Site selection of aquifer storage and recovery in Taiwan

Student:Bo-Feng Lee
Advisor: Prof. Jui-Sheng Chen
Co- Advisor : Prof. Ching-Ping Liang
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Outline

- Introduction
- Methods and material
- Results and discussion
- Conclusion

01

Introduction

Water resources issue

With the economic development and population increase in Taiwan, the demand for water for agriculture, fishery, industry and people's livelihood has increased,water resources is an important issue to be concerned.

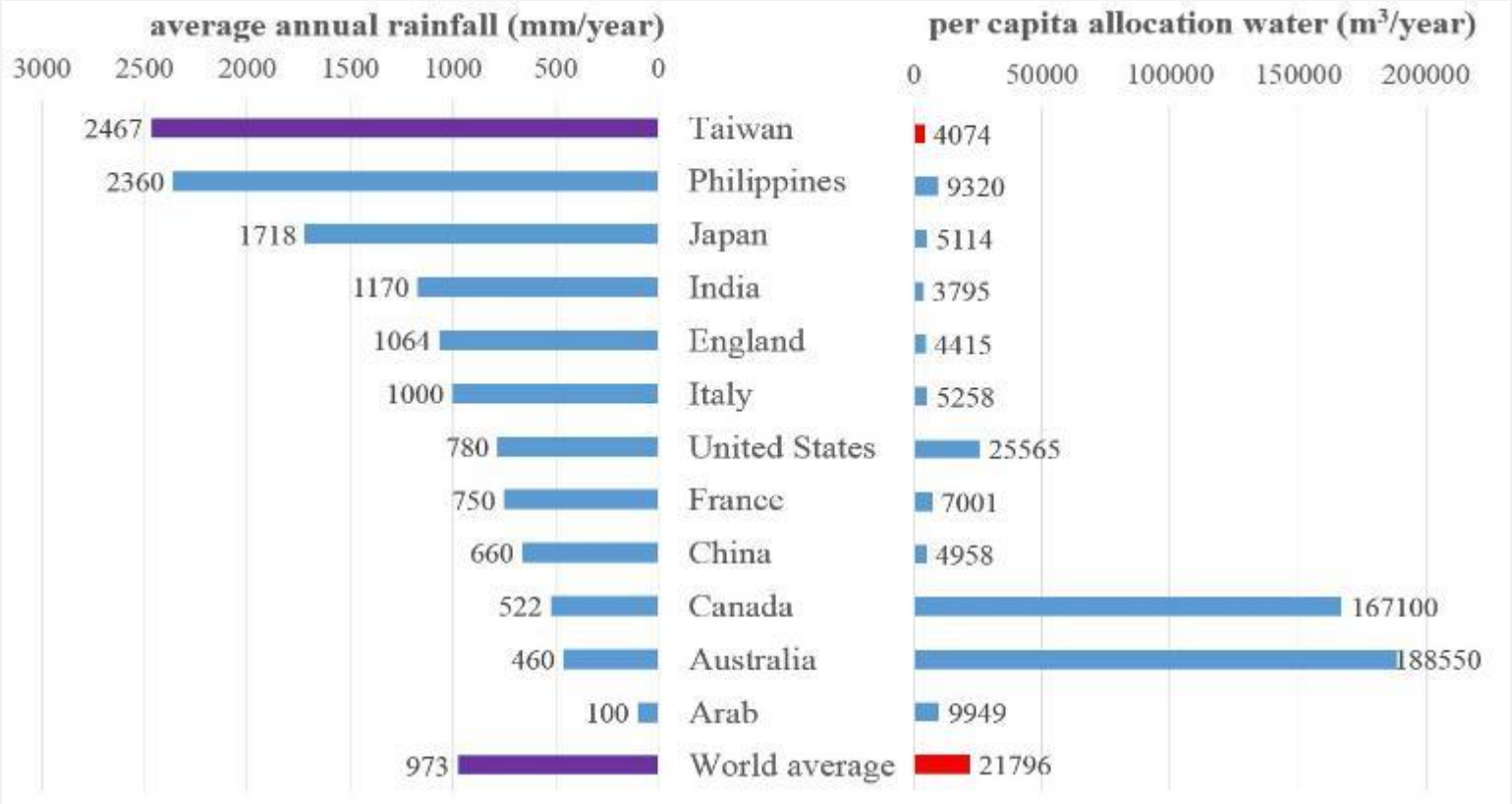
2023/03/13 https://tw.news.yahoo.com

https://esg.businesstoday.com.tw/

Rainfall in Taiwan

Taiwan's annual average rainfall is about 2,500mm, which is about three times more than the global rainfall of 1155mm.

However, Taiwan’s average annual water volume for Taiwanese people is only 3,752 m^3/year, which is 1/6 of the world average. Taiwan suffers from water shortage all the time.

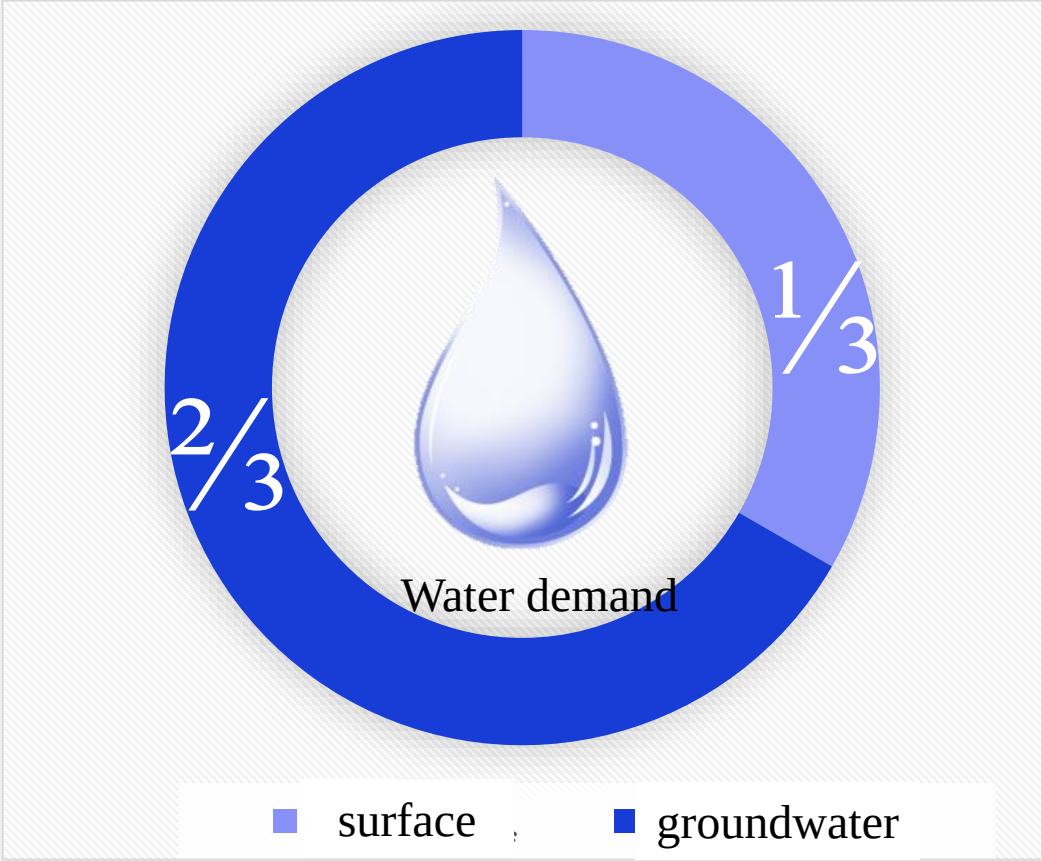


(Water resources Agency, 2018)

Overpumping in Taiwan

- Water consumption was 16.8 billion tons .
- 1/3 supplied by the surface and 2/3 supplied by the groundwater. (Water resources Agency, 2018)
- There was no concept of sustainable development in the early years, overpumping has led to:

1. subsidence(Budhu and Adiyaman, 2010; Dokka, 2011; Jones et al., 2016)
2. saltwater intrusion often before there are any signs of water deficit. (Agarwal et al., 2013; Ross and Hasnain, 2018).



Groundwater quality in Taiwan

•Southern Taiwan pump groundwater as a water source.

•The dirty water detected in the groundwater of landfill has exceeded the drinking water quality standard, and the pollution has become very serious.

https://www.chinatimes.com/newspapers/20191102000474-260114?chdtv

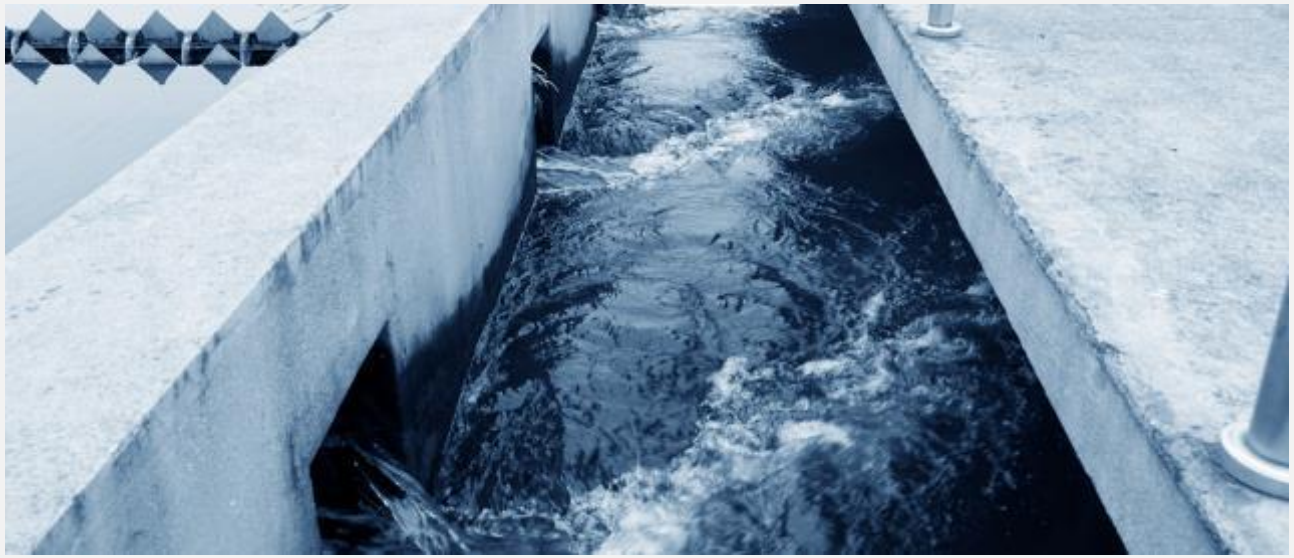
Innovative water management strategies

•We need innovative water management strategies to：

1.preserve the integrity of coastal systems

2.sustain their water supply, both in quantity and quality

3.necessary for the economic and environmental viability of these regions(US National Research Council, 1994)



http://ewaters.biz/Column/Index/180182059472

https://go.microsoft.com/fwlink/?linkid=799165

Managed aquifer recharge (MAR)

- MAR use groundwater aquifers as a means for storing excess water for future use while avoiding the concerns with surface storage (Sheng and Zhao, 2015)

- There are two common types of MAR:

1. surface infiltration, such as infiltration basins(Bouwer et al., 2009)
2. subsurface well injection, such as aquifer storage and recovery (ASR) (Pyne, 2005).

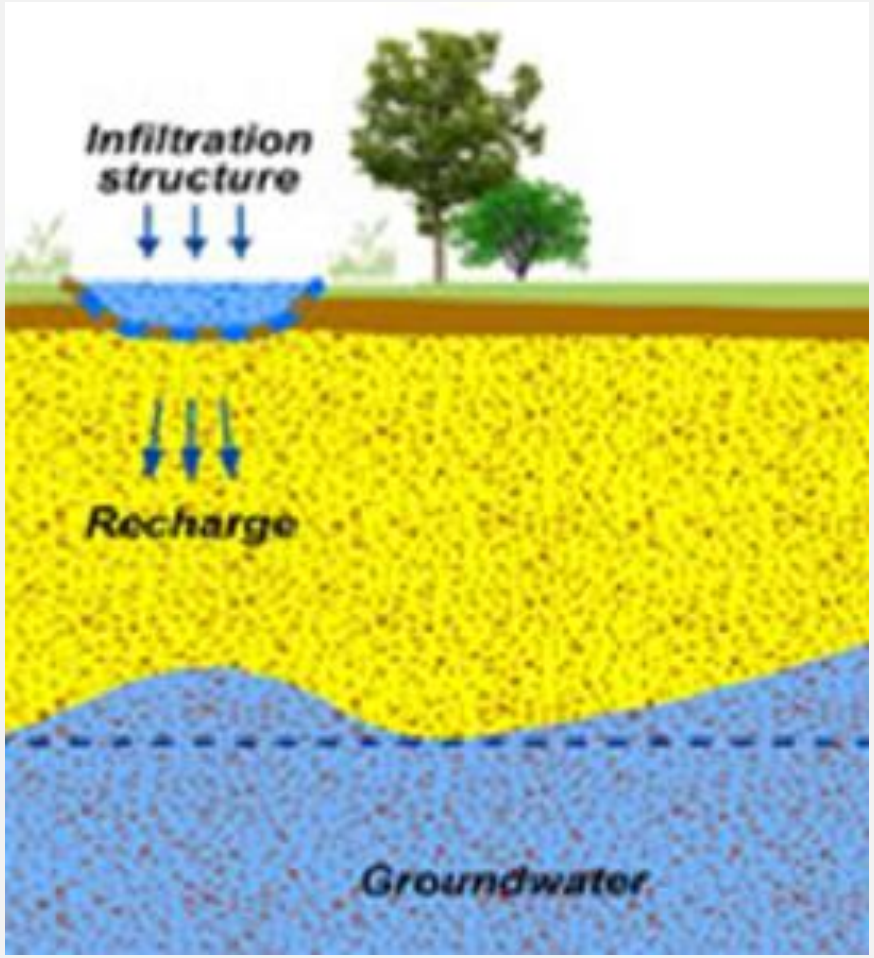
Infiltration basins

•**Infiltration basins is** used to increase natural recharge for the aquifer：

1.highly permeable or unconfined aquifers

2.require ample land space

3.maintenance(Dillon et al., 2009)

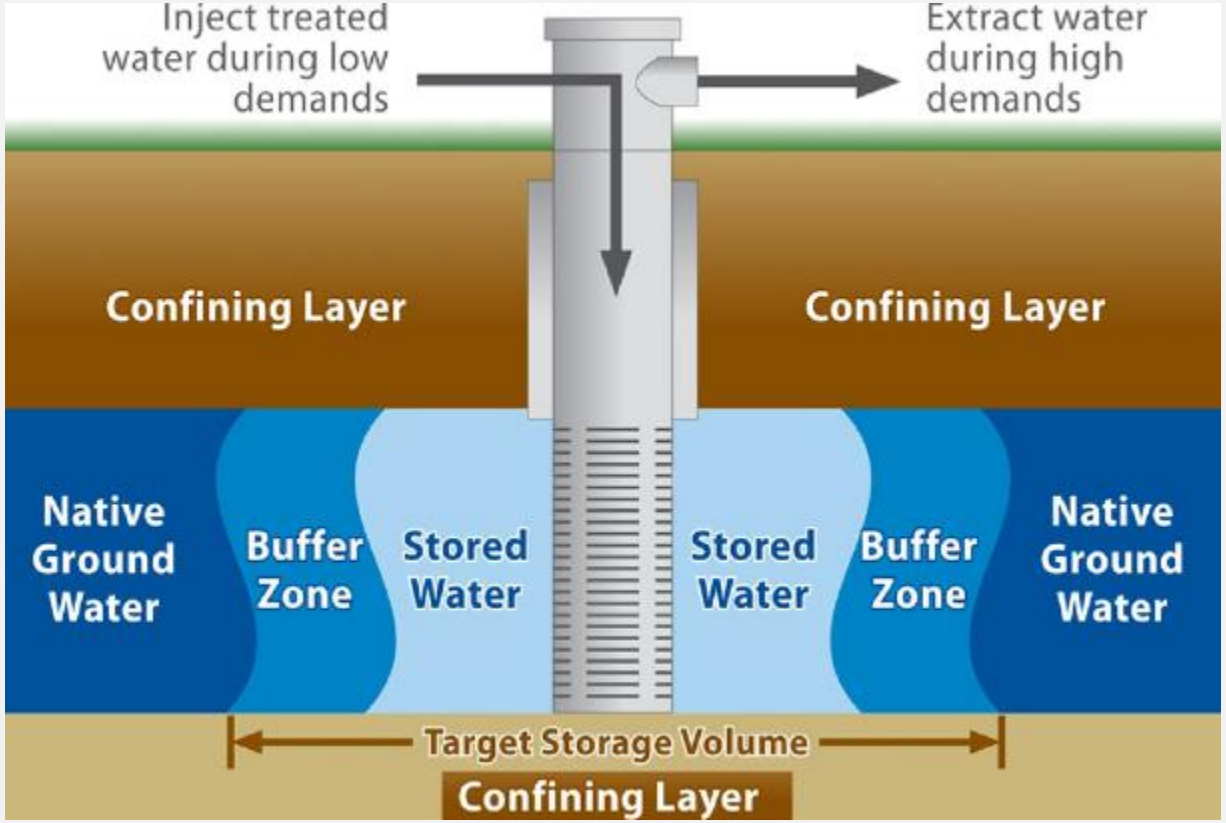


Source : NWRM

Aquifer storage and recovery(ASR)

- **Aquifer storage and recovery(ASR)** is based on collecting excess water from surface sources and injecting it into a subsurface aquifer to be stored for anticipated use (CDM Federal Programs Corporation, 2017).

1. applied most anywhere
2. suitable for all types of aquifer
3. requires little land space
4. mitigate stress due to seasonal water deficits or droughts
5. protect the aquifer from saltwater intrusion and subsidence(Kelly et al., 2013; Webb, 2015).



Source : TRWD

Literature review

Australia

Shahbaz Khan(2008)

- MODFLOW
- Aquifer characteristics
- Water availability
- recharge potential

Zhuoshui River (Taiwan)

Huang (2016)

- MODFLOW
- Transmissivity
- Water quality

Louisiana (USA)

Olivia LaHaye et al.(2021)

- MODFLOW
- Aquifer characteristics
- Water availability
- Water quality
- Land cover

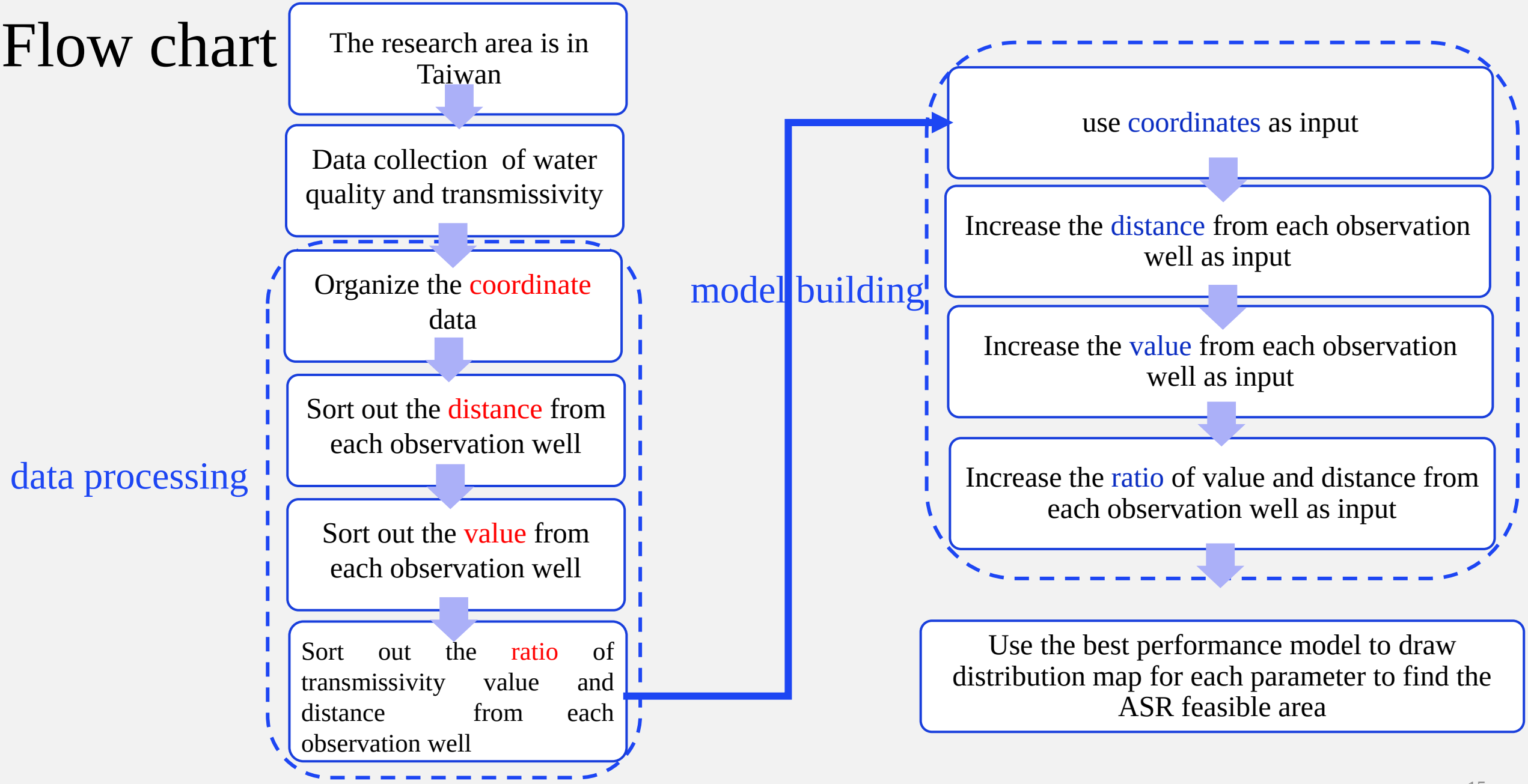
Objective

> The purpose of this study was to assess the feasibility of ASR in Taiwan.

02

Methods and material

Flow chart


The research area is in Taiwan
Data collection of water quality and transmissivity
data processing
Organize the coordinate data
Sort out the distance from each observation well
Sort out the value from each observation well
Sort out the ratio of transmissivity value and distance from each observation well
model building
use coordinates as input
Increase the distance from each observation well as input
Increase the value from each observation well as input
Increase the ratio of value and distance from each observation well as input
Use the best performance model to draw distribution map for each parameter to find the ASR feasible area

Study area

- area :

  36,193 km^2

- rainfall :

  2,197 mm/ year

- Well number:

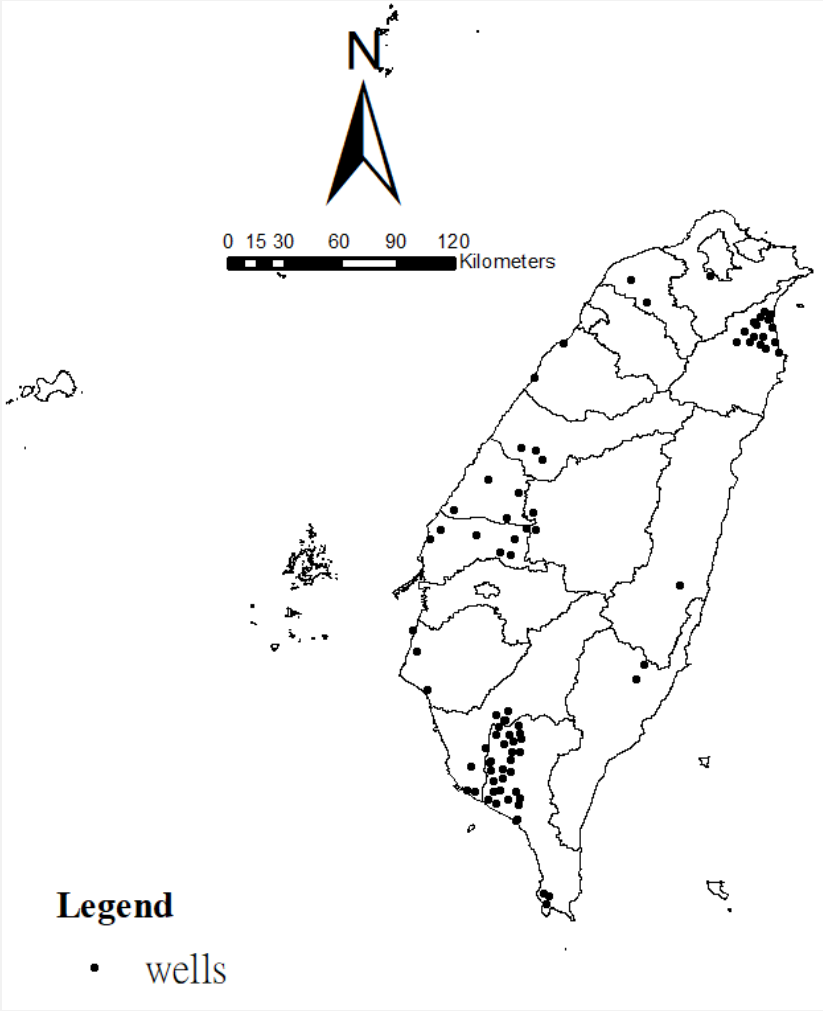
  water quality: 561

  transmissivity:82

https://ithelp.ithome.com.tw/articles/10307239

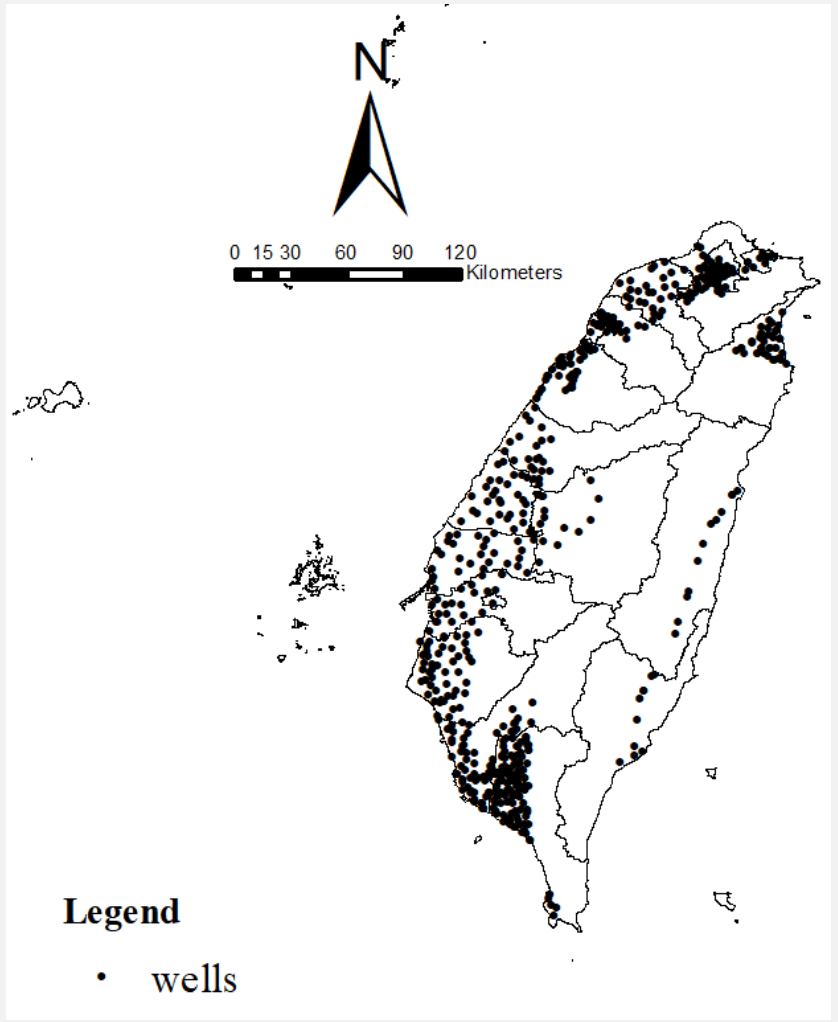
transmissivity

- The data of transmissivity comes from the 2018 shallow observation wells of the water resources agency with a total of 82 wells.
- Transmissivity too low limits the aquifer's ability to rapidly inject large volumes of water and too high causes the injected water to disperse and not concentrate in the aquifer,

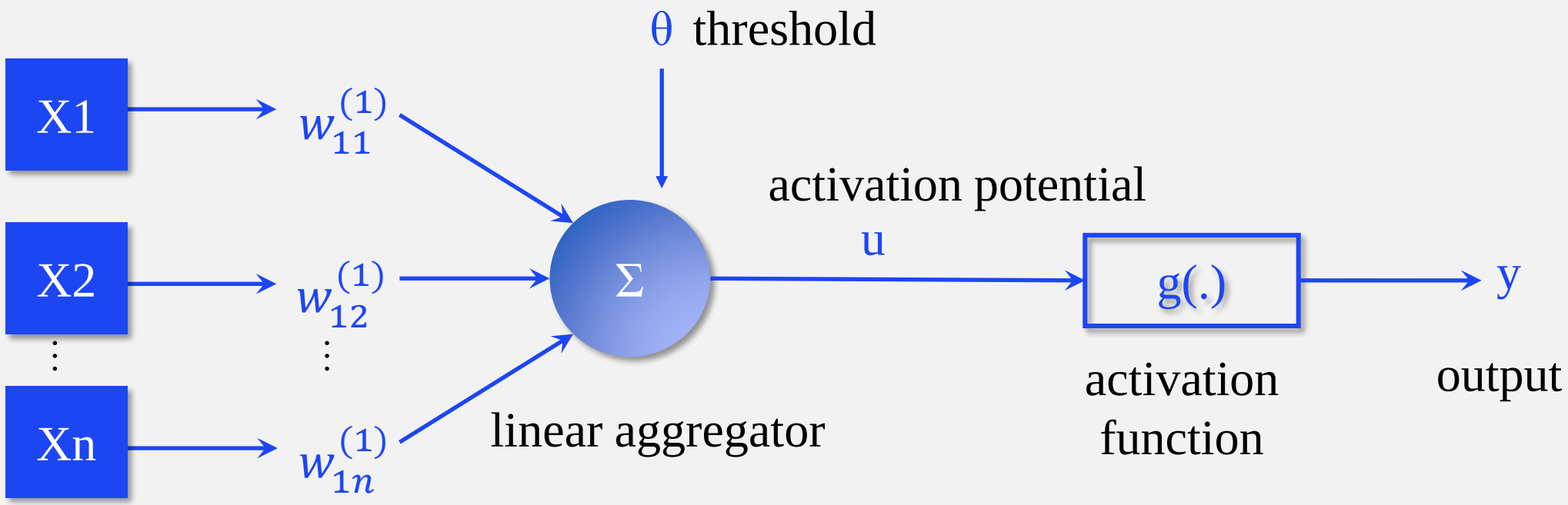


Groundwater quality

- The water quality data comes from the 2018 shallow observation wells of the Water Resources Administration and the 2018 observation wells of the Environmental Protection Agency of the Executive Yuan. The distribution is shown in the figure, with a total of 561 wells.
- Contamination including arsenic, cadmium, chromium, iron, manganese, zinc, copper, chloride salts, nitrate nitrogen, ammonia nitrogen, sulfate.

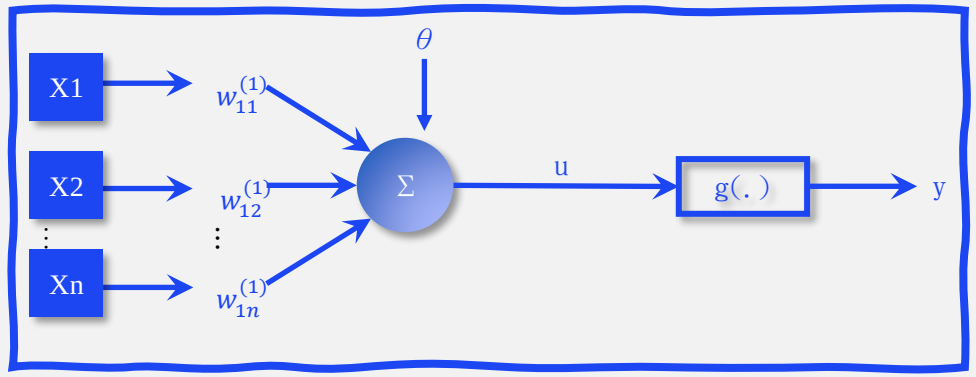


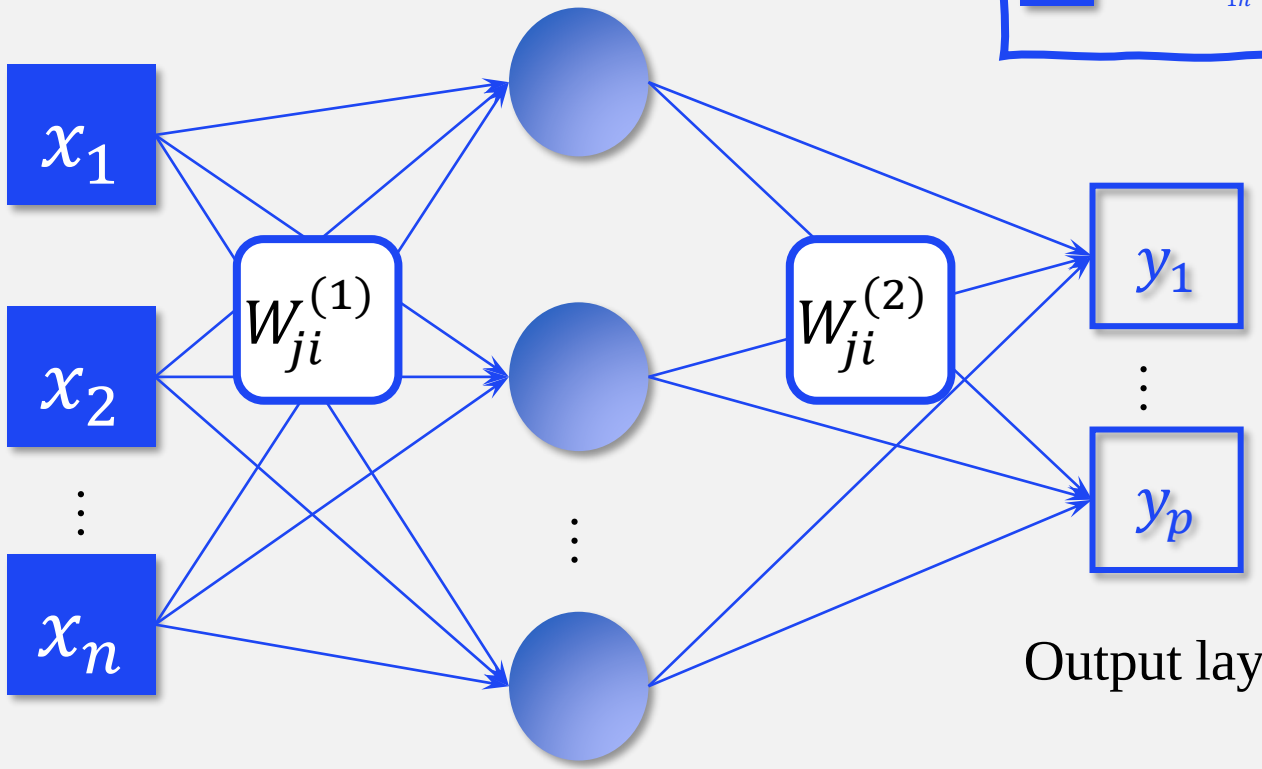
artificial neuron



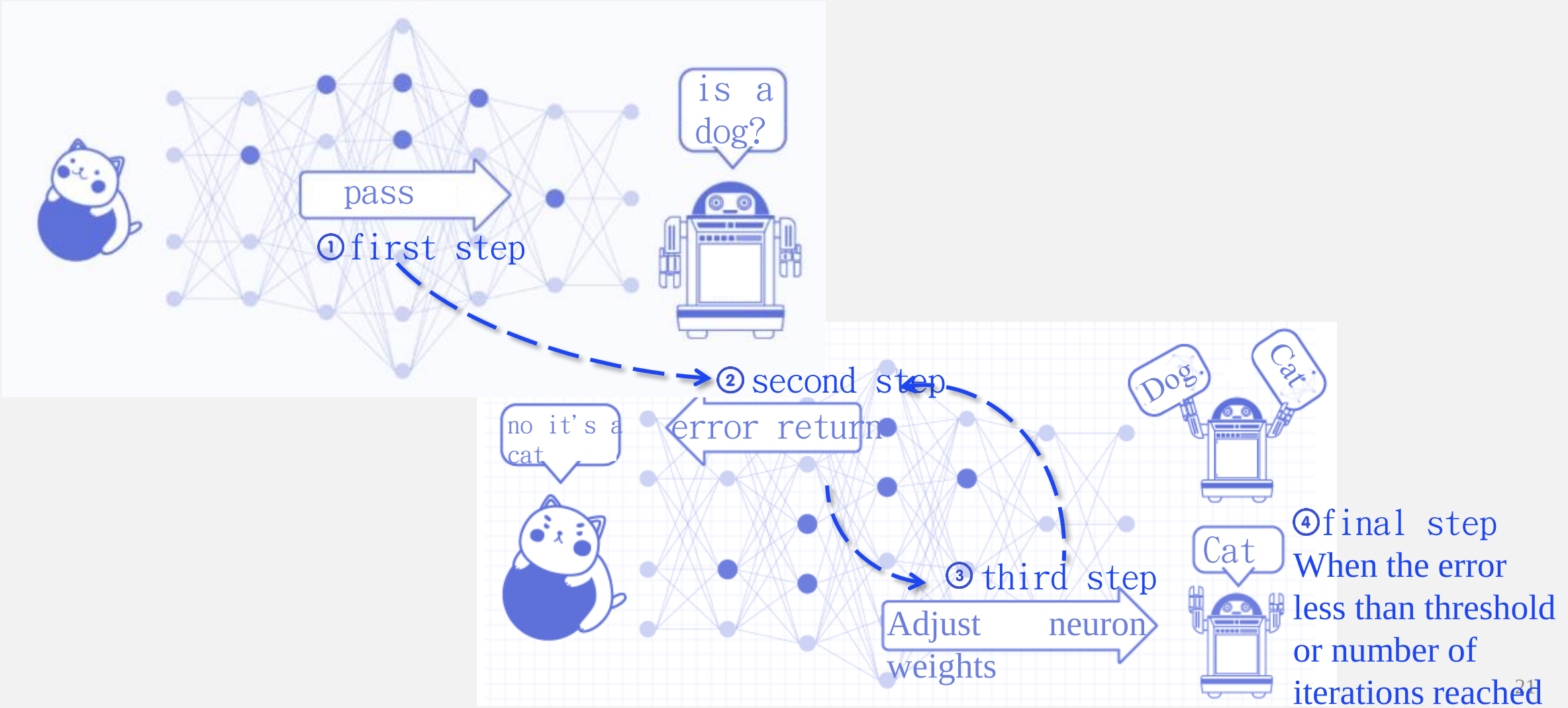
$$u = \sum_{i=1}^{n} w_i x_i - \theta$$
$$y = g(u)$$

Artificial neural networks





feedforward back-propagation neural network

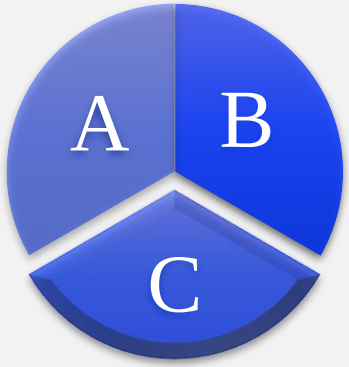


03

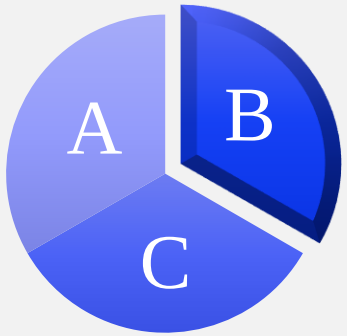
Results and discussion

Cross-validation

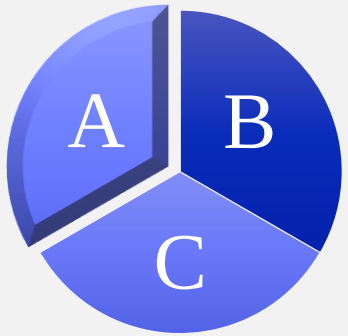
- The cross-validation method can be applied to the case where the number of data items is small. All the data are cut into k small sample subsets on average, and one group is taken as the verification data, and the remaining K-1 samples are used as the training data.
- This method can also ensure that all data have been tested, and can also know the combination with the best accuracy rate among the K combinations, as the best sample combination for building this model.



train : A+B
validation : C



train : A+C
validation : B



train : B+C
validation : A

1. use coordinates as input

Train : A+B
Val : C

Nodes	Train R^2	Val R^2
[2,2,1]	**0.02**	**0.03**
[2,4,1]	**0.01**	**0.02**
[2,6,1]	**0.08**	**0.09**
[2,8,1]	**0.13**	**0.09**
[2,10,1]	**0.26**	**0.11**
[2,12,1]	**0.29**	**0.13**
[2,14,1]	**0.37**	**0.14**
[2,16,1]	**0.37**	**0.07**

Train : A+C
Val : B

Nodes	Train R^2	Val R^2
[2,2,1]	**0.00**	**0.01**
[2,4,1]	**0.03**	**0.12**
[2,6,1]	**0.04**	**0.05**
[2,8,1]	**0.26**	**0.26**
[2,10,1]	**0.25**	**0.11**
[2,12,1]	**0.35**	**0.09**
[2,14,1]	**0.30**	**0.14**
[2,16,1]	**0.33**	**0.16**

Train : B+C
Val : A

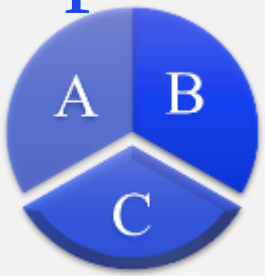
Nodes	Train R^2	Val R^2
[2,2,1]	**0.01**	**0.03**
[2,4,1]	**0.08**	**0.06**
[2,6,1]	**0.12**	**0.06**
[2,8,1]	**0.16**	**0.15**
[2,10,1]	**0.31**	**0.13**
[2,12,1]	**0.34**	**0.13**
[2,14,1]	**0.38**	**0.07**
[2,16,1]	**0.40**	**0.12**

average

Train R^2	Val R^2
0.01	**0.02**
0.04	**0.07**
0.08	**0.07**
0.18	**0.17**
0.27	**0.12**
0.33	**0.12**
0.35	**0.12**
0.37	**0.12**

【Note】[The number of variables in the input layer, the number of neurons in the first hidden layer, the number of neurons in the second hidden layer, the number of variables in the output layer]

2. Increase the distance from each observation well as input



Train : A+B
Val : C

Nodes	Train R^2	Val R^2
[83,2,1]	**0.29**	**0.19**
[83,4,1]	**0.34**	**0.27**
[83,6,1]	**0.39**	**0.23**
[83,8,1]	**0.34**	**0.25**
[83,10,1]	**0.40**	**0.29**
[83,12,1]	**0.46**	**0.22**

Train : A+C
Val : B

Nodes	Train R^2	Val R^2
[83,2,1]	**0.25**	**0.16**
[83,4,1]	**0.25**	**0.25**
[83,6,1]	**0.26**	**0.37**
[83,8,1]	**0.38**	**0.27**
[83,10,1]	**0.42**	**0.40**
[83,12,1]	**0.42**	**0.23**

Train : B+C
Val : A

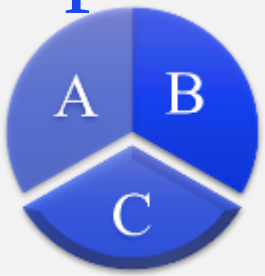
Nodes	Train R^2	Val R^2
[83,2,1]	**0.18**	**0.01**
[83,4,1]	**0.24**	**0.08**
[83,6,1]	**0.33**	**0.05**
[83,8,1]	**0.38**	**0.13**
[83,10,1]	**0.55**	**0.20**
[83,12,1]	**0.56**	**0.01**

average

Train R^2	Val R^2
0.24	**0.12**
0.28	**0.20**
0.33	**0.22**
0.37	**0.22**
0.46	**0.30**
0.48	**0.15**

【Note】[The number of variables in the input layer, the number of neurons in the first hidden layer, the number of neurons in the second hidden layer, the number of variables in the output layer]

3.Increase the value from each observation well as input



Train : A+B
Val : C

Nodes	Train R^2	Val R^2
[164,2,1]	**0.20**	**0.20**
[164,4,1]	**0.21**	**0.02**
[164,6,1]	**0.28**	**0.16**
[164,8,1]	**0.27**	**0.15**
[164,10,1]	**0.31**	**0.25**
[164,12,1]	**0.37**	**0.30**
[164,14,1]	**0.47**	**0.14**

Train : A+C
Val : B

Nodes	Train R^2	Val R^2
[164,2,1]	**0.12**	**0.01**
[164,4,1]	**0.12**	**0.16**
[164,6,1]	**0.20**	**0.05**
[164,8,1]	**0.34**	**0.30**
[164,10,1]	**0.40**	**0.29**
[164,12,1]	**0.46**	**0.26**
[164,14,1]	**0.41**	**0.20**

Train : B+C
Val : A

Nodes	Train R^2	Val R^2
[164,2,1]	**0.15**	**0.01**
[164,4,1]	**0.18**	**0.04**
[164,6,1]	**0.36**	**0.11**
[164,8,1]	**0.38**	**0.12**
[164,10,1]	**0.49**	**0.11**
[164,12,1]	**0.42**	**0.12**
[164,14,1]	**0.43**	**0.10**

average

Train R^2	Val R^2
0.16	**0.07**
0.17	**0.07**
0.28	**0.11**
0.33	**0.20**
0.40	**0.22**
0.42	**0.23**
0.44	**0.15**

【Note】[The number of variables in the input layer, the number of neurons in the first hidden layer, the number of neurons in the second hidden layer, the number of variables in the output layer]

4. Increase the ratio of value and distance from each observation well as input

Train : A+B
Val : C

Nodes	Train R^2	Val R^2
[245,2,1]	**0.23**	**0.10**
[245,4,1]	**0.35**	**0.07**
[245,6,1]	**0.33**	**0.05**
[245,8,1]	**0.50**	**0.18**
[245,10,1]	**0.51**	**0.04**
[245,12,1]	**0.60**	**0.04**
[245,14,1]	**0.69**	**0.01**

Train : A+C
Val : B

Nodes	Train R^2	Val R^2
[245,2,1]	**0.19**	**0.06**
[245,4,1]	**0.23**	**0.03**
[245,6,1]	**0.39**	**0.10**
[245,8,1]	**0.51**	**0.04**
[245,10,1]	**0.54**	**0.01**
[245,12,1]	**0.57**	**0.01**
[245,14,1]	**0.55**	**0.01**

Train : B+C
Val : A

Nodes	Train R^2	Val R^2
[245,2,1]	**0.36**	**0.02**
[245,4,1]	**0.30**	**0.06**
[245,6,1]	**0.41**	**0.02**
[245,8,1]	**0.53**	**0.05**
[245,10,1]	**0.53**	**0.07**
[245,12,1]	**0.56**	**0.02**
[245,14,1]	**0.67**	**0.04**

average

Train R^2	Val R^2
0.26	**0.06**
0.29	**0.05**
0.38	**0.06**
0.51	**0.09**
0.53	**0.04**
0.58	**0.02**
0.64	**0.02**

【Note】[The number of variables in the input layer, the number of neurons in the first hidden layer, the number of neurons in the second hidden layer, the number of variables in the output layer]

Network Model for Deep Learning

Train : A+B
Val : C

Nodes	Train R^2	Val R^2
[83,2,2,1]	**0.23**	**0.12**
[83,4,4,1]	**0.28**	**0.15**
[83,6,6,1]	**0.43**	**0.15**
[83,8,8,1]	**0.50**	**0.19**
[83,10,10,1]	**0.54**	**0.22**
[83,12,12,1]	**0.53**	**0.23**
[83,14,14,1]	**0.53**	**0.36**
[83,16,16,1]	**0.74**	**0.19**

Train : A+C
Val : B

Nodes	Train R^2	Val R^2
[83,2,2,1]	**0.21**	**0.04**
[83,4,4,1]	**0.37**	**0.16**
[83,6,6,1]	**0.55**	**0.22**
[83,8,8,1]	**0.49**	**0.22**
[83,10,10,1]	**0.46**	**0.24**
[83,12,12,1]	**0.49**	**0.30**
[83,14,14,1]	**0.67**	**0.41**
[83,16,16,1]	**0.76**	**0.32**

Train : B+C
Val : A

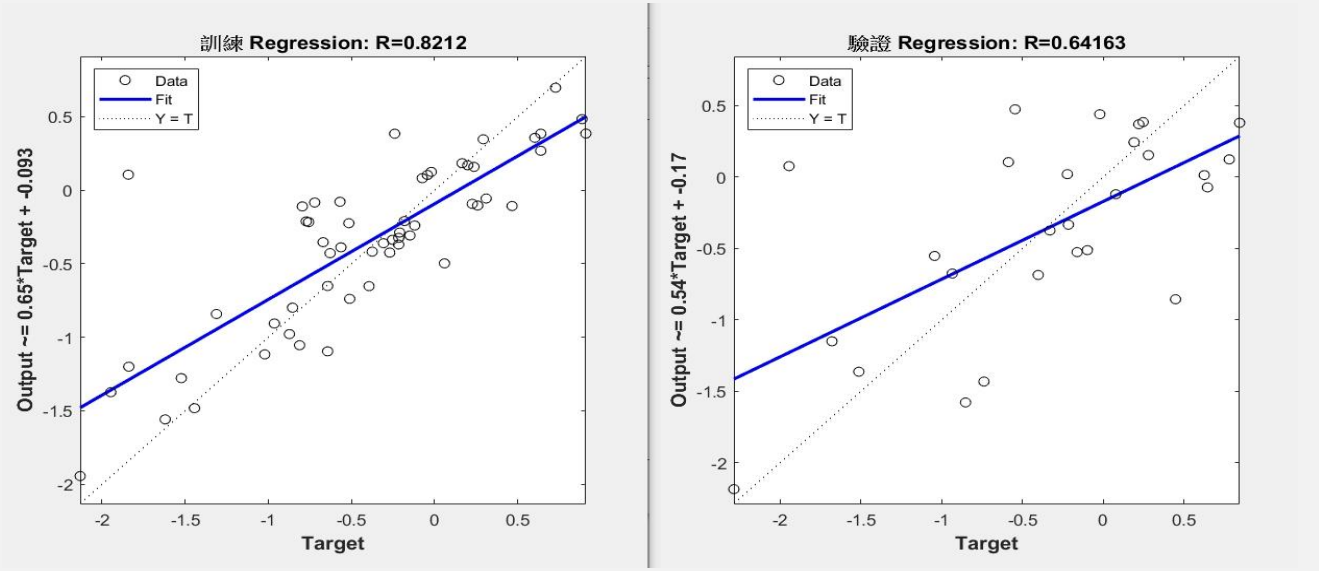
Nodes	Train R^2	Val R^2
[83,2,2,1]	**0.21**	**0.10**
[83,4,4,1]	**0.31**	**0.07**
[83,6,6,1]	**0.47**	**0.10**
[83,8,8,1]	**0.52**	**0.08**
[83,10,10,1]	**0.56**	**0.08**
[83,12,12,1]	**0.59**	**0.25**
[83,14,14,1]	**0.67**	**0.17**
[83,16,16,1]	**0.71**	**0.04**

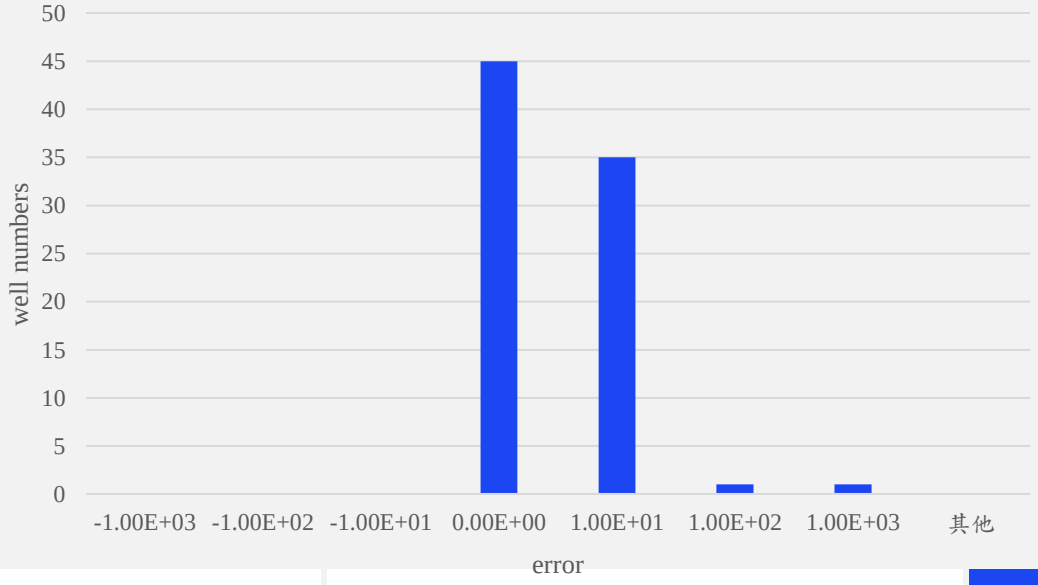
average

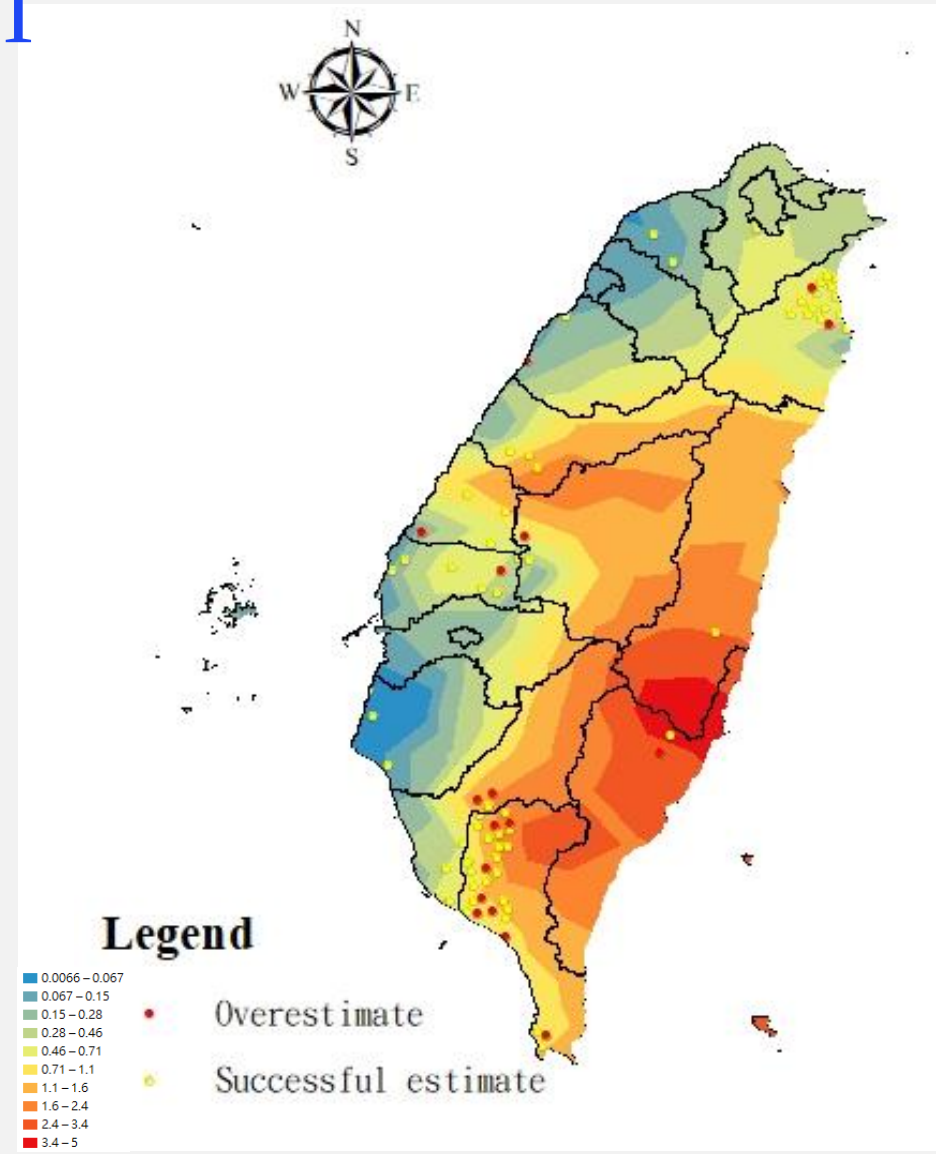
Train R^2	Val R^2
0.22	**0.09**
0.32	**0.13**
0.48	**0.16**
0.50	**0.16**
0.52	**0.18**
0.54	**0.26**
0.62	**0.31**
0.74	**0.18**

【Note】[The number of variables in the input layer, the number of neurons in the first hidden layer, the number of neurons in the second hidden layer, the number of variables in the output layer]

Optimal architecture of ANN model







04

Conclusion

1. Aquifer storage pumping (ASR) is a potentially effective water resource management method in coastal areas, which can solve the problem of excessive use of groundwater resources and reduce ground subsidence and saline intrusion.

2. The model has the best predictive performance when there are two hidden layers and the number of neurons is 14.

3. Transmissivity has higher value at the Southeastern Taiwan.

4. The results can be used by government agencies to conduct water quality monitoring and investigations, which can better prevent groundwater pollution.


Thanks for the attention