Framework for Mapping Groundwater Resilience to Climate Change and Human Development in Asian Cities

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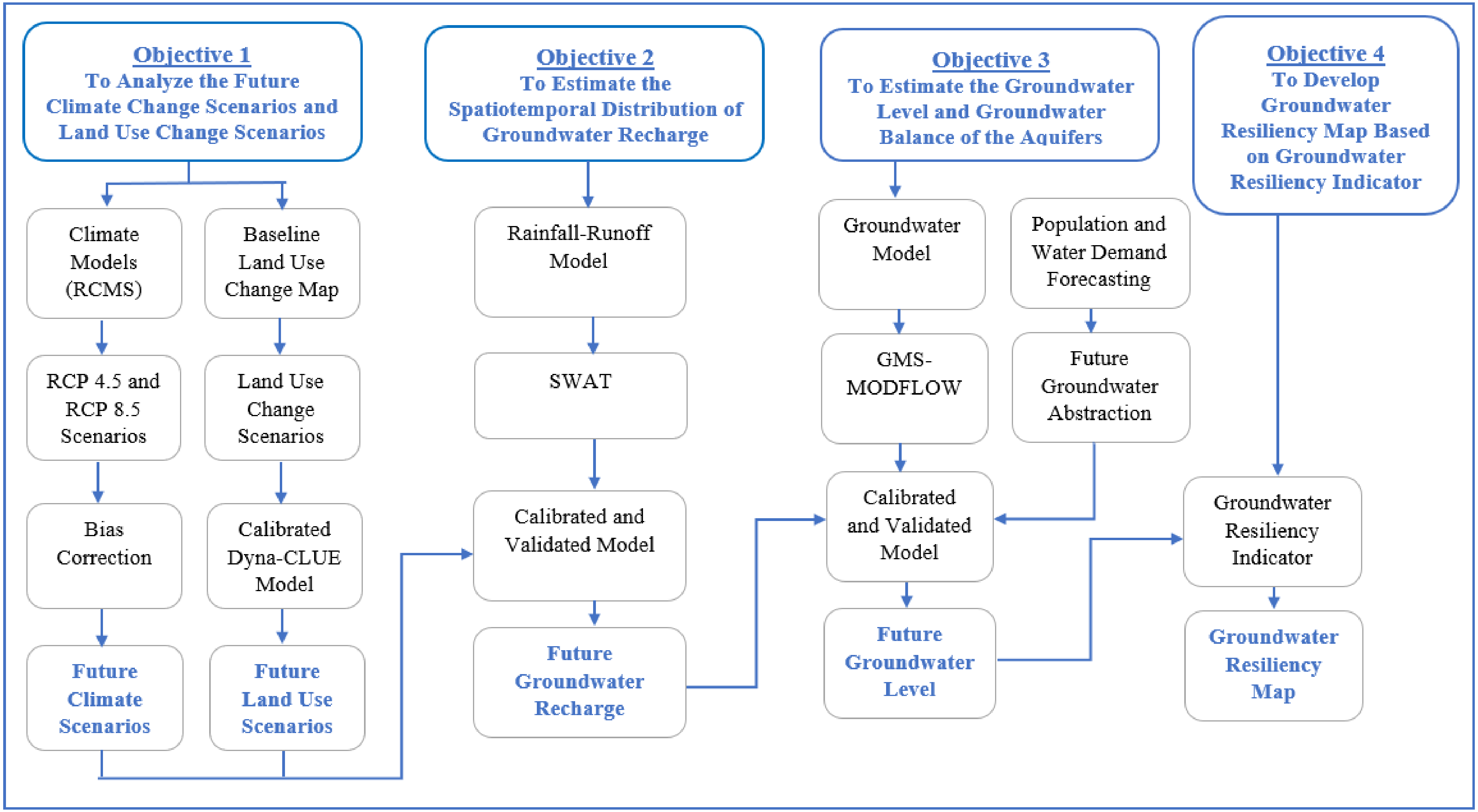
1. Objectives

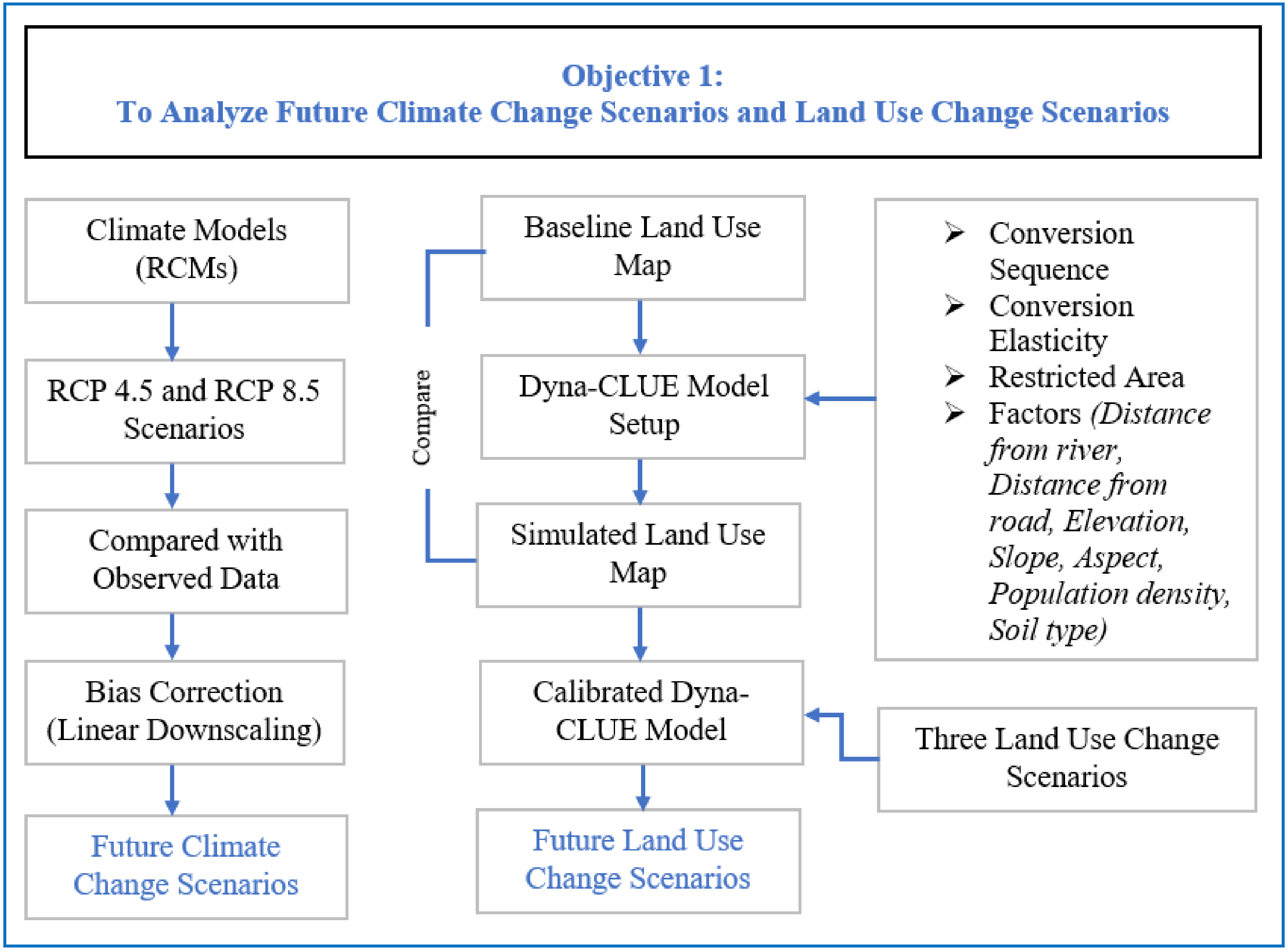
The objective of this presentation is:

1. To explain the overall methodological framework that we have proposed on the background paper.
2. To get the valuable comments and suggestion from the participants to improve our methodological framework.

2. Overall Methodology



3. Methodology: Objective 1



i. Regional Climate Model (RCMs)

Table: List of potential RCMs for Climate Change Impact Studies

RCM	Research Institute	Spatial/Temporal Resolution	Scenarios	Average Coverage	Data set Coverage Year
ACCESS1	Collaboration for Australia Weather and Climate Research, Australian Government	0.5°/Daily	Historical RCP 4.5 RCP 8.5	Global	Historical:1975-2005 RCP 4.5: 2006-2099 RCP 8.5: 2006- 2099
MPI-ESM-LR	National Center for Meteorological Research	0.5°/Daily			Historical:1975-2005 RCP 4.5: 2006-2099 RCP 8.5: 2006- 2099
CNRM-CM5-CSIRO-CCAM	European Network for Earth System Modelling	0.5°/Daily			Historical:1975-2005 RCP 4.5: 2006-2099 RCP 8.5: 2006- 2099

ii. Linear Downscaling of Temperature and Precipitation

- Precipitation will be corrected with an aspect on the proportion of long-term mean observed and control data
- Temperature will be corrected using an additive term obtained from the difference of long-term monthly mean observed and control data

$$P_{his}(d)^{*} = P_{his}(d)[\mu_m\{P_{obs}(d)\}/\mu_m\{P_{his}(d)\}]$$

$$P_{sim}(d)^{*} = P_{sim}(d)[\mu_m\{P_{obs}(d)\}/\mu_m\{P_{his}(d)\}]$$

$$T_{his}(d)^{*} = T_{his}(d) + [\mu_m\{P_{obs}(d)\} - \mu_m\{P_{his}(d)\}]$$

$$T_{sim}(d)^{*} = T_{sim}(d) + [\mu_m\{P_{obs}(d)\} - \mu_m\{P_{his}(d)\}]$$

Where,
P is the precipitation
T is temperature
d stands for daily
μ_m is the long-term monthly mean
(*) represent bias corrected
his refers to historical raw RCM data
obs refers to observed data
sim is the raw RCM future data.

i. Dyna-CLUE model

- Dyna-CLUE is a dynamic, spatially explicit, land use change model.
- It considers five types of input files i.e., land use demands, location suitability, neighbourhood suitability, spatial restrictions and conversion parameters.
- The stepwise logistic regression method is used for location suitability and neighbourhood suitability for each land use type. Logistic regression can be calculated as- (*Verburg et al., 2002*)

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

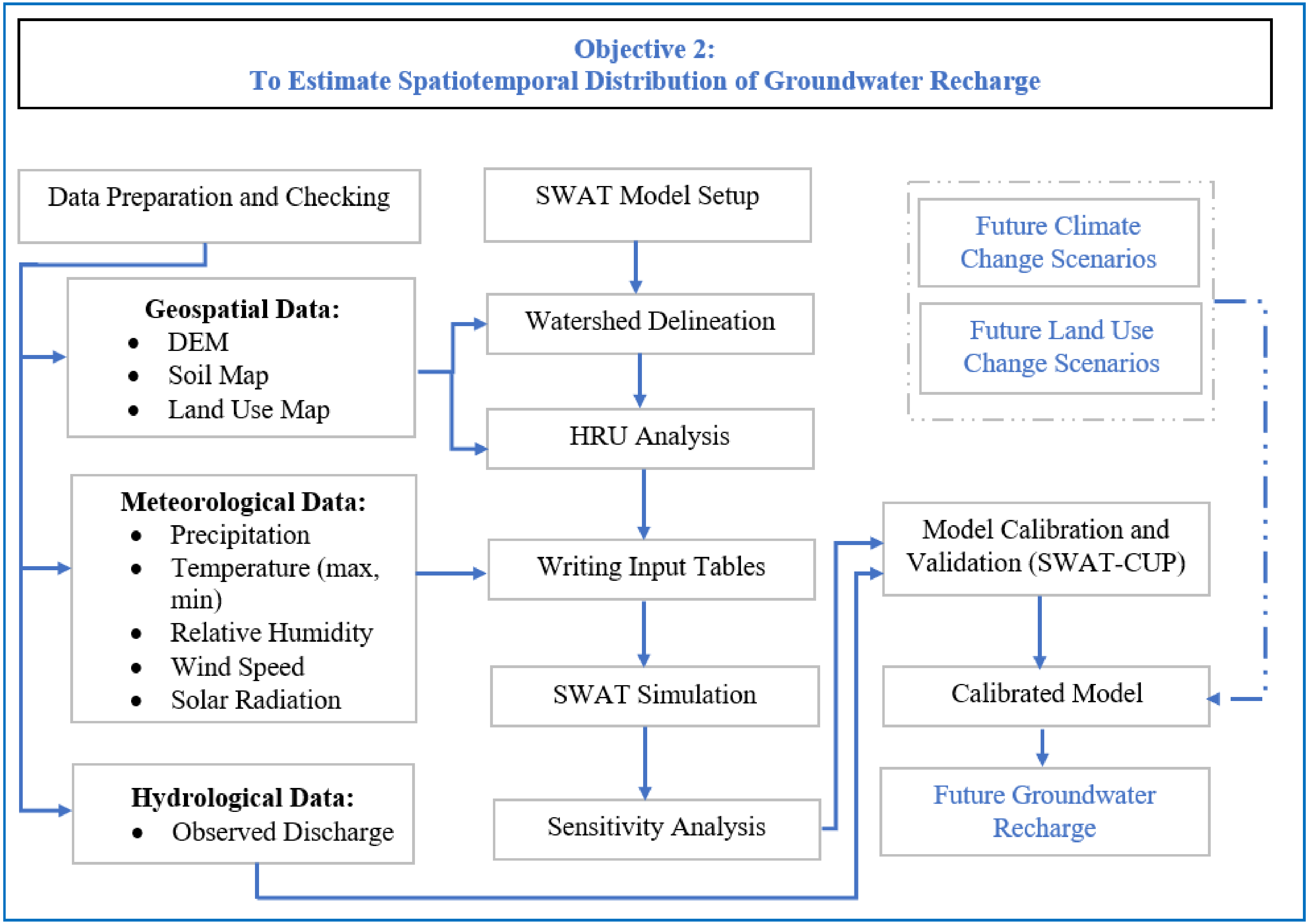
Where,

Pi *is the probability of a grid cell for the occurrences of the considered land use features.*

Xs *are the driving factors.*

β (coefficient) is estimated using a logit regression

4. Methodology: Objective 2



i. SWAT Model

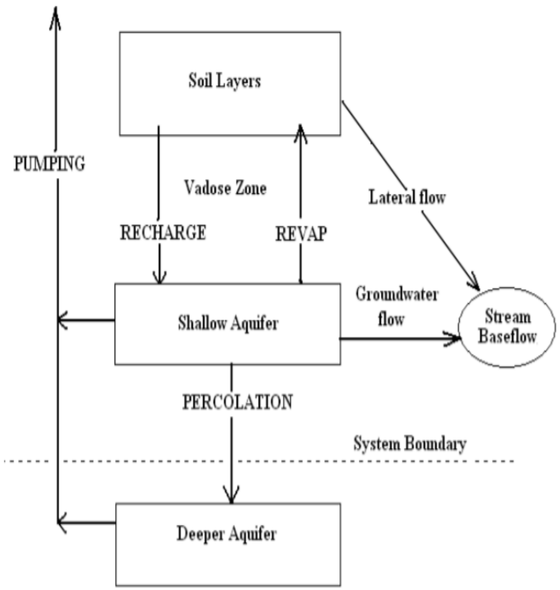
- The Soil and Water Assessment Tool (SWAT) developed by the United States Department of Agriculture is a physically based semi-distributed hydrological modelling tool which can predict runoff and water balance, erosion, sediment and nutrient transport from agricultural watershed under different management practices

- SWAT simulation are bases on the water balance equation:

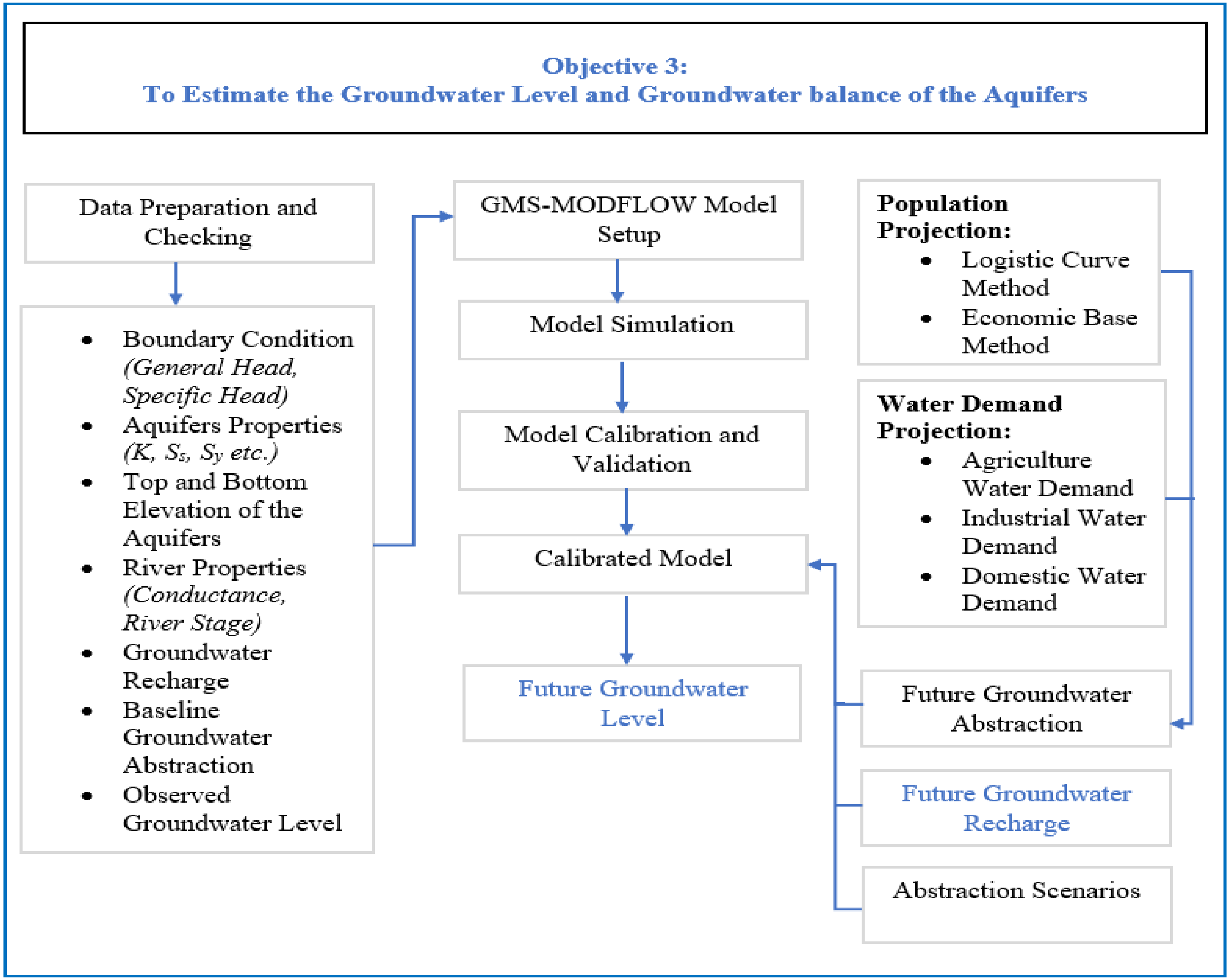
$$SW_t = SW_0 + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

SW_t *is the soil water content (mm water) at the end of the time step t (days),*
SW_0 *is the initial soil water content in day i (mm water),*
R_{day} *is the amount of precipitation on day i (mm water),*
Q_{surf} *is the amount of surface runoff on day i (mm water),*
E_a *is the amount of evapotranspiration on day i (mm water)*
Q_{gw} *is the amount of base flow from the shallow aquifer on day i (mm water)*

W_{seep} *is the amount of water entering the vadose zone from the soil profile on day i (mm water),*



5. Methodology: Objective 3

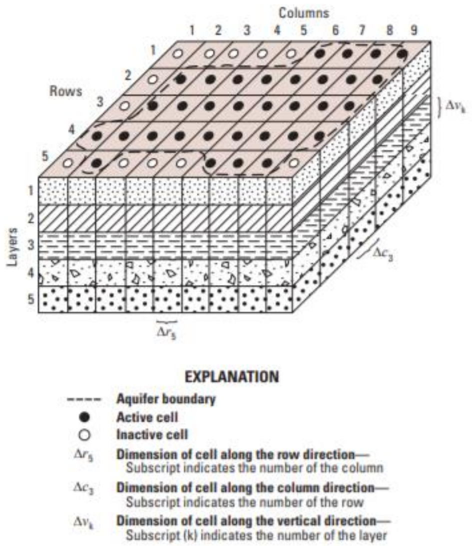


i. MODFLOW Model

- MODFLOW is an extremely flexible groundwater model that simulates three-dimensional groundwater flow through a porous medium (McDonald and Harbaugh, 1988) and developed by United States Geological Survey (USGS)

- 3D groundwater flow through porous medium is governed by the following equation:

$$\frac{\partial}{\partial x}\left(K_x \frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial h}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial h}{\partial z}\right) = S_s \frac{\partial h}{\partial t} - W$$



***K_x, K_y, K_z** are values of hydraulic conductivity along x, y and z axes,*
***h** is the hydraulic head,*
***W** is flux per unit volume, representing sink and/or sources of water,*
***S_s** is specific storage of the aquifer*

b. Methods of Population Projection

i. Logistic Curve Methods

$$P_t = \frac{P_{sat}}{1 + e^{(a+b\Delta t)}}$$

$$P_{sat} = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$a = \ln\left(\frac{P_{sat} - P_0}{P_0}\right)$$

$$b = \frac{1}{n}\ln\frac{P_0(P_{sat} - P_1)}{P_1(P_{sat} - P_0)}$$

Where,
P1, P2*= population at time periods*
Pt*= population at time period t*
Psat*= population at saturation level*
*Δ**t** = number of years after base year*
***a, b** = data constants*
***n** = time interval between successive years*

ii. Economic Based Methods

A simple method of producing employment-based population projections is to forecast employment and then apply a population/employment ratio which can be defined as follows:

$$R(t) = \frac{P(t)}{E(t)}$$

$$P(t) = \sum_q E^q(t)\, R^q(t)$$

Where,
***E=** Employment*
***P**= Population*
***R**= Population, Employment Ratio*
***q**= Employment Category*

c. Methods to Estimate Water Demand

i. Agricultural Water Demand

- CROPWAT model will be used to estimate the agricultural water demand

- CROPWAT is a decision support tool for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data

- Based on changes in agricultural area and climate future crop water requirement will be calculated in temporal scale.

ii. Industrial Water Demand

Total water use over n sectors can be calculated using the following equation:

$$Q_{Total} = \sum_{k=1}^{n} (\alpha_k - X_k)$$

Where,

Q_{Total} = *water use for n sectors*
α_k = *water use coefficient of sector k*
x_k = *size of sector k*
n = *number of sectors*

c. Methods to Estimate Water Demand

iii. Domestic Water Demand

The general form of the equation to calculate domestic water demand can be expressed as follows in linear terms

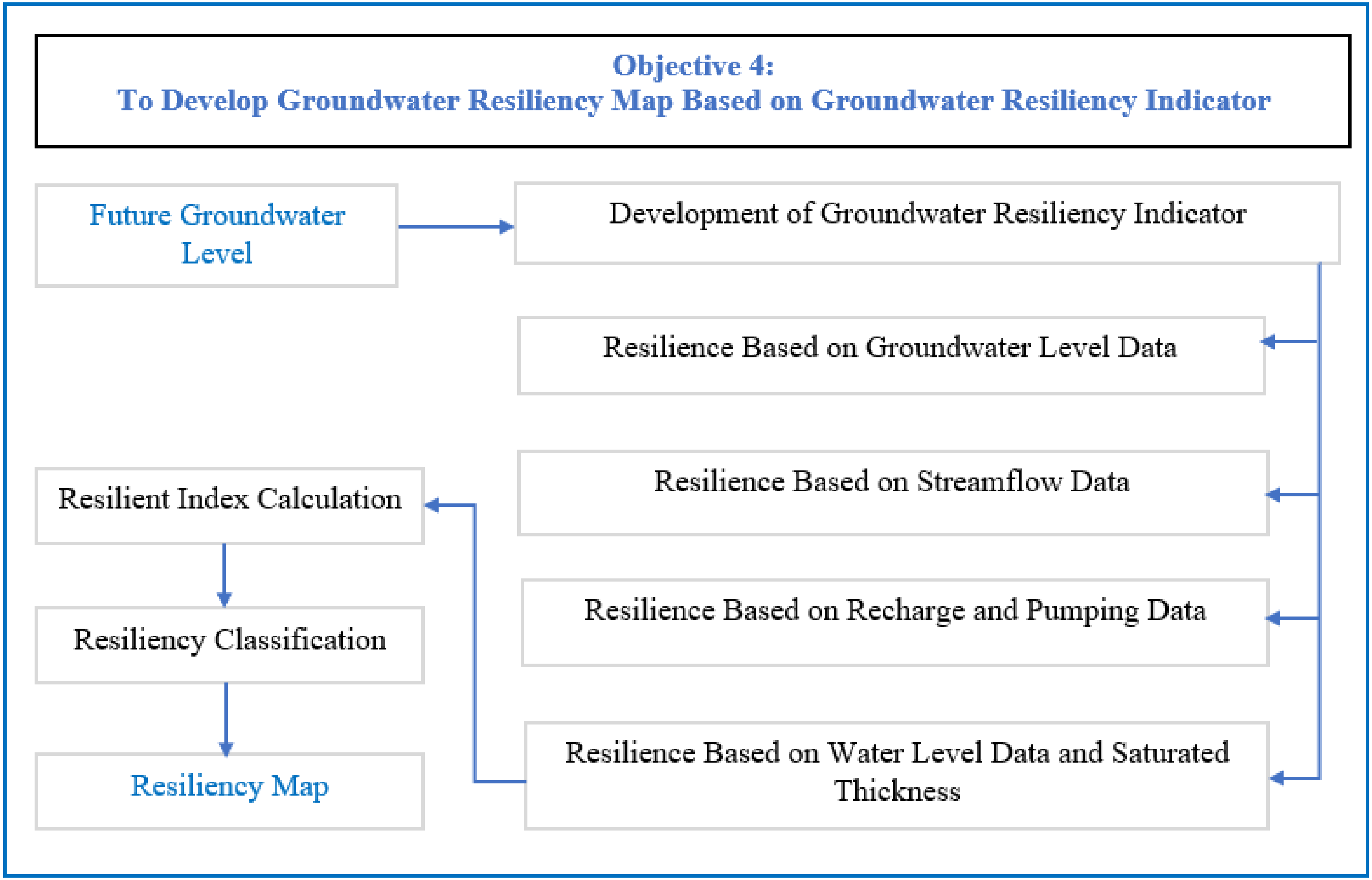
$$Y = b_0 + b_1 (X_1) + b_2 (X_2) + b_3 (X_3) + \cdots \cdots + bn (Xn)$$

where,
Y *is the total water use/demand (dependent variable)*
X_1 to Xn *are different relevant factors affecting the water use/demand*
b_0 to bn *are the regression coefficients*

Relevant Factors

- *number of connections*
- *water tariff rate after minimum allowance of water supply*
- *population, per capita GDP at the current price*
- *number of households*
- *annual rainfall in mm*
- *average household size*
- *average annual temperature and rainfall etc.*

6. Methodology: Objective 4



7. Expected Outputs

Based on the overall methodology, following outputs are expected at the end of the study:

- Future climate scenarios under RCP 4.5 and RCP 8.5 scenarios
- Future land-use scenarios of the Asian Cities
- The spatiotemporal distribution of groundwater recharge based on well calibrated and validated hydrological model
- Future population and future water demand of Asian Cities
- Groundwater level and groundwater balance of the aquifers in Asian Cities using groundwater model
- Groundwater resiliency indicator based on the result of hydrological and groundwater model, which in-turn are used to develop groundwater resiliency map of Asian Cities

Any Questions?