model interface is combined with GIS system. So, the advantage of physical model compared with the other two models is that physical model can give more interpretation of the process. SWAT and MIKE SHE are typically public domain physical models.

In my research, the Soil and Water Assessment Tool (SWAT) will be used to build rainfall-runoff models. The purpose of SWAT is to predict the impact of land management practices on the production of water, sediments and agrochemicals in different soils, land use and management basins. It is continuous in time and can be simulated for a long period of time. SWAT can be used to simulate the quality and quantity of surface water and groundwater at different watershed scales. It can predict the impact of land use, land management practices and climate change on the environment. The operation of this model divides watersheds into sub-basins, and then divides them into hydrological response units (HRU). These HRUs are a unique combination of land use, vegetation and soil characteristics. The model runs on daily time steps and can effectively run data for many years. It was developed as a long-term profit model.

Calibration is a procedure to improve the accuracy of the simulation and reduce the uncertainty from model parameters. In general, calibration process is finding a group of parameters to get the minimum error between simulated results and observation data in one selected duration.

The error can be represented in many ways, such as the Nash-Sutcliffe efficiency coefficient (NSE)(Nash and Sutcliffe, 1970), coefficient of determination (R^2). Validation is to check out the performance of the group of parameters identified in calibration by assessing the simulation performance in another period. Validation process also can assess the model output uncertainty (Rivas-Tabares, Tarquis, Willaarts and De Miguel, 2019). Uncertainty can be evaluated by statistics value, such as P-factor, R-factor.

In my research, SWAT-CUP will be carried out for calibrating and analyzing uncertainty from hydrological model construction. SWAT-CUP tool can give the function of automatic calibration by global optimization algorithm, sensitivity analysis and uncertainty analysis. SWAT-CUP includes many algorithms, such as SUFI2, PSO, GLUE, ParaSol, and MCMC (Abbaspour, 2013).

4.3 Future simulation under climate change

After the SWAT model is completed, the model can be used to simulate the impact of climate change on water resources. In this phase, the input data required for the model is the forecast data of climate change. This data is usually obtained from the GCMs model. GCMs model is the abbreviation of general circulation model, which simulates the operation of the earth's atmospheric circulation. It is widely used in climate prediction, climate change research and other fields. There are many different GCMs models available. There are also many different scenarios for climate change prediction, such as RCP2.6 and RCP8.5, which represent different degrees of prediction of future greenhouse gas emissions and other drivers of climate change.

However, GCMs model regularly has a low resolution and is not enough accuracy in analyzing a regional hydrological cycle. So, regional climate change data need to be collected in the process of preparing climate change data. The process of changing GCMs data to RCMs data is called as downscaling. The two potential sources of RCM (regional climate change model) data are Mexico Nation Meteorological Service and downscaling GCMs model data. And if downscaling is necessary, two potential tools to downscale are the LARS-WG weather generator and LOCA.

After completing the preparation of climate data, the prepared climate change data can be input into the hydrological model built in the first phase. The amount of different components in the water balance (e.g., surface runoff, literal runoff, evaporation etc.) can be obtained after the simulation of SWAT model under climate change scenarios. Subsequently, by comparing the distribution of water resources under different climate change scenarios and the current situation, the distribution of the impact of climate change on water resources can be summarized. At the same time, it is worth noting that through the output of the model, we can also analyse the uncertainty of the impact of climate change on water resources. Uncertainty will not only come from the model itself, but also from climate change and the impact process.

4.4 Estimate reservoirs water availability

After running SWAT, the long-term runoff sequence can be predicted. This can reflect the amount of water resources in the future, but it cannot derive the actual amount of water available for hydraulic engineering, such as reservoirs. Under the premise of the same operating rules, the amount of available water is not only related to the amount of water resources but also related to the temporal changes of runoff. Therefore, the last phase is to estimate the amount of water available. The calculation of available water is relatively complicated. In my research, I will focus on calculating the available water volume of the reservoirs in the area.

There are two existing reservoirs in the area. The estimation of available water will be carried out for these two reservoirs. Using the runoff data output by the SWAT model and calculating in accordance with the existing operating rules of the reservoir, the water availability volume of the reservoir under the existing operating rules under future climate change conditions can be obtained. Comparing this amount of available water with the existing operation, we can get the specific impact of climate change on the available water of the two reservoirs and the uncertainty of this impact.

Chapter 5 Data requirement and acquisition

The data required for constructing a rainfall-runoff model by SWAT is 1) topography data 2) land use data 3) soil data, and 4) climate data. These four types of data are considered to be the minimum inputs to the runoff model. Observation data is necessary for calibrating, especially flow observation data. And for simulating climate change influence, the climate projection data is essential. For estimating reservoirs water availability, reservoir operation rules and previous operation data is needed. The data need and potential sources are listed in Table 3.

Table 3. Data need and potential source

Data		Potential data source	Resolution/ type
Topography		National Institute of Statistics and Geography, Mexico	Grid data: 30m,15m,5m (LIDAR)
Land use		Conabio, remote-sensing-based	Shape file, grid
Climate data	Temperature	Nation Meteorological Service (SMN), Mexico	Daily time series, weather stations
		Climate Research Unit, University of East Anglia	Monthly gridded data
	Precipitation	Nation Meteorological Service (SMN), Mexico	Daily time series, weather stations
		Tropical Rainfall Measuring Mission (TRMM), NOAA	Daily/monthly gridded data, satellite-based
		ERA-Iterim 5	Daily gridded data from reanalysis
	Solar Radiation	Nation Meteorological Service (SMN), Mexico	Daily time series, weather stations
	Relative humidity	Nation Meteorological Service (SMN), Mexico	Daily time series, weather stations
	Wind speed	Nation Meteorological Service (SMN), Mexico	Daily time series, weather stations
Soil		National Commission for the Knowledge and Use of Biodiversity ,Mexico	Shape file, different scales
Climate change data		ERA-Iterim 5	Daily gridded data from reanalysis
		Nation Meteorological Service (SMN), Mexico	Daily time series, weather stations
Observation data		Nation Meteorological Service (SMN), Mexico	Daily time series, weather stations
Reservoir data		National Water Council (CONAGUA), Mexico	Daily time series

Chapter 6 Novelty and significance

Water resources and water availability changing trend influenced by climate change in Toluca Valley is uncertain. Thus, the main novelty is to assess the climate change influence on water resources in Toluca Valley. Secondly, the water availability of two reservoirs under climate change conditions will be estimated, which is beneficial for water resources management. Thirdly, the sensitivity and uncertainty analysis about hydrological process and model is not clear till now. This part will also be carried out in this study. The significance of the expected result of my research is the water resources amount in the future, which is critical to many stakeholders.

Chapter 7 Work plan

Tasks	Oct 2020					Nov 2020				Dec 2020					Jan 2021				Feb 2021				Mar 2021					Apr 2021			
Week	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Literature review																															
Data collection																															
Proposal development																															
Proposal defense																															
SWAT construction																															
SWAT calibration																															
SWAT simulation																															
Uncertainty analysis																															
GCMs preparation																															
Downscaling data																															
Estimating water availability																															
Thesis writing																															
Thesis defense																															

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