MAR in Southeast Asia

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The level of progress in MAR in Southeast Asia is considered to be limited (Table 1). This review could only identify a handful of case studies worthy of note. Literature based on general discussions or on hypothetical modelling has not been considered. Across the region, there has been a tendency for applying deep recharge methods (wells) over surface methods (basins) owing to an absence of favorable shallow geological conditions in targeted areas or limited access to land. Most studies have been carried out in Thailand, with a lesser number carried out in Vietnam, Malaysia and Indonesia.

The earliest known work dates back to the early 1970s in Thailand where a pilot injection trial was carried out in response to land subsidence issues in the Bangkok metropolitan area due to heavy groundwater withdrawals resulting in groundwater quality deterioration and increased flood risk. The trial, carried out by government hydrogeologists, experienced two major sets of problems – high rates of aquifer clogging due to inadequate pretreatment of source water and rapturing of overlying clay layers due to excessive injection pressures (Ramnarong, 1989). Subsequent tests in a nearby area, carried out two decades later by local academics involved eight months of recharge testing which yielded successful results as evidenced by observations of rebound in pore pressures in adjacent aquitards (Phien-wej et al. 1998).

Efforts to test the viability of ASR in a coastal province of the country (Rayong) in the early 2000s was unsuccessful, once again due to irreversible well clogging (Pavelic et al. 2010). This result may be attributed to a degree of institutional memory loss on behalf of the government hydrogeologists, although international technical assistance was also provided.

A more concerted program of ASR testing extending over two phases from 2008 to 2014 was carried out in the Central Plains of Thailand (Sukhothai province) to address groundwater overexploitation caused by high groundwater use for agriculture. This testing has concluded that high levels of system maintenance are needed to address inherent well clogging problems (Bral et al. 2015).

Basin recharge methods based on harvesting wet season river flows were applied in an alluvial floodplain setting of Phitsanulok province between 2008-2011 to restore depleted groundwater levels in irrigation command areas. This was the first known trial of its kind in Thailand and one of the first in the region. A stage-wise, integrated approach was followed covering site suitability mapping, recharge system performance, hydrology & numerical modelling, hydrochemistry and cost-benefit analysis. Results of the trial appeared to be technically and economically promising (Nadeeet al. 2012; Pavelic et al. 2012; Srisuk et al. 2012; Uppasit et al.

2013). The large land area needed for wetland pretreatment of canal water prior to the recharge step may be a constraint unless methods with lower areal footprints can be identified. The study provided the foundation for the development of technical guidelines of a range of different MAR technologies to be applied (Chusanatus et al. 2012).

MAR assessments have been carried out in the coastal sand dunes of Binh Thuan province in Vietnam to examine the role of MAR in mitigating drought impacts by restoring groundwater storage capacity and improving ecosystems. Whilst extensive baseline studies of the water resources were carried out to characterize the baseline hydrology and hydrogeology of the area, it would appear that the project did not advance to the stage of conducting pilot recharge testing (Thoa et al. 2008; Hoanh et al. 2013).

Small scale testing of recharge into dry wells with rainwater to restore depleted groundwater levels and control impacts of land subsidence has also been applied in the highly water stressed Bandung basin in West Java, Indonesia. It was proposed that implementation should focus on industrial areas where large roof areas could be harnessed (Taufiq, n.d.). In Batu Pahat district, Malaysia, a favorable feasibility assessment led to the recommendation of recharge testing to boost groundwater storage in area of high demand and flooding. The documentation available suggests that the pilot testing had yet to proceed (Tjahjanto et al. 2008; Musa et al. 2009).

Enabling conditions for MAR

MAR has received minimal interest in SEA, with cases limited to feasibility studies or trial. The enabling conditions for consideration of MAR would appear to be three-fold, namely:

i) pressing groundwater quantity or quality issues
ii) local technical expertise in groundwater and an appropriate institutional setup to allow human and other resources to be mobilized
iii) links to international networks and institutions

The importance of these 3 pre-requisite is exemplified for several of the case studies described above (Table 2). By deduction, this also serves to explain the absence of MAR experience in countries such as Laos, Cambodia and the Philippines where problems are either not apparent, or unable to be addressed with current technical capacity. Singapore, with the most highly developed economy contrasting with the lowest per capita water availability in the region, has invested heavily in rainwater harvesting and water recycling in order to reduce its dependence on imports from Malaysia. This appears not to have extended down to harnessing the storage potential of underlying aquifers.

There are no known cases of MAR moving beyond feasibility studies or trials into larger scale, long term schemes. The rationale for this is possibly more case specific and diverse. In the case of the ASR trials carried out in Bangkok, whilst recommendations were made for larger-scale testing, policy mechanisms other than MAR ultimately provide more expedient and were found

to successful in addressing the subsidence issue across the Bangkok metropolitan area (Foster, 2002). Raising the profile of MAR and its merits under specific contexts, has not yet advanced to the policy level in SEA and has remained largely within the scientific community. It is the role of the scientific community to change the perceptions of the policy makers that water resources problems do not justify the exploration into technologies which are not yet mainstreamed and therefore risky.

Table 1. Compilation of MAR case studies in Southeast Asia

No.	Site	Project type	Objective	Aspects covered	Problems faced	Impacts achieved	References
1	a) Bangpoon (1972) b) AIT campus (1993-94), Pathumthani province, Thailand	pilot injection trials (single injection well)	restore depleted GW levels and control impacts of land subsidence	aquifer characterization, well hydraulics, ground movement	- rupturing of overlying clay - clogging when untreated canal water was used	- policy mechanisms other than MAR proved successful in addressing the subsidence issue	a) Ramnarong, (1989) b) Phien-wej et al. (1998)
2	Nong Taphan, Rayong province, Thailand	pilot ASR trial	trial ASR technology using treated canal water	aquifer characterization, recharge performance & well clogging	- trial abandonment due to excessive well clogging		Pavelic et al. (2010)
3	Sawankhalok, Sukhothai province, Thailand	pilot trial (multiple ASR wells)	restore depleted GW levels in an irrigation command area through recharge of wet season river flows	aquifer characterization, recharge performance & well clogging, hydrochemical tracing, solute transport modelling	- well clogging even with physioco-chemical treatment requiring high levels of system maintenance		Mallonee, (2013) Bral et al. (2015) Mungkang et al. (2015)
4	Ban Nong Na, Phitsanulok province, Thailand	basin recharge pilot trial	restore depleted GW levels in irrigated areas through infiltration of wet season river flows	site suitability mapping; recharge performance & clogging; hydrology & numerical modelling; hydrochemistry; cost-benefit analysis	- large land area sacrificed for wetland pretreatment of canal water	- foundation for guidelines to be developed over the wider area affected by similar problems - led to new work being initiated on MAR for co-managing floods and droughts	Chusanatus et al. (2012) Nadeeet al. (2012) Pavelic et al. (2012) Srisuk et al. (2012) Uppasit et al. (2013)
5	Hong Phong district, Binh Thuan province, Vietnam	basin recharge pilot trial	arrest drought impacts and restore GW storage capacity and improve ecosystems	hydrological and hydrogeological characterization, hydrochemistry, modelling	- project carried out extensive baseline studies of the water resources but does not appear to have recharge the piloting stage		Thoa et al. (2008) Hoanh et al. (2013)
6	UTHM campus, Batu Pahat district, Malaysia	pilot recharge trial	boost groundwater storage in area of high demand and flooding	aquifer characterization (geophysics, grainsize, analytical modelling)	- feasibility assessment was favorable but pilot testing had yet to proceed		Tjahjanto et al. (2008) Musa et al. (2009)
7	Bandung Basin, Indonesia	pilot recharge of dry wells	restore depleted GW levels and control impacts of land subsidence	pilot recharge, laboratory test of pretreatment, risk assessment modelling		- roof water harvesting in industrial areas proposed, following treatment (zeolite) to neutralize pH of rainwater	Taufiq, (n.d.) Fildebrandt et al. (2003)

Table 2. Enabling conditions for MAR implementation

No.	Country	Problem	GW expertise / institution	International linkages
1-4	Thailand	GW depletion and/or land subsidence	Department of Groundwater Resources (formerly Department of Mineral Resources)	Intl technical assistance, IAH
5	Vietnam	drinking/domestic/agricultural water provision in drought prone areas	Vietnamese Academy of Science and Technology (Institute of Geophysics, Institute of Geological Sciences)	Vietnam Atomic Energy Commission, UNESCO (Jakarta office), University La Sapienza (Italy)

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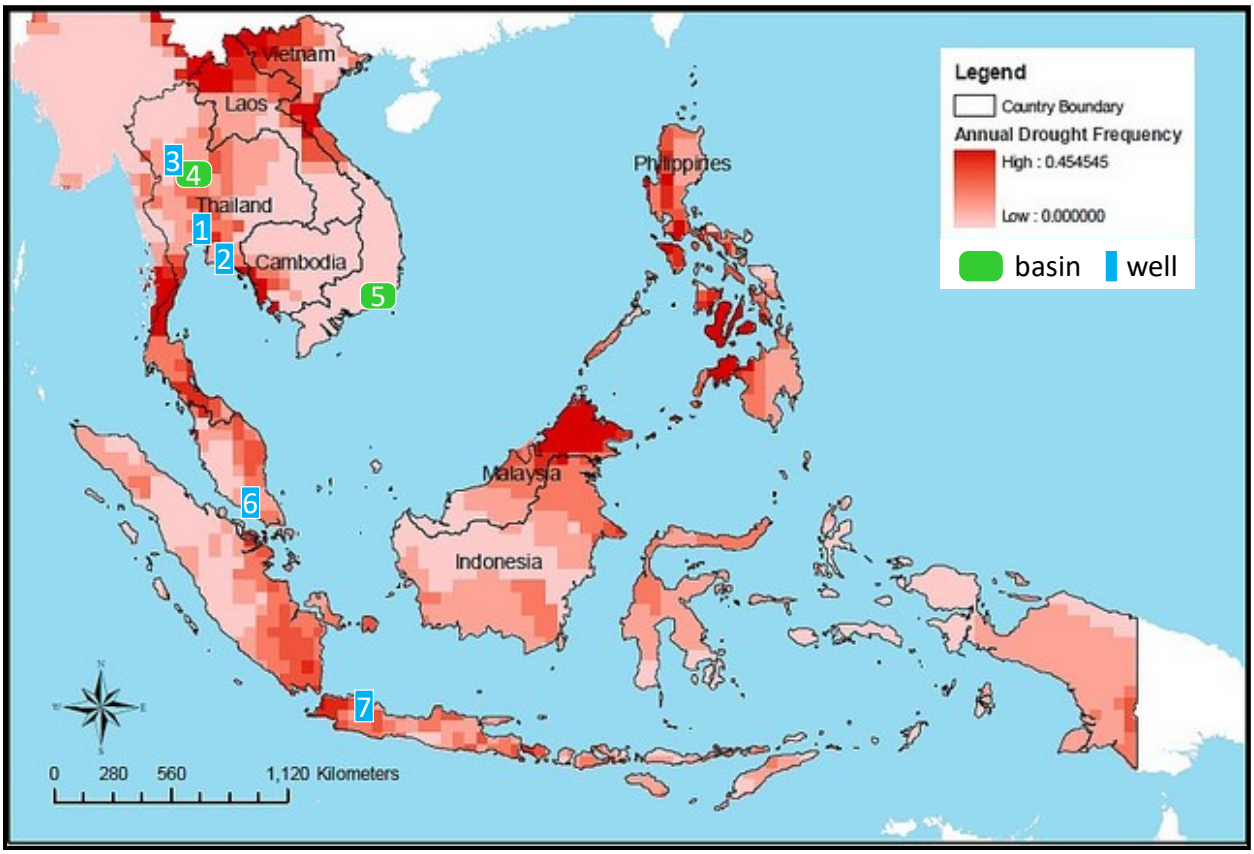

Figure 1. Map of MAR trial sites in SEA, identified according to recharge technology. Base map is taken from Yusuf and Francisco, (2009)