EMBASSY OF THE KINGDOM OF DENMARK
Beijing

MAR CHINA
WORKSHOP ON MAR IN CHINA

ONLINE MEETING - CHINA-DENMARK MARCH 22ND 2021 DENMARK (8:00-11:40) - CHINA (15:00-18:40)

Progress of Managed Aquifer Recharge in China

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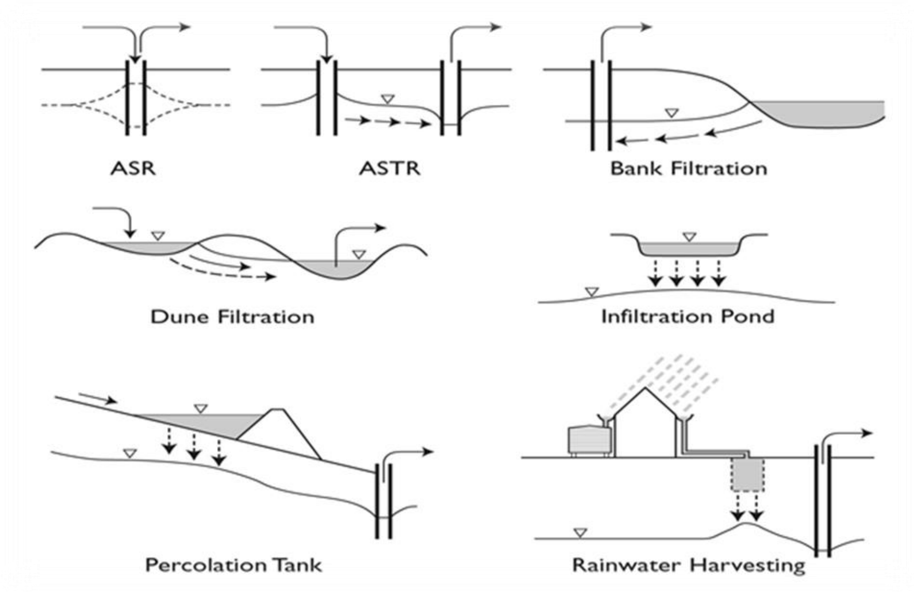
Outlines

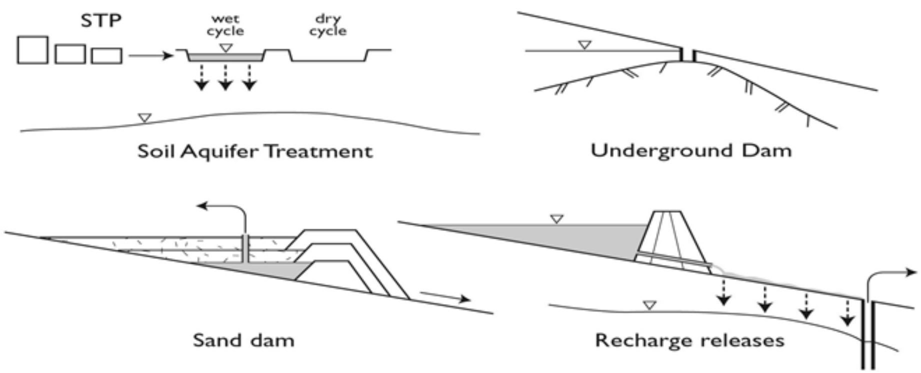
1. Why Did MAR in China
2. Types of MAR
3. Progress of MAR
4. Facing Problems of MAR
5. Potential for MAR of Channel Infiltration
6. Conclusions

1. Why Did MAR

- **Groundwater over-exploitation in North China resulted in geological hazards of land subsidence, karst collapse, springs stopping flowing, salt water intrusion and intensified the groundwater pollution etc..**
- **Managed Aquifer Recharge is the intentional recharge of water to aquifer for subsequent recovery or environmental benefit（*Peter Dillon*）.**
- **Managed Aquifer Recharge is an effective measure of conjunctive uses of surface water and groundwater to solve those challenges.**

2. Types of MAR





Australia NRMMC–EPHC–NHMRC, 2009

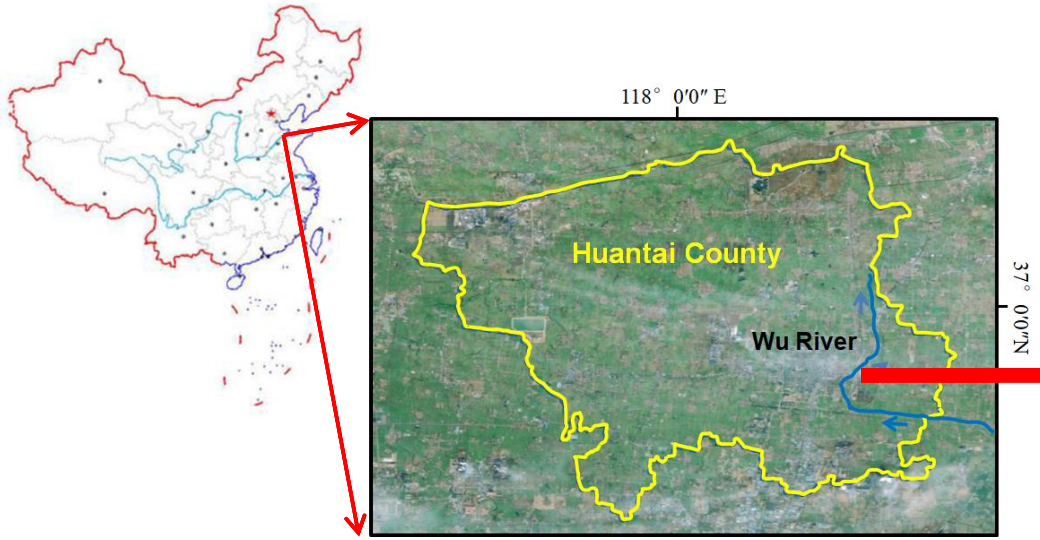
3 Progress of MAR in China

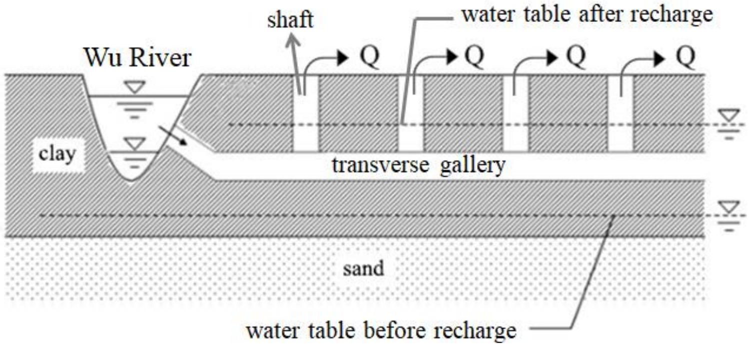
Three stages of MAR development

- **Stage 1** MAR applied to agricultural production and industrial production.
- **Stage 2** MAR applied to ecological protection and increase in urban water supplies.
- **Stage 3** MAR applied to multi-objectives with multi-source water of reclaimed water, inter-basin water transfer, roofwater, etc.

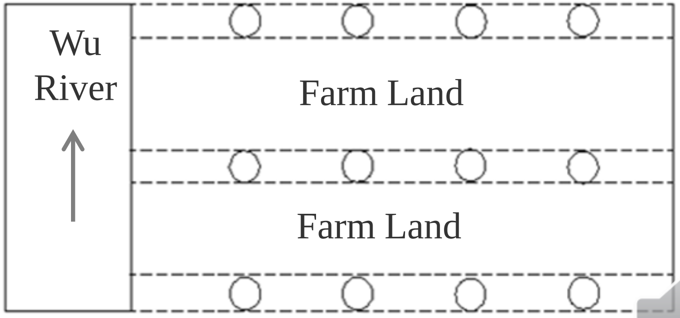
Stage 1

Case 1：MAR Applied to agricultural production in Huantai County in piedmont plain area



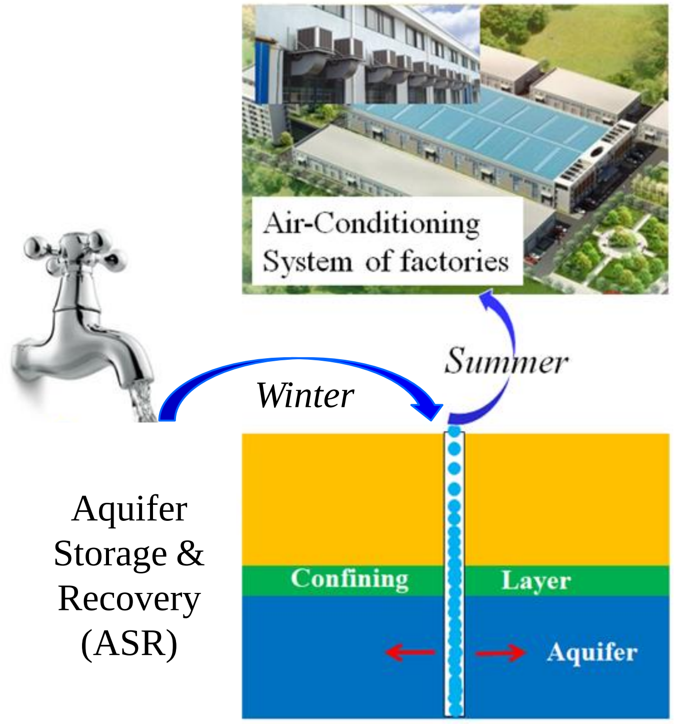


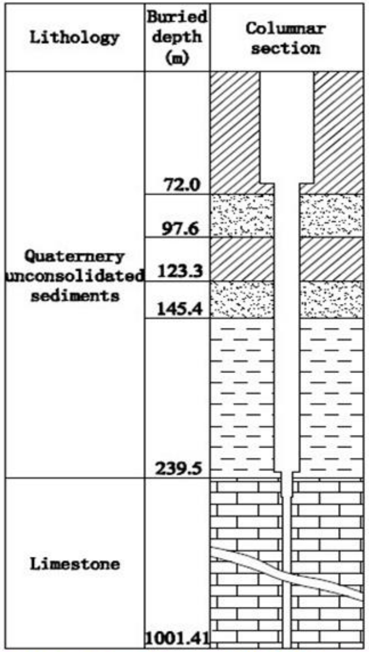
Schematic cross section of a transverse gallery



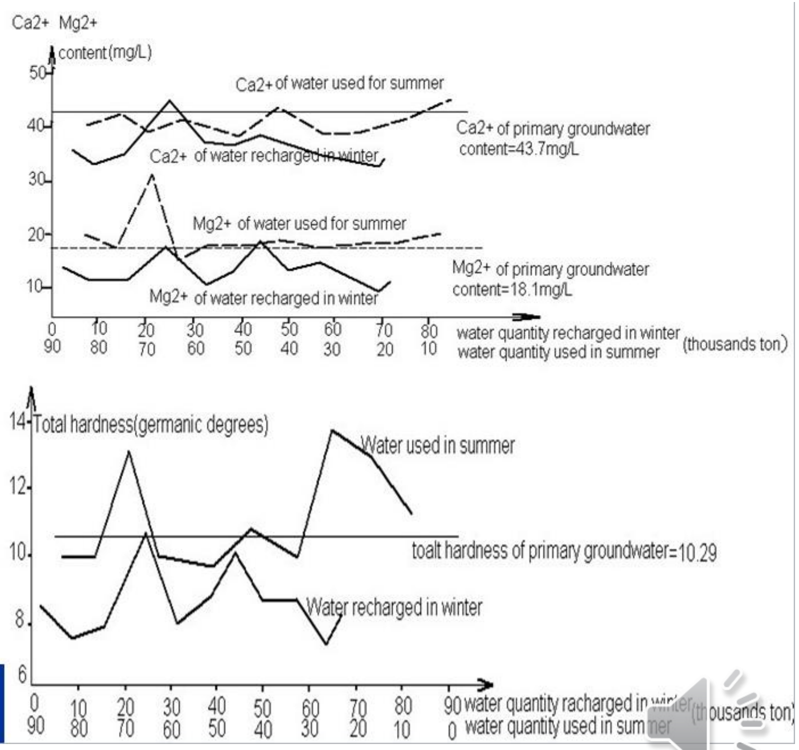
Schematic plan of a transverse gallery

Case 2： ASR of fracture-karst aquifer recharge with tap water for storing and recycling energy

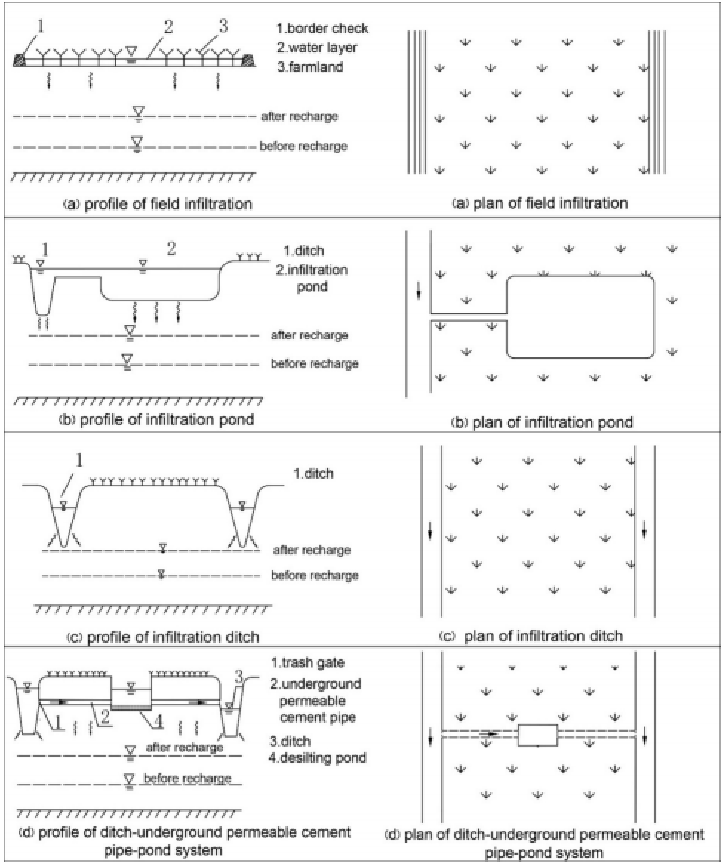


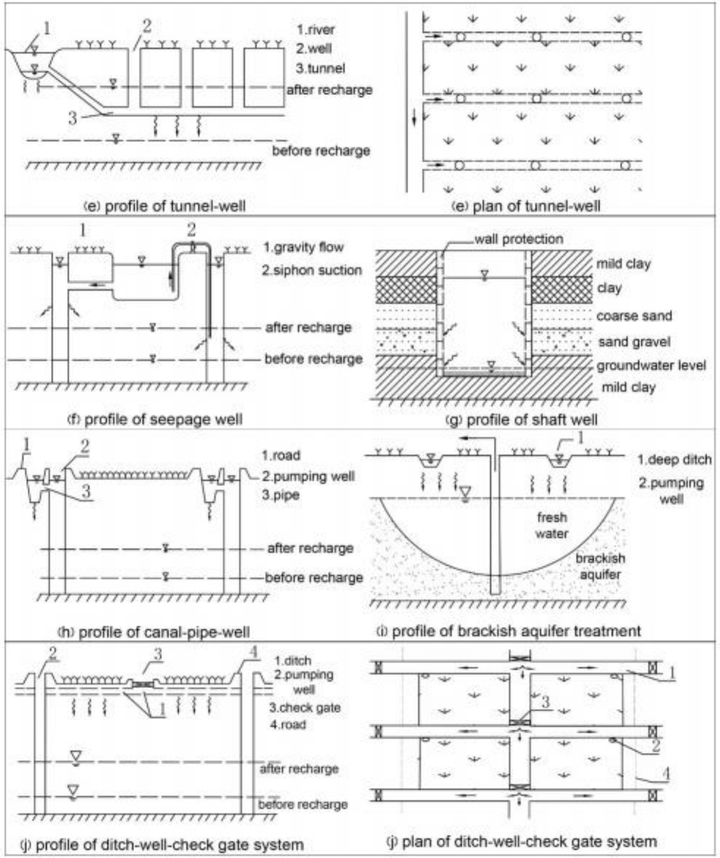


The structure of inject well in Shanghai



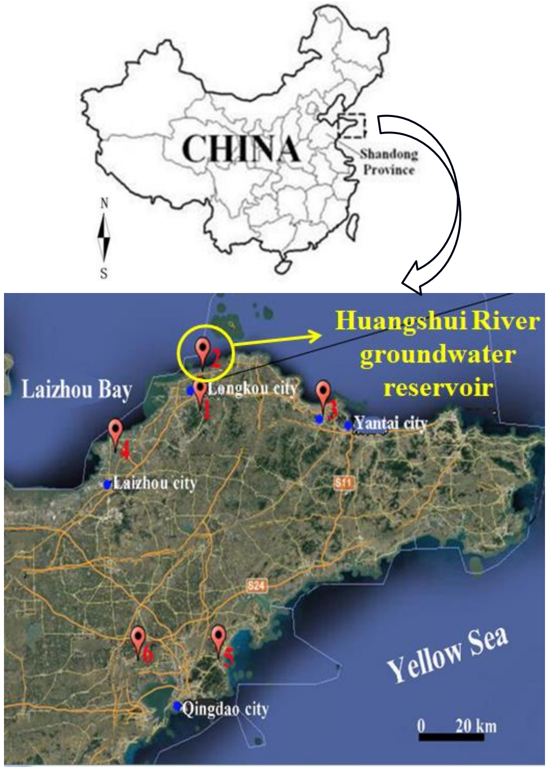
Case 3：Diversity MAR applied to agricultural production in NCP

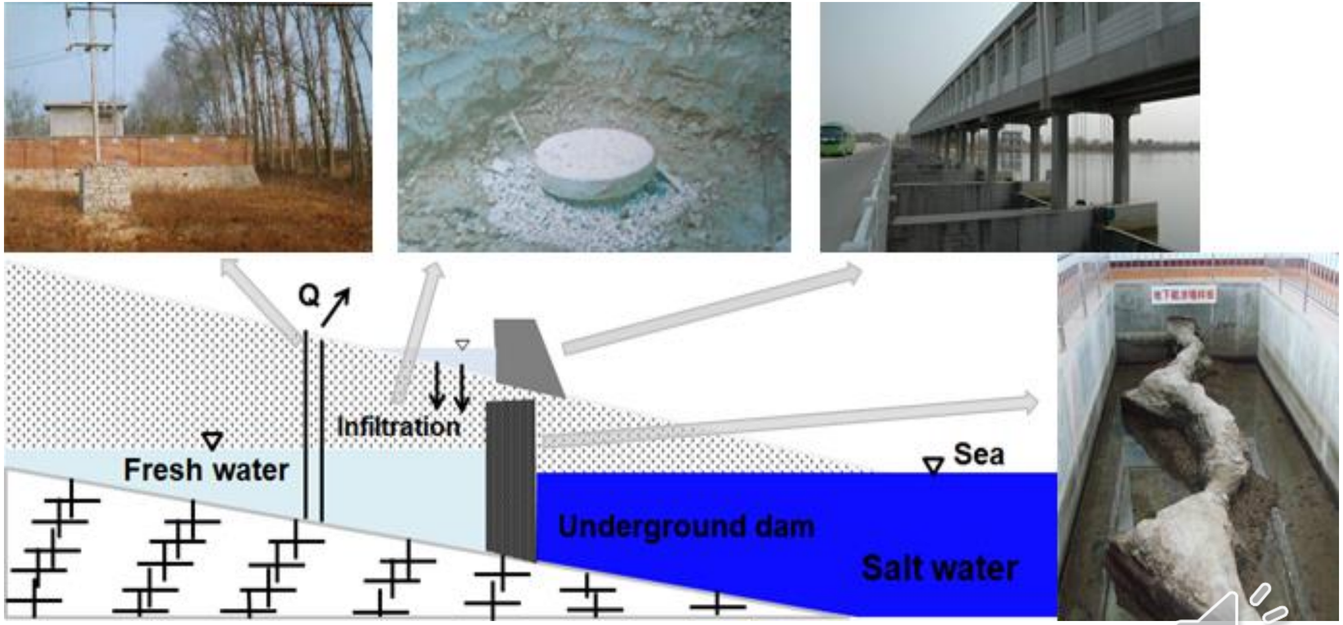




Stage 2

Case 1：Groundwater dam in Shandong Peninsular applied in preventing salt water intrusion and augment water supply





Four underground reservoirs indices

Reservoir	TSC	DMAC	CA (km^2)	NCA (km^2)	RA (km^2)	LUD (m)	ADD (m)	WS (10^4 m^3)	CT
Balisha River	42.9	35	14.7	8.8	14	756	8.5	1699	1988
Huangshui River	5359	3852	1015.7	102.9	51	5842	10	4000	1992
Shiren River	130	120	20.85	20.85	21	620	17	100	1994
Wanghe River	5693	2080	326.8	173.4	68	14500	10	5416	2005

NOTE TSC: Total storage capacity(10^4 m^3); DMAC: Designed Maximum Active Capacity(10^4 m^3); CA: Catchment Area; NCA: Net Catchment area; RA: Reservoir Area; LUD: Length of Underground Dam; ADD: Average Depth of Dam; WS: Water Supply; CT: Completion Time.

Stage 2

Case 2：Karst aquifer recharged by water releasing from reservoir at the strong leakage reach of river for multi-objectives

Table 1 Basic control items and limit value of groundwater recharge in municipal wastewater

Order number	Basic control items	Unit	Surface spreading[a]	Well injection
1	Chroma	Diluted multiples	30	15
2	Turbidity	-	10	5
3	PH	mg/L	6.5～8.5	6.5～8.5
4	Total hardness($CaCO_3$)	mg/L	450	450
5	Dissolved total solids	mg/L	1000	1000
6	Sulfate	mg/L	250	250
7	Chloride	mg/L	250	250
8	Volatile phenol class(Phenol)	mg/L	0.5	0.002
9	Anionic surfactant	mg/L	0.3	0.3
10	COD	mg/L	40	15
11	BOD_5	mg/L	10	4
12	Nitrate(by N)	mg/L	15	15
13	Nitrite(by N)	mg/L	0.02	0.02
14	Ammonia nitrogen(by N)	mg/L	1	0.2
15	Total phosphorus(by P)	mg/L	1	1
16	Animal and plant oil	mg/L	0.5	0.05
17	Petroleum	mg/L	0.5	0.05
18	Cyanide	mg/L	0.05	0.05
19	Sulfide	mg/L	0.2	0.2
20	Fluoride	mg/L	1	1
21	Fecal coliform number	A/L	1000	3

[a] Clay thickness in soil should not be less than l m，If less than lm according to the well injection requirements.

ICS 13.060
P 40

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中 华 人 民 共 和 国 国 家 标 准

GB/T 19772—2005

城市污水再生利用　地下水回灌水质

The reuse of urban recycling water
Water quality standard for groundwater recharge

2005-05-25 发布　　2005-11-01 实施

中华人民共和国国家质量监督检验检疫总局
中 国 国 家 标 准 化 管 理 委 员 会　发 布

Table 2 Basic control items and limit value of groundwater recharge in municipal wastewater

Order number	Selection control items	limiting value	Order number	Selection control items	limiting value
1	Total mercury	0.001	27	Trichloroethylene	0.07
2	Mercury alkyl	Negative	28	Four chloroethylene	0.04
3	Total cadmium	0.01	29	Benzene	0.01
4	Six valent chromium	0.05	30	Toluene	0.7
5	Total arsenic	0.05	31	Xylene[a]	0.5
6	Total lead	0.05	32	Ethylbenzene	0.3
7	Total nickel	0.05	33	Chlorobenzene	0.3
8	Total cymbals	0.0002	34	1,4-Dichlorobenzene	0.3
9	Total silver	0.05	35	1,2-Dichlorobenzene	1
10	Total copper	1	36	Nitrochlorobenzene[b]	0.05
11	Total zinc	1	37	2,4-Dinitrochlorobenzene	0.5
12	Total manganese	0.1	38	2,4-Dichlorophenol	0.093
13	Total selenium	0.01	39	2,4,6-Trichlorophenol	0.2
14	Total iron	0.3	40	Dibutyl phthalate	0.003
15	Total barium	1	41	Dioctyl phthalate	0.008
16	Benzo (a) pyrene(BaP)	0.00001	42	Acrylonitrile	0.1
17	Formaldehyde	0.9	43	Dichlorodiphenyltrichloroethane(DDT)	0.001
18	Aniline	0.1	44	Hexachlorocyclohexane	0.005
19	Nitrobenzene	0.017	45	Hexachlorobenzene	0.05
20	Malathion	0.05	46	Heptachlor	0.0004
21	Dimethoate	0.08	47	Hexachlorocyclohexane gamma-isomer	0.002
22	Parathion	0.003	48	Trichloroacetaldehyde	0.01
23	Methyl parathion	0.002	49	Acrolein	0.1
24	Pentachloropheno	0.009	50	Boron	0.5
25	Trichloromethane	0.06	51	Total alpha radioactivity	0.1
26	Carbon tetrachloride	0.002	52	Total beta radioactivity	1

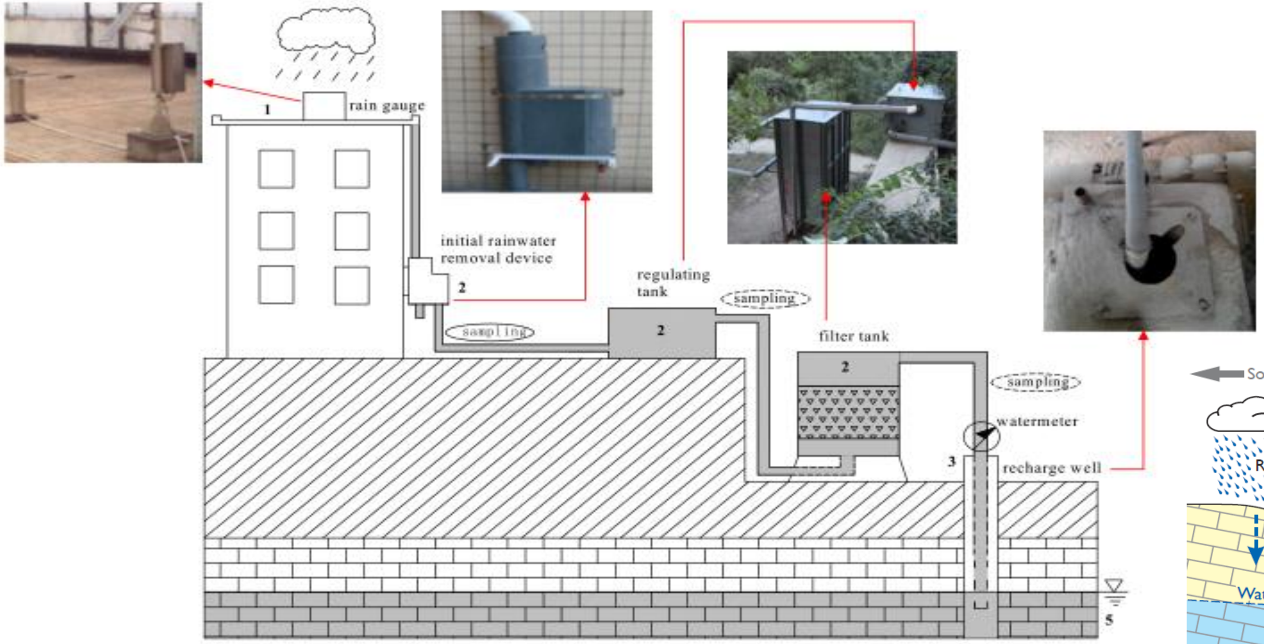
Note: the unit of the 51,52 item are Bq/L, and the units of the other items are mg/L.

[a] Xylene refers toP-xylene, M - xylene and O - xylene.

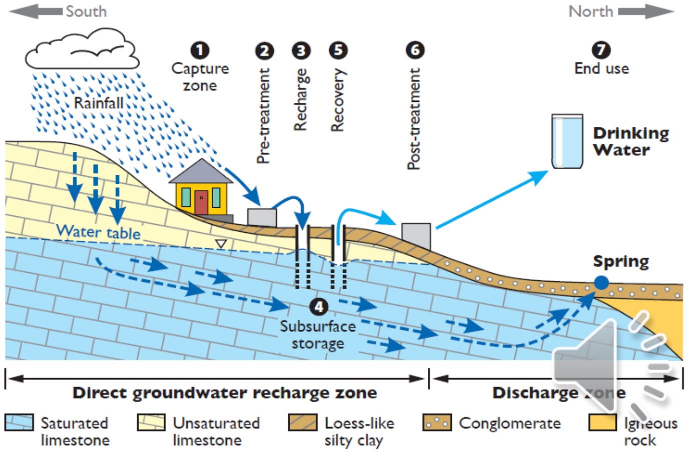
[b] Nitrochlorobenzene refers to P - nitrochlorobenzene, M - nitrochlorobenzene and O - nitrochlorobenzene.

Stage 3

Case 2：MAR with roofwater for drinking water in Jinan



Jinan pilot stormwater recycling system components



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Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-020-11353-3

RESEARCH ARTICLE

Managing aquifer recharge with multi-source water to realize sustainable management of groundwater resources in Jinan, China

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Received: 4 May 2020 / Accepted: 20 October 2020

Abstract
Managed aquifer recharge (MAR) is an important approach to address water security, water quality decline, ground subsidence, and aquifer degradation. In this study, the large-scale recharge experiments were conducted in a natural river with multiple water sources. The MAR with multi-source water was investigated by developing an improved matter-element model under a limited recharged quantity and period in Jinan, China. Results showed that the background levels (BL) of groundwater quality before recharge was relatively good. However, the use of different water sources would cause a significant increase in the content of some groundwater quality indexes, which might further induce deterioration of regional groundwater quality. And the water quality in porous and karst aquifer displayed deteriorating trends during different water source recharge. Additionally, the adverse effects of recharge water sources on regional groundwater quality in turn was South-to-North Water Diversion Project (SN) > Yellow River (YR) > Wohushan Reservoir (WR). Meanwhile, the high-risk indexes in groundwater quality were presented during different water source recharge. Accordingly, relevant suggestions and measures were then put forward to optimize the MAR with multi-source water and explore the high-efficiency and low-risk recharge mode.

Keywords Managed aquifer recharge · Artificial recharge · Multi-source water · Improved matter-element model · Groundwater quality

Introduction

Managed aquifer recharge (MAR) was an increasingly common measure for increasing urban water supply and sustaining water resilience (Dillon 2005; Rodríguez-Escales et al. 2017). Excess water was stored in the aquifers for future consumption by MAR. And the major methods used for MAR include bank filtration, well injection, rainwater harvesting, and infiltration ponds (Ebrahim et al. 2016; Ganot et al. 2017). MAR provided a series of technical solutions to sustainably manage water resources by not only recharging groundwater but also displaying an integrated vision of water resources, following the EU Water Framework Directive approach (Escalante et al. 2019). The groundwater level dropped rapidly over 10 m per year in China. And groundwater overexploitation had occurred in 164 areas of China's 31 provinces, affecting more than 180,000 km^2 (Werner et al. 2013). Groundwater funnel formed gradually and expanded by the groundwater depletion, which caused frequent land subsidence, water quality deterioration, and seawater intrusion. To alleviate the abovementioned issues, a series of water management measures had been carried out in China, such as improving irrigation technology and water efficiency, implementing water price reforms, and water use rights. However, the lack of detailed information on the amount of groundwater extracted, and limited groundwater monitoring wells, as well as complex recharge water sources, make groundwater management still face severe challenges.

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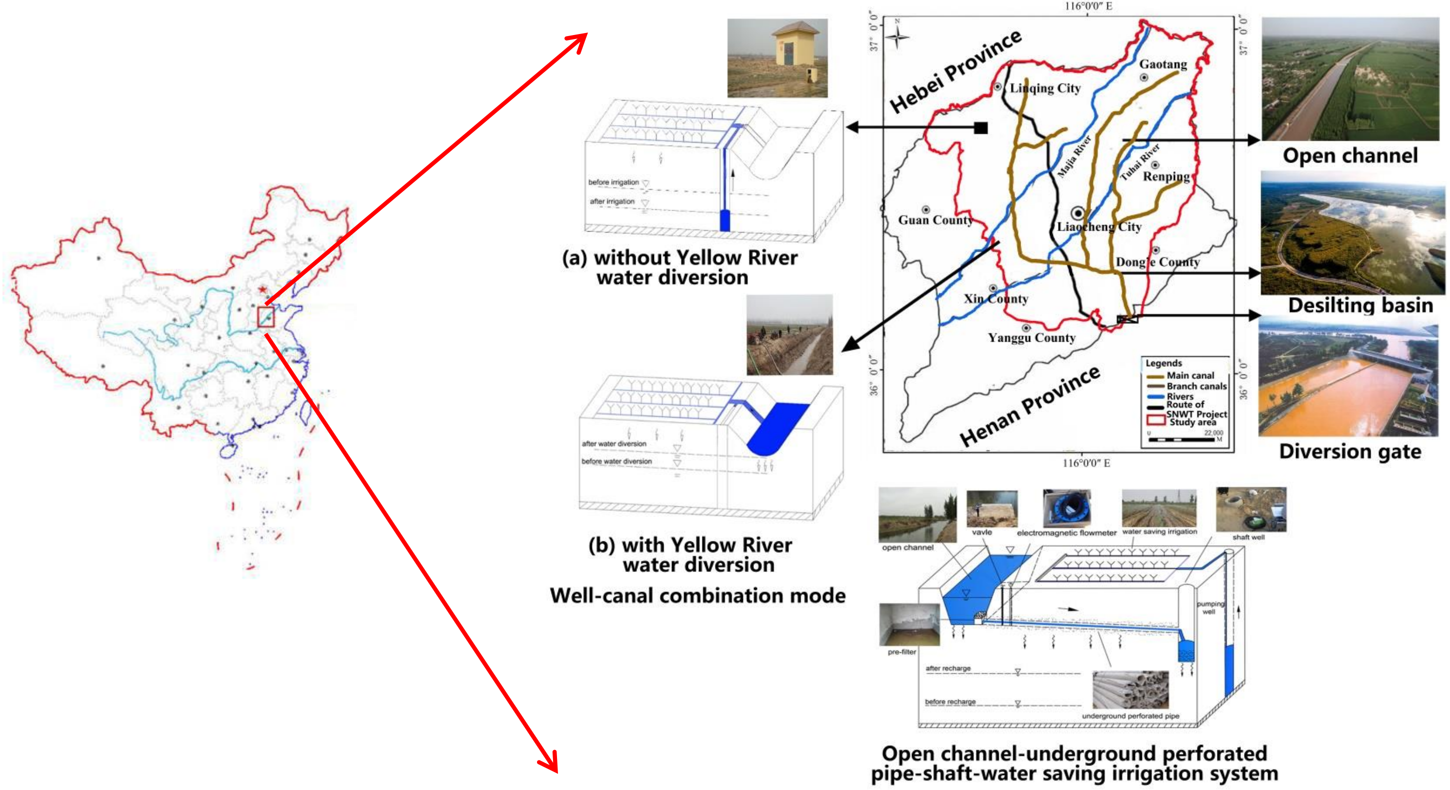
Springer

TITLE	JOURNAL	TIME	DOI
Managing aquifer recharge with multi-source water to realize sustainable management of groundwater resources in Jinan, China	Environmental Science and Pollution Research	2020.12.14	https://doi.org/10.1007/s11356-020-11353-3
Specific Types and Adaptability Evaluation of Managed Aquifer Recharge for Irrigation in the North China Plain	Water	2020.2.18	https://doi.org/10.3390/w12020562
Physical clogging experiment of sand gravel infiltration with Yellow River water in the Yufuhe River channel of Jinan, China	Frontiers of Earth Science	2019.12.23	https://doi.org/10.1007/s11707-019-0772-x
Effective water quantity of multi-source water recharging aquifers in Yufuhe River based on groundwater and surface water semi-coupled modelling	Water Supply	2019.1.1	https://doi.org/10.2166/ws.2019.109
A New Perspective to Explore the Hydraulic Connectivity of Karst Aquifer System in Jinan Spring Catchment, China	Water	2018	https://doi.org/10.3390/w10101368
Modeling colloid-associated atrazine transport in sand column based on managed aquifer recharge	Environmental Earth Sciences	2018	https://doi.org/10.1007/s12665-018-7859-7

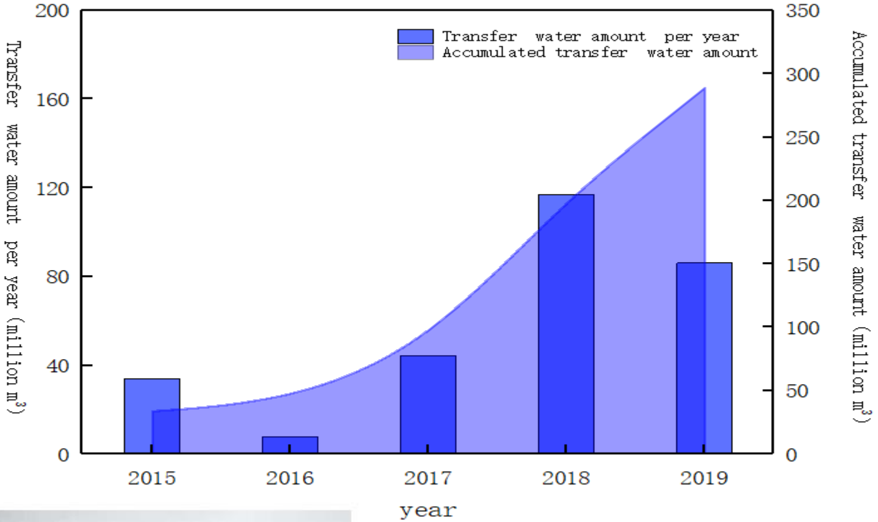
Stage 3

Case 4：MAR of open canal-underground perforated pipe-shaft system for irrigation in Linqing County, Yellow river flood plain area of NCP



Stage 3

Case 5：MAR of natural in-channel infiltration with South to North water for drinking and ecological water in Chaobai River, Beijing

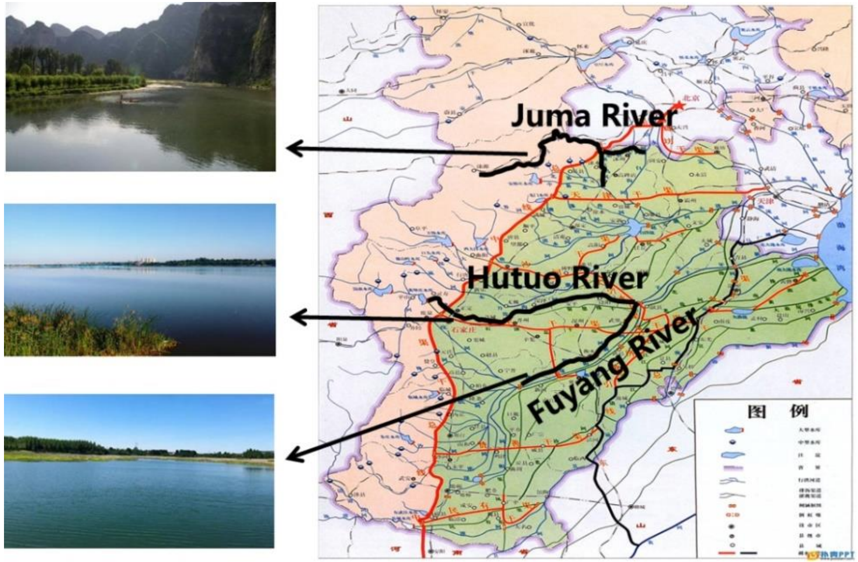


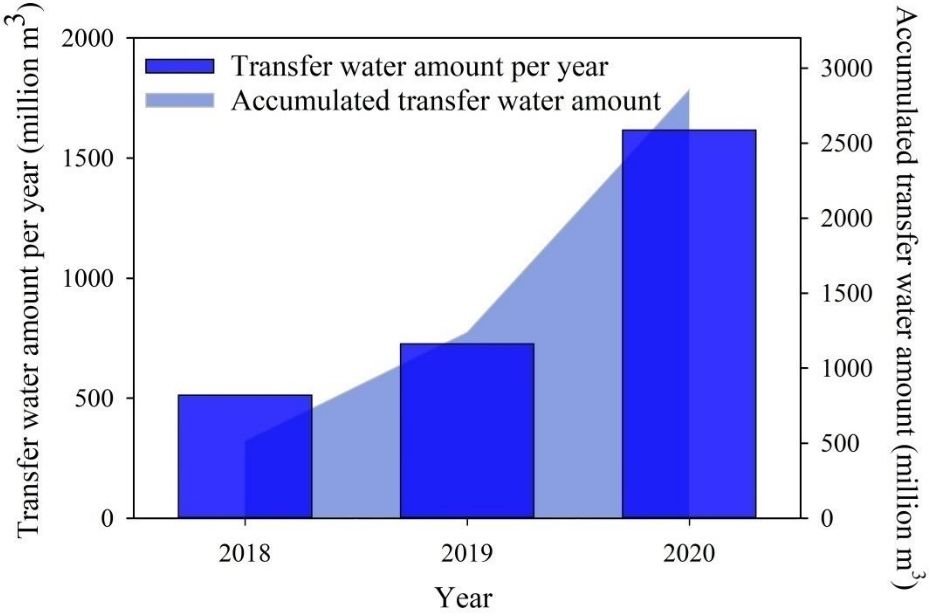
Transfer water amount: From 2015 to 2019: total 290 million m^3.

From Binghua Li, Water Science and Technology Institute of Beijing (BWSTI)

Stage 3

Case 6：MAR of natural in-channel infiltration with South to North water for drinking and ecological water in Hutuo River, Fuyang River and Juma River, Hebei Province





Layout of South-to-North Water Transfer Project in Hebei Province

Transfer water amount: From 2018 to 2020: total 2856 million m^3.

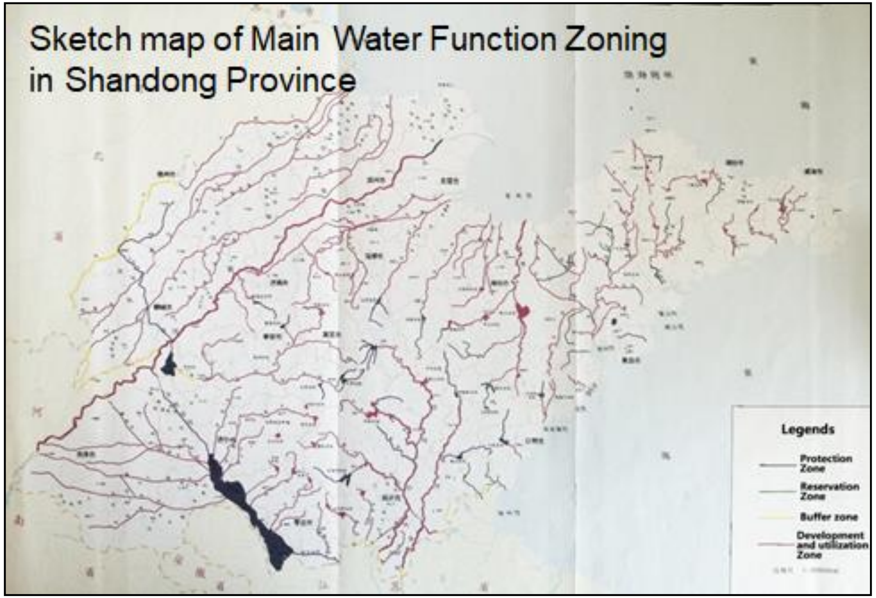
4. Facing Problems of MAR in China

- Lack of investigations on water quality risks of MAR to support development of technical guides and risk management strategies
- Guidelines for MAR with respect to types of recharge methods, especially infiltration by natural channels or canals, are urgently needed.
- A diverse range of feasible, convenient and cost-effective Mar techniques fitting to local hydrogeological conditions still need to be developed and demonstrated through pilot projects.
- More attentions to operate and maintain MAR are also helpful.

5. Potential for MAR of channel infiltration

中华人民共和国国家标准 GB 水功能区划分标准

GB/T 50594 2010 Standard for water function zoning



Water Function Zones	Proportion of River Length
Drinking water	31.9%
Agricultural water	47.5%
Industrial water	14.4%
Fishery water	0.7%
Landscape and entertainment water	1.2%
Transition region	0.7%
Sewage control area	3.7%
Total river lengths	7820.1 Km

The water function zoning in China since 2010 has provided a necessary condition for applying MAR of channel infiltration in quality of source water and end use.

6. Conclusions

- With the completion of the Middle and East Route of the south-to-North Water Transfer Project, new stable water has transferred in the North China Plain except Yellow River water for MAR.
- The quality and quantity of reclaimed water are stable and sufficient due to the development of urban sewage treatment technologies. Groundwater recharge with reclaimed water project can provide reliable irrigation water for agriculture.
- Further research is necessary to realize all the potential of MAR: improving water quality, conjunctive use of surface and groundwater, storing water from long distance transfer, augmenting urban and irrigation supplies

Thank You for Attention !