Managed aquifer recharge implementation criteria to achieve water sustainability

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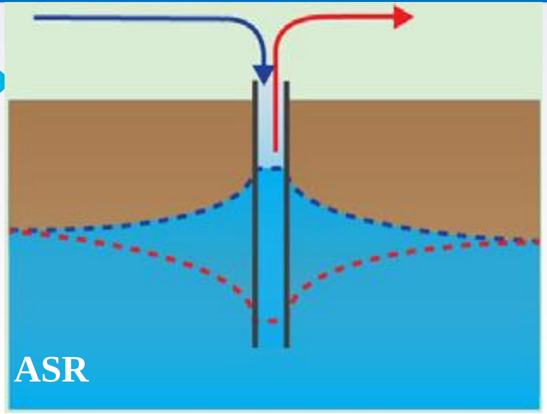
Introduction

- Due to growing water demand for use in urbanized areas, agriculture, the energy industry, and declining surface water under climate change, groundwater depletion is expedited.

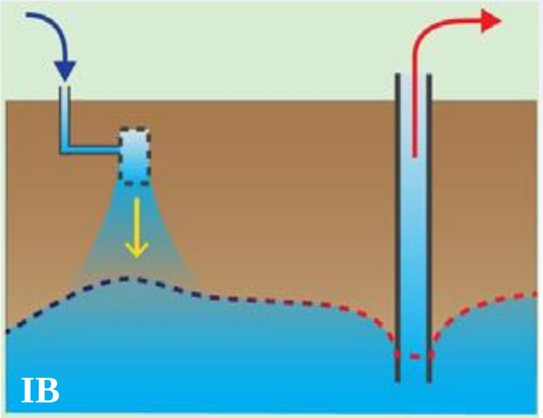
- Managed aquifer recharge (MAR) is one of the several methods that can help achieve long-term water sustainability by increasing the natural recharge of groundwater reservoirs with water from non-traditional.

- This study analyzed 1127 MAR projects with various research topics and highlights several key components to make a successful MAR project.

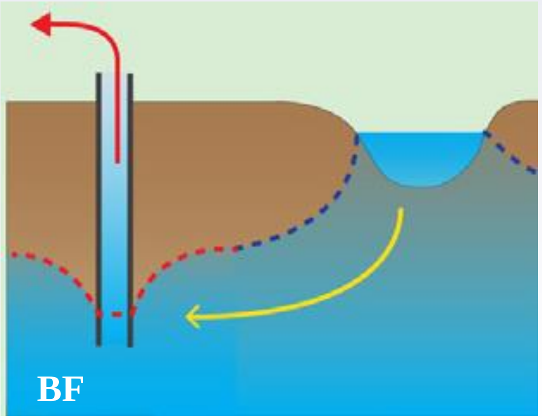
Introduction



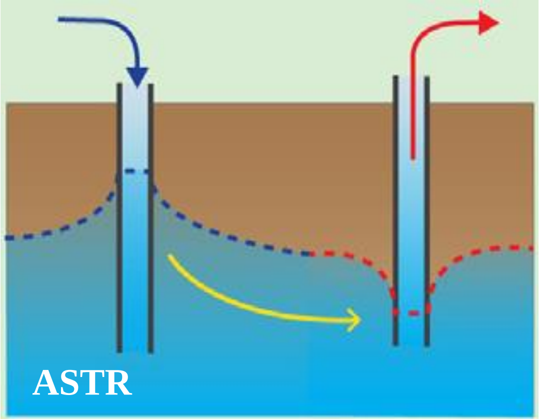
Aquifer storage and recovery



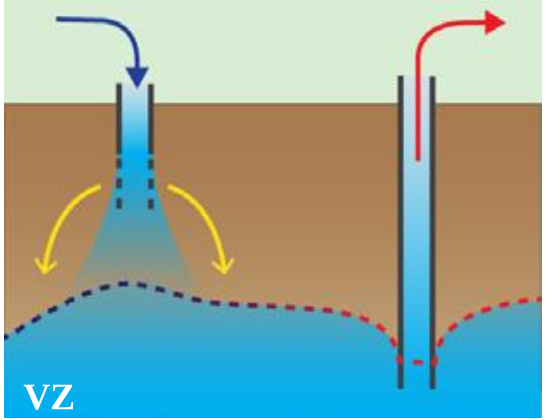
Infiltration basin



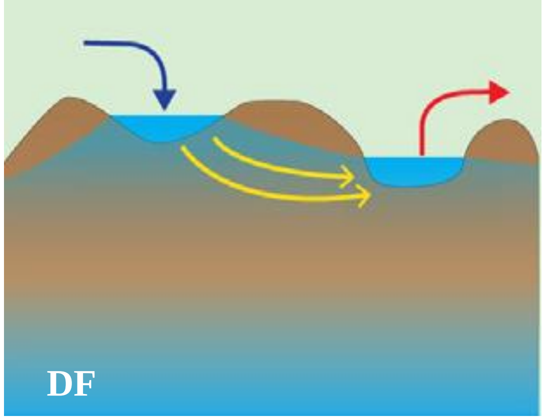
Bank filtration



Aquifer storage transport and recovery

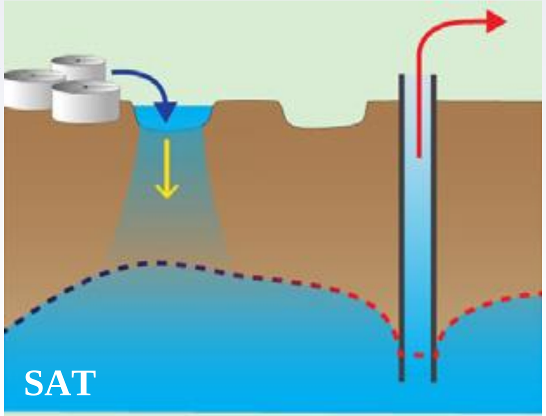


Vadose zone infiltration

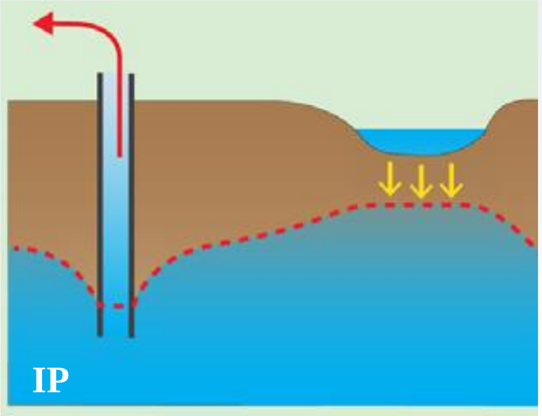


Dune filtration

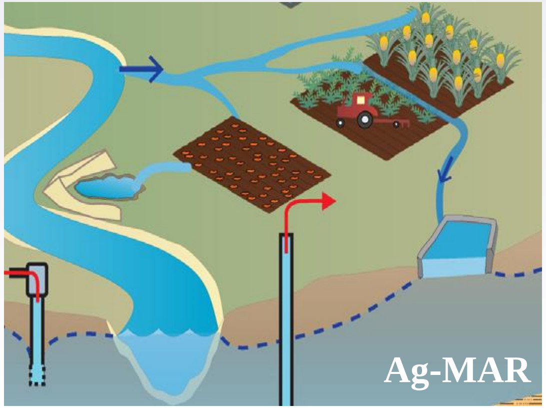
Introduction



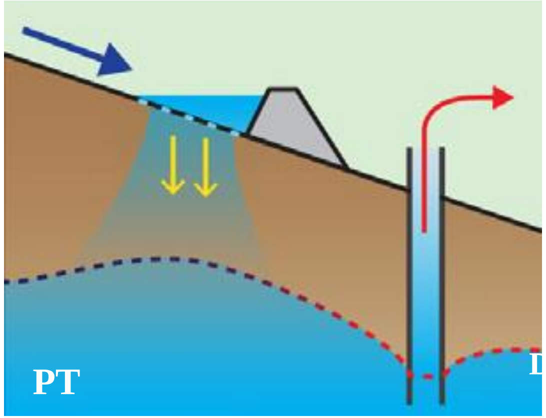
Soil-aquifer treatment



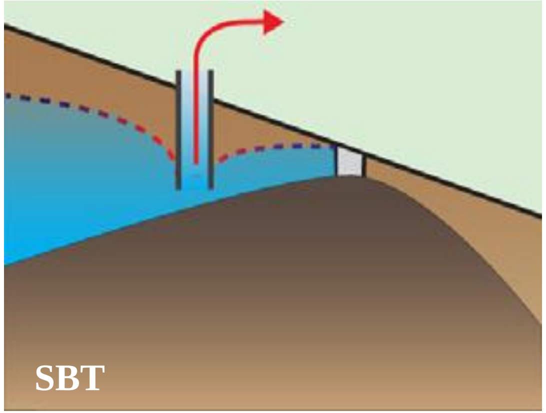
Infiltration ponds



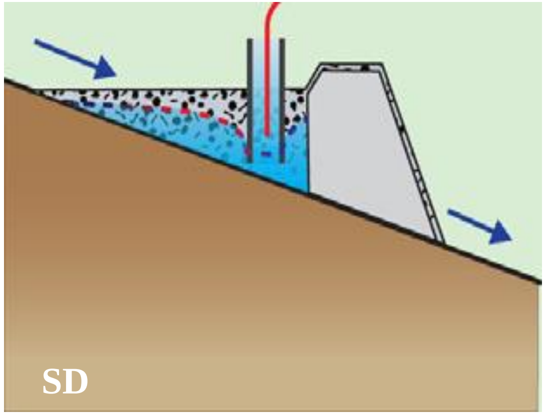
Agriculture MAR



Percolation tanks

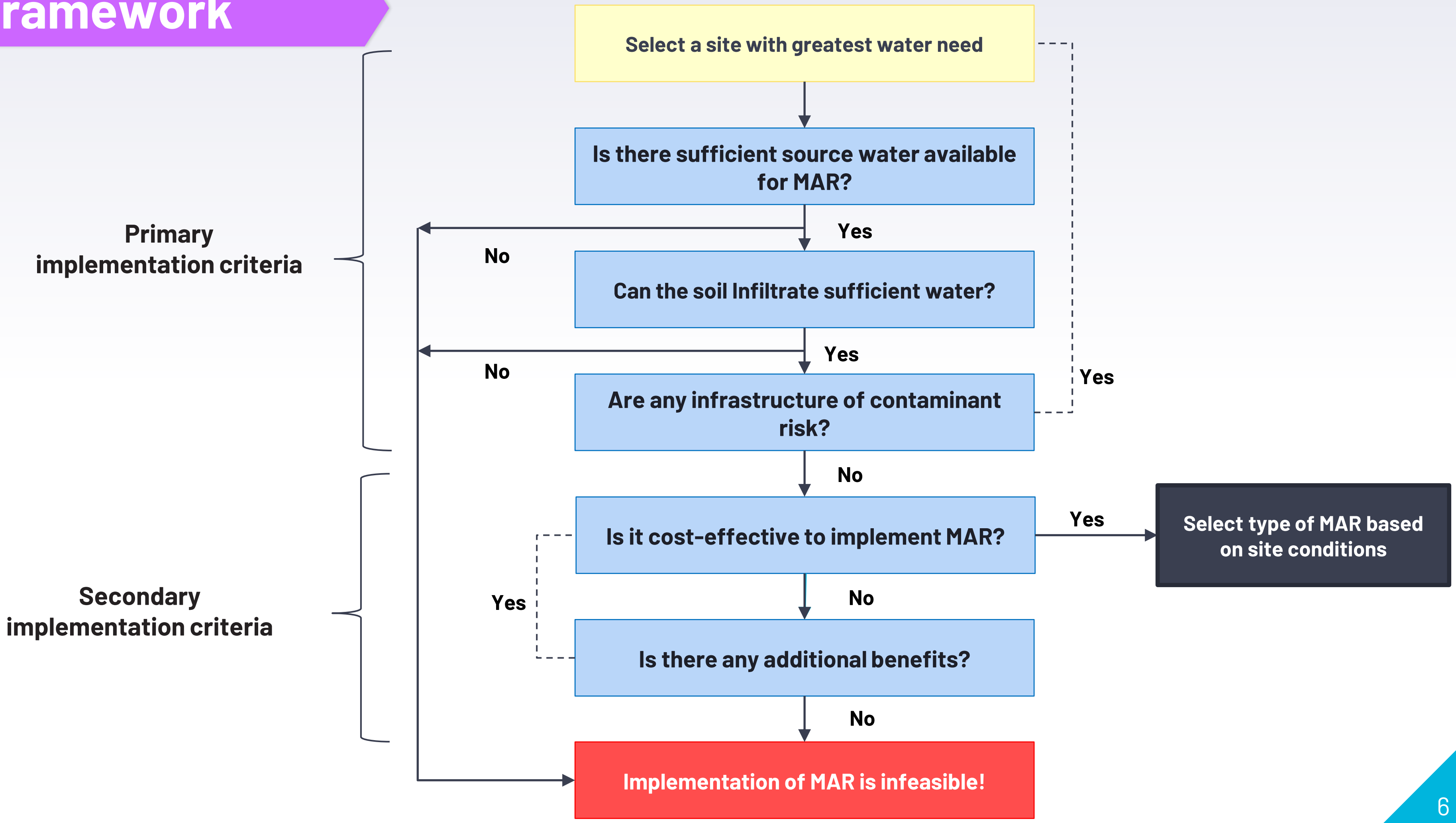


Sub-surface dam



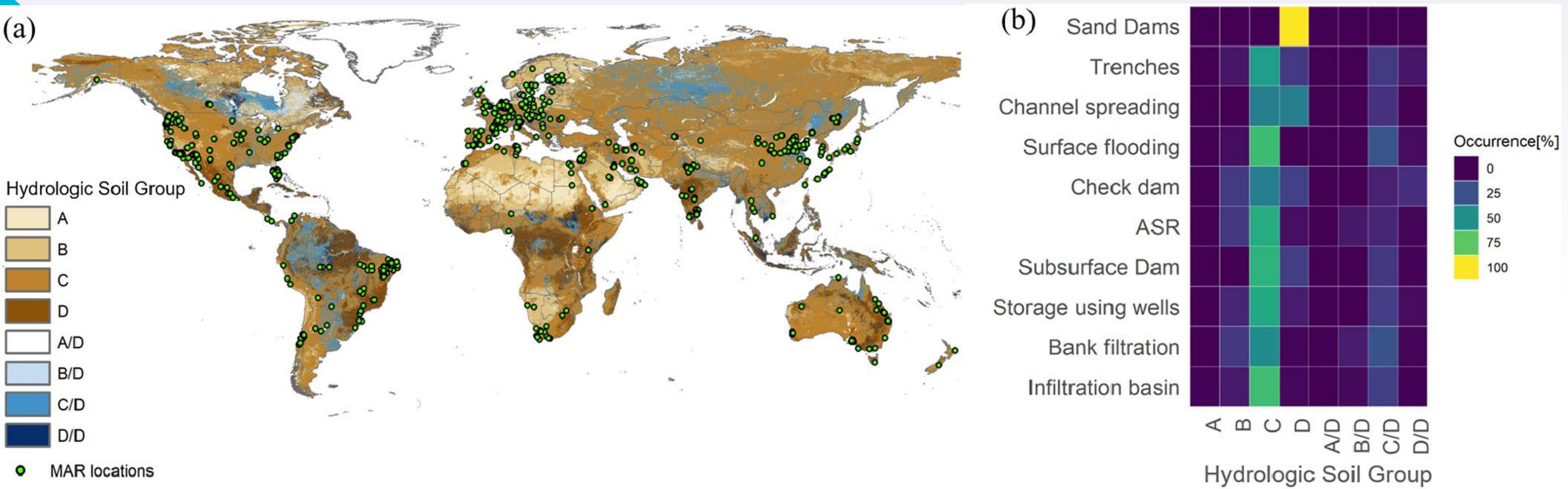
Sand dam

Framework


Primary
implementation criteria
Secondary
implementation criteria
Select a site with greatest water need
Is there sufficient source water available for MAR?
Yes
No
Can the soil Infiltrate sufficient water?
Yes
No
Are any infrastructure of contaminant risk?
Yes
No
Is it cost-effective to implement MAR?
Yes
Select type of MAR based on site conditions
No
Yes
Is there any additional benefits?
No
Implementation of MAR is infeasible!

Primary Criteria

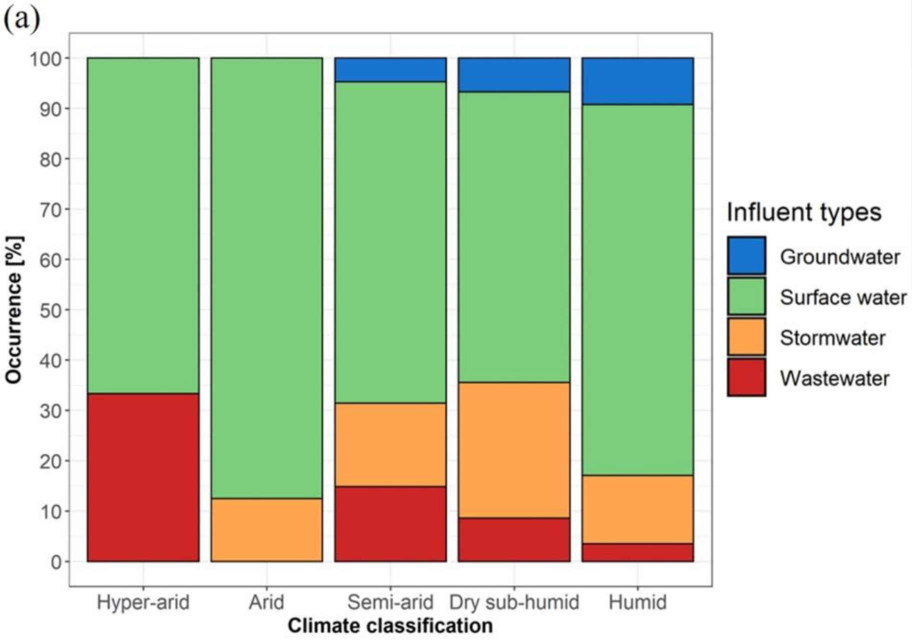
Soils properties

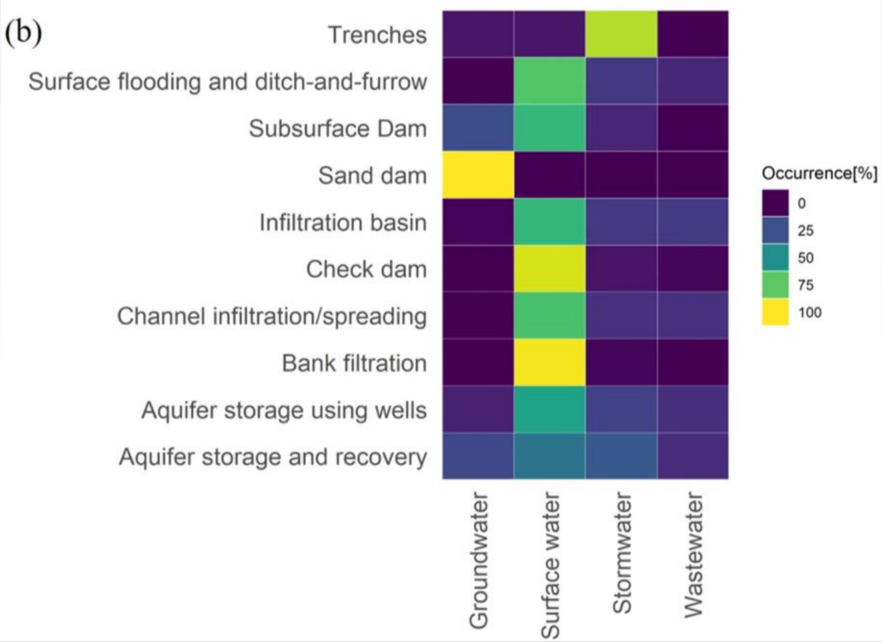


➢ Based on soil **grain size distribution**, soils can be classified into four major Hydrologic Soil Groups (HSG): **HSG-A** (>90% of sand), **HSG-B** (50–90% sand and 10–20% clay), **HSG-C** (<50% sand and 20–40% clay), and **HSG-D** (<50% sand and >40% clay). ***(NRCS,1996)***

Primary Criteria

Types of water and climate conditions

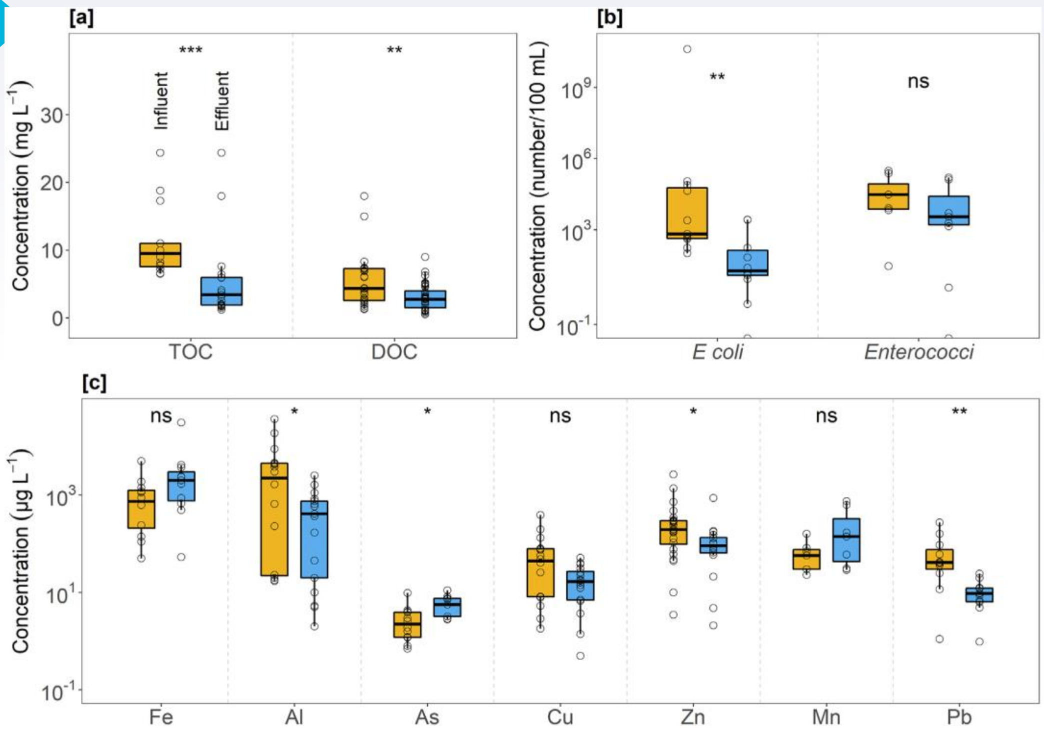




- The climate and water available affected the purpose and type of MAR; the type of MAR should be used based on the site's source water.
- Source water types are a critical choice for the specific type of MAR due to differences in the contaminant removal capacity of MAR technologies.

Primary Criteria

Quality of water



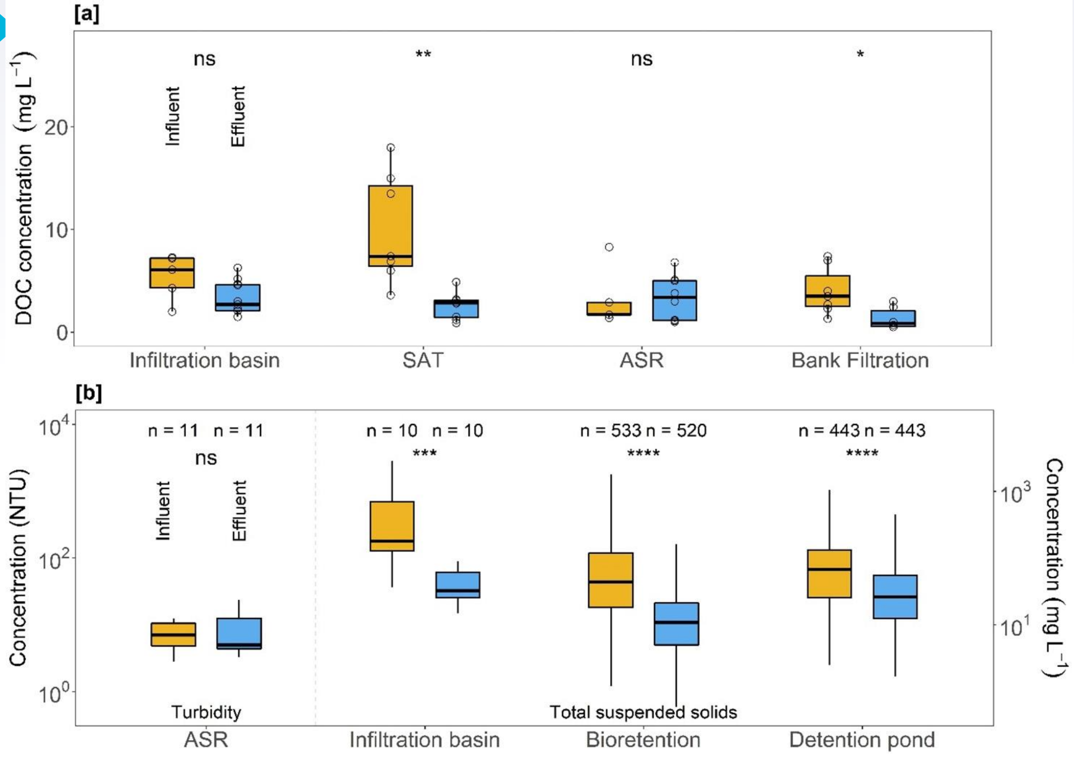
Changes in the concentration of pollutant elements under the effects of 33 MAR projects (used stormwater)

- MAR has been particularly effective in reducing the concentrations of total organic carbon (TOC), E. coli, and heavy metals such as Aluminium, Zinc, and lead from stormwater

- MAR can be applied in regions where the disposal of stormwater and wastewater to surface waters creates environmental concerns

Primary Criteria

Quality of water



The dissolved organic carbon and suspended sediments removal efficiency of different MAR types

- The ability of MAR to remove contaminants varies on the types of MAR and pollutants; poor application might result in groundwater contamination.

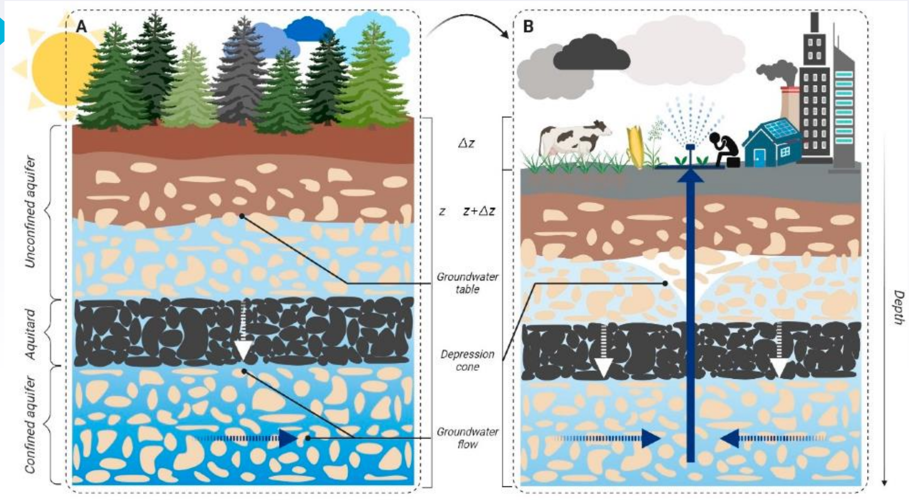
- Pollutant types in source water and aquifer redox condition must be considered to minimize groundwater pollution risk.

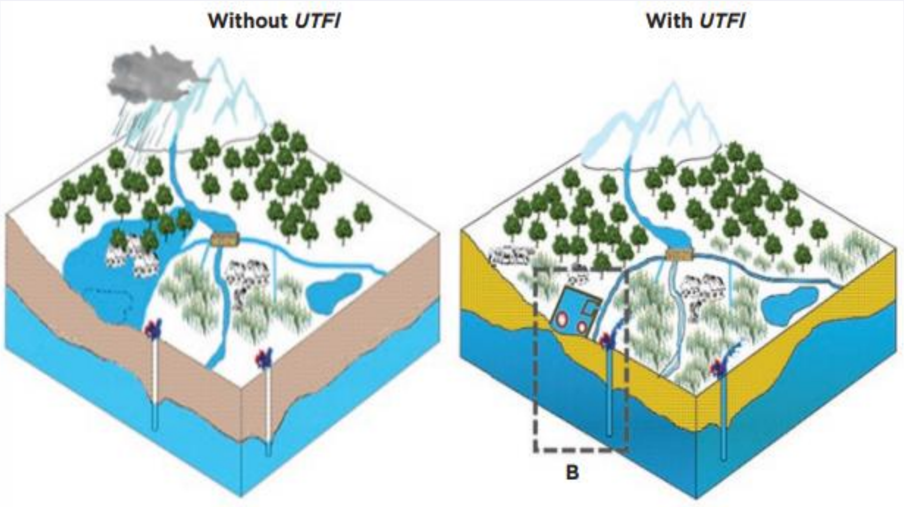
Primary Criteria

Selection of specific MAR based on on-site physical characteristics.

Condition						Recommendation
Recharge site land use	Water availability	Aquifer soil property[1]	Topographic slope[2]	Surface soil layer condition	Source water quality[3]	MAR type recommendation[4]
Open land	Medium to high	Sy: moderate to high K: moderate to high	Low	High infiltration rate	Good	IB, ASR, VZ, PT
					Poor	IB, SAT, VZ, PT
				Low infiltration rate	Good	ASR
					Poor	Do not implement
		Sy: moderate to high K: Low K of subsurface	Low	Any	Good	ASR, VZ, PT
					Poor	VZ, PT
Agriculture	Medium to high	Sy: moderate to high K: moderate to high	Low	Any	Good	SFD, Ag-MAR
					Poor	Do not implement
River channel	High	Sy: low to high K: moderate to high	Moderate to low	NA	Any	CIS, BF
	Low to medium	Sy: moderate to high K: moderate to high	Moderate to low	High infiltration rate	Any	Do not implement
				Low infiltration rate	Any	CSD
Urban	Medium to high	Sy: moderate to high K: moderate to high	Low	Any	Good	BMP, PT, IB
					Poor	BMP, PT, IB
Forest, Impervious land	No water	Sy: very low K: Very low	High	High sodium causing soil crust Prone to erosion	NA	MAR is not feasible.

Secondary Criteria





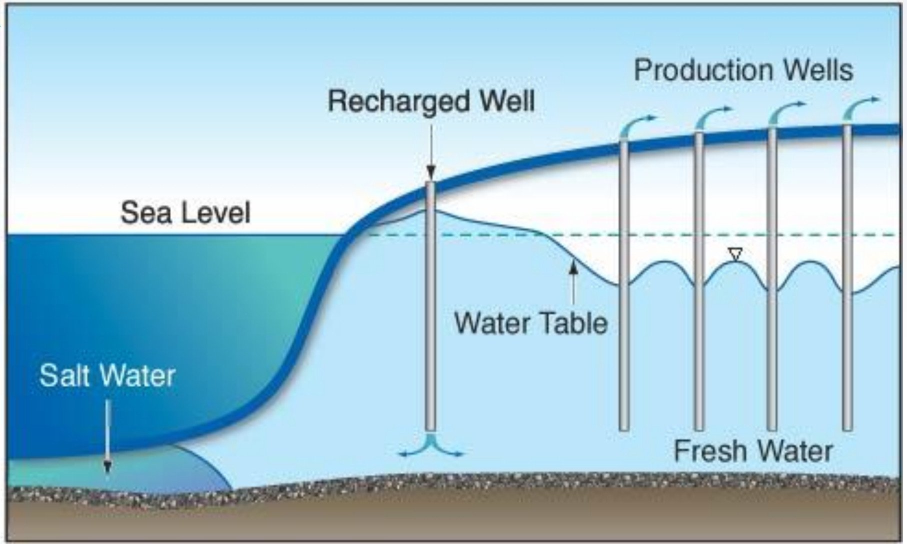
Minimizing land subsidence

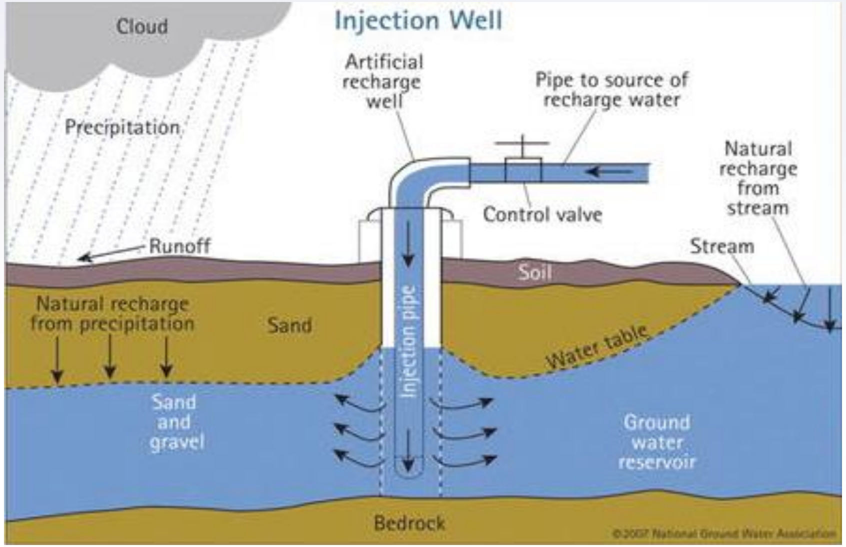
- When groundwater extraction exceeds the natural recharge, the empty pore collapse under stress, irreversibly lowering the storage capacity of the aquifer ***(Smith et al., 2017)***

Mitigating flood risk

- MAR basins provide temporary storage to flood water and reduce the flood peak, timing, and variability by diversion river flow ***(Chinnasamy et al., 2018; Yaraghi et al., 2019).***

Secondary Criteria





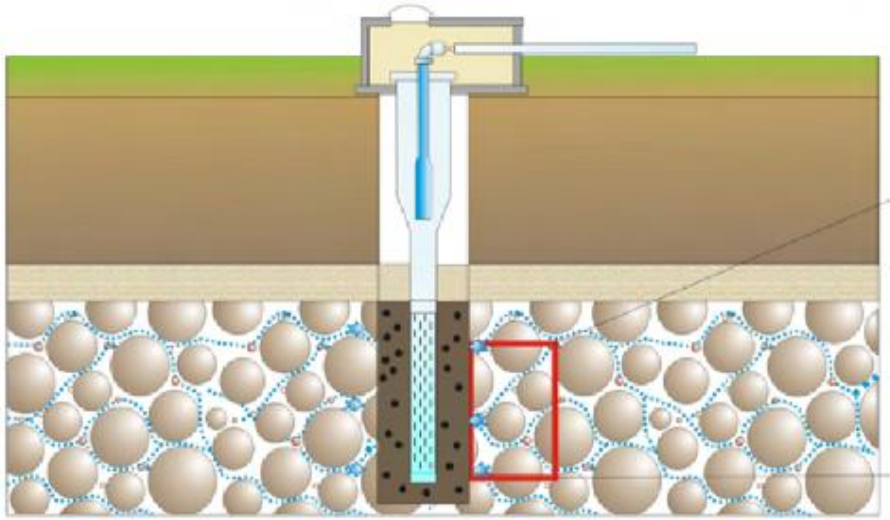
Minimize salt-water intrusion

- MAR can reduce the salinity of groundwater by injecting surface water, stormwater, and wastewater ***(ElRawy et al., 2019; Russo et al., 2015)***

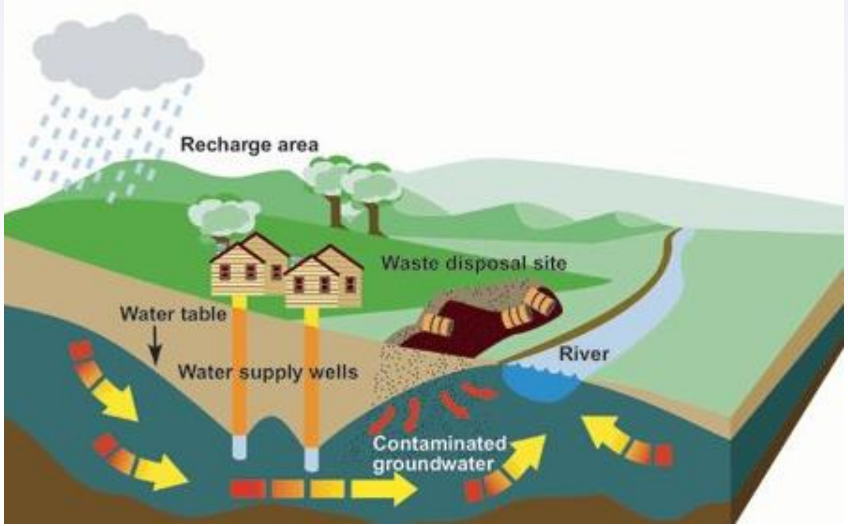
Augment low dry-season flow

- MAR can effectively raise groundwater level (and baseflow) by diverting excess flood water into the aquifer ***(Barber et al., 2009; Ronayne et al., 2017)***.

Challenges



(HuanWang,2020)



(Samer Talozi, 2016)

Clogging and crop damage

- Clogging can occur due to the deposition of suspended sediments in the source water and compaction of the soil layer that permits filtration

Groundwater contamination

- A site that permits rapid infiltration of source water can increase the risk of groundwater contamination

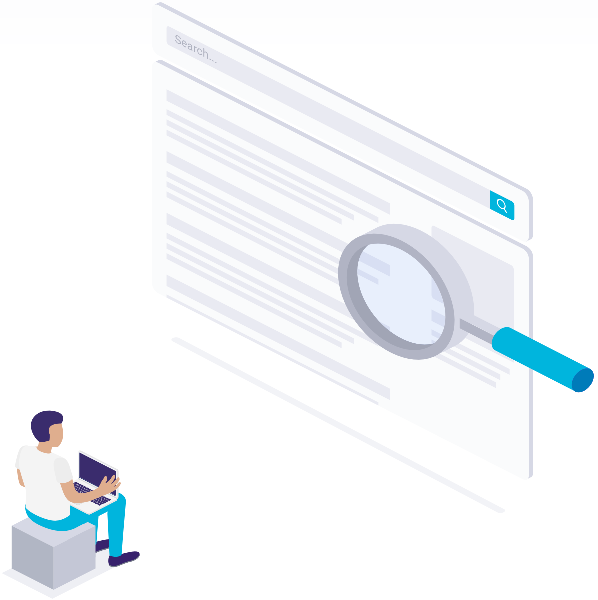
Conclusions

1. MAR has been implemented predominantly in sites with **hydrologic soil group C (sandy clay loam soil)** and water available for recharge.

2. MAR can **remove pollutants**, but the removal efficiency can vary with **MAR design and site conditions**. Depending on the type of pollutants and MAR technology, pretreatment of the recharge water or post-treatment of the recovered water may be necessary before its usage.

3. MAR implementation could provide additional benefits, including reducing saltwater intrusion into the groundwater, land subsidence mitigation, and drought mitigation strategy, which could lower the cost of MAR per benefits they provide at a site.

Thanks for your attention



Equation

Water Infiltration	*Darcy's Law (Saturated conditions)* $Q = -KAdh/dl$ A = application area for MR, dh/dl = change in head per unit depth, K = hydraulic conductivity *Green Ampt equation (Unsaturated conditions)* $F(t) - \|\varphi\|\Delta\theta ln\left(\left\|1+\frac{F(t)}{\|\varphi\|\Delta\theta}\right\|\right) = Kt$ $F(t)$ = cumulative depth of infiltration θ = water content, K = hydraulic conductivity, φ = wetting front pressure head	Contaminant transport	Advection-diffusion equation: $\frac{\partial C}{\partial t} + \frac{1-n}{n}\frac{\partial F}{\partial t} = -v\frac{\partial C}{\partial x} + D_h\frac{\partial^2 C}{\partial x^2} - \mu C + \gamma$ C = Contaminant concentration, v = water velocity, n= porosity, F = contaminant concentration in solid phase, D_h = hydrodynamic dispersion, μ = first order decay constant, γ = zero order production constant (Das and Singh, 2019)
Storage	Groundwater storage change (water balance method) $\Delta GW = P + Q_{in} - \Delta SM - \Delta SWE - Q_{out} - ET - \Delta SW$ *where* ΔGW = groundwater storage change, P = precipitation, Q_{in} and Q_{out} = surface water inflow and outflow, ΔSM = soil moisture change, ΔSWE = snow water equivalent change, ET = evapotranspiration, ΔSW = surface water storage change	Sorption	Freundlich isotherm (assuming high sorption capacity): $C_s = K_f C_w{}^{1/n}$ C_s and C_w are pollutant concentrations in soil and water at equilibrium, respectively. K_f, n are constants. For n =1, it becomes a linear isotherm. Langmuir isotherm (assuming exhaustion of sorption sites): $C_s = \frac{Q_0 K_L C_w}{1+K_L C_w}$ Q_0, K_L = constants.