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Key Note Paper

Crucial Role of Aquifer Mapping in Sustainable Groundwater Management in the context of Changing Environment

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INTRODUCTION

We all are aware that *Groundwater*, as a resource, is progressively moving out of the shadows of surface water hydrology, although it is part of the global water cycle. The nature of the resource and the relative ease and often, convenience of decentralised access has meant that groundwater is the backbone of India's agriculture and drinking water security. It is a common-pool resource, used by millions of farmers across the country. It remains the only drinking water source in most of India's rural households. Many industrial units in the country depend upon groundwater. With more than 20 million groundwater structures, India is fast moving swiftly towards a serious crisis of groundwater overuse and groundwater quality deterioration. The report of CGWB on Dynamic Groundwater Resources of India (2006), states that, in 2004,there was alarmingly high levels of groundwater use in 28% of the blocks of our country. A recent assessment by NASA showed that during 2002 to 2008, India lost about 109 km3 of water leading to a decline in water table to the extent of 0.33 metres per annum (Tiwari et al, 2009). In addition to depletion, many parts of India report severe water quality problems, causing drinking water vulnerability. At the national level, nearly 60% of all districts in India have problems related to either the quantitative availability or quality of groundwater or both. This is a serious situation warranting immediate attention.

The desired shift from "groundwater development" to "groundwater management" needs to be embodied in a National Groundwater Management Programme integrating such a shift. There is no dedicated programme on groundwater management in the country today. Most groundwater-related interventions are currently part of other programmes like Integrated Watershed Management Programme (IWMP), river basin management and other programmes on water resources and rural development, including the Mahatma Gandhi Rural Employment Guarantee Scheme (MGNREGS). Therefore, groundwater resources are simply perceived as a part – watersheds, landscapes, river basins, villages, blocks, districts, states etc, but *aquifers are seldom considered*. Such narrow and segmented perspectives ignore the unity and integrity of the hydrological cycle. More importantly, it ignores the common pool nature of groundwater. The delinking of groundwater from land ownership and a change in property rights regime from an ownership to a trusteeship paradigm must begin with a new, aquifer-based national programme on groundwater.

Whilst there is talk about conflicts and wars on water, the parallel between oil and water ends there. Worldwide, the oil industry cannot function without specific reference to "oil reservoirs" or formations of rock, having the capacity to bear oil. Sadly, in India, this parallel never worked for groundwater resources! Despite efforts by CGWB, the country's premier agency working on groundwater, and work by some State Departments and Civil Society Organizations, aquifers as groundwater bearing units never found a place in mainstream thinking on management of groundwater resources. In fact, aquifers do not figure in a central way in any of the water resource plans, particularly in regions where groundwater forms the core component of planning. Comprehensive mapping of India's aquifers, on a priority, must become the keystone of developing any sustainable groundwater management programme.

Specific programmes such as drinking water and sanitation still seem to be bound to sources rather than resources. This approach is restrictive and concludes at understanding groundwater prospects with a special reference to locating drinking water sources. In many ways, the objective of locating sources restricts the potential use of advanced techniques like remote sensing, geophysics and GIS-type platforms for data-management. Even today a good "strike" of groundwater is considered a sound measure of success, without any reference to the strength and potential of the aquifers behind "sources of water supply". The utility of many advanced techniques used in such an effort is well-known, but with the absence of a clear-cut picture on aquifers, the purpose with which such exercises are conducted remains unclear in the context of managing groundwater as a common pool.

It is imperative to design an aquifer mapping programme with a clear-cut groundwater management purpose. This will ensure that aquifer mapping does not remain an academic exercise and that it will seamlessly flow into a participatory groundwater management programme including the effective implementation of policy instruments that include a strong legislative framework including a detailed Central Groundwater Model Bill. Implementation of an integrated aquifer mapping and groundwater management programme is possible only through strong partnerships between government departments, research institutes, gram panchayats/urban local bodies, industrial units, civil society organizations and the local community. Groundwater management will also require improved participation by all, especially women and particularly the land-less.

Traditionally, groundwater has always been considered secondary to surface water development in India. However, available official statistics themselves are very clear in showing that exploitation of groundwater has clearly seen an alarming increase in the post-independence era.The table (from CWC Statistics 2004) below shows how the relative importance of groundwater has increased over this period.

Most surface water reservoirs stand a fairly reasonable chance of being replenished in the monsoon following a summer to a lesser or larger degree, but groundwater replenishment remains a subject that is not well understood. In light of this, the treatment of groundwater can no longer be subjugated to surface water or simply taken for granted in the context of purely systemic thinking like watersheds and river basins. Moreover, it should not simply be considered under programmes and ministries like "drinking water and public health", which consider only one dimension of groundwater use, often at the expense of another (like agriculture or industry). Groundwater deserves an independent, well-thought out system of monitoring and management. Providing rightful

NET IRRIGATED AREA (million hectares)				PERCENTAGE CHANGE FROM 1951		PERCENTAGE OF DISTRIBUTION		
	1951	1968	1997	1968	1997	1951	1968	1997
Surface water	14.90	19.30	23.80	29.53	59.73	71.29	64.98	43.91
Groundwater	6.00	10.40	30.40	73.33	406.67	28.71	35.02	56.09
TOTAL	20.90	29.70	54.20	42.11	159.33	100.00	100.00	100.00

place to groundwater resources in policy thinking, programmes and institutions is the way forward to dealing with the crisis of groundwater management playing out in different forms across the length and breadth of the country.

The goal of a National Groundwater Management Programme should be equitable, safe and sustainable management of India's groundwater resources through improved systems of resource mapping, utilization and governance, including improvements in energy use and pricing and legislative instruments of regulating groundwater overuse (Planning Commission, 2011).The five essential components identified for improved groundwater management and governance in National Groundwater Management Programme are:

1. Aquifer mapping and delineation
2. Recharge systems and well-use efficiencies aligned to aquifers
3. Groundwater – Energy co-management
4. Participatory demand management of aquifers
5. Groundwater legislation

LINKAGE BETWEEN GROUNDWATER ASSESSMENT AND MANAGEMENT

Presently, in a majority of the cases, quantitative estimation of groundwater resources and the classification of blocks and watersheds into over-exploited, critical, semi-critical and safe categories are the sole criteria for identification of areas for implementation of various groundwater management programmes. However, several other aspects of groundwater resources need consideration during implementation of groundwater management programmes. These are: groundwater availability, groundwater accessibility and groundwater quality.

- The total availability gives an idea of the potential storage in an aquifer and the amount of water actually available under various degrees of exploitation. This depends on Specific Yield or Storativity and the Saturated Thickness of the Aquifer.

- Groundwater Accessibility is the measure of how easily water flows through or can be pumped from an aquifer. Groundwater Accessibility is the function of depth to water and Transmissivity (T) / Hydraulic Conductivity (K) of the aquifer.

- Groundwater Quality: At present, salinity is the only component of groundwater quality being considered in groundwater resources assessment. The question of scale arises with reference to other groundwater quality parameters since the quality estimations are mostly at sources and habitations in contrast to quantitative assessments at the block level. Aquifer-based groundwater quality understanding is almost missing from current assessments of groundwater resources in the country.

The aquifer mapping approach can help integrate the above-mentioned aspects. The aquifer mapping exercise can integrate existing information onto a GIS platform wherein different layers can be developed and one can superimpose the layers to arrive at a solution for various groundwater management programmes. Categorization maps, quality maps and water level maps are available and aquifer maps will only form the template to port this information to, particularly in an attempt to arrive at improved decision support. However, all such information should be ported to the proposed aquifer mapping framework.

An indicative hydraulic conductivity is reflected in the Hydro-geological Map of India, where well yields give a measure of the ease of groundwater pumping. Similarly, estimates of recharge are also emerging through different studies, both within and outside CGWB. However, if information is available at a more disaggregated level, such as in an atlas of aquifer maps, the managers of

groundwater resources could consult such an atlas before taking decisions on various groundwater management options.
The main idea behind this approach is to go beyond the present practice of opting for a management solution based solely on the category of quantitative assessment. A set of data on various attributes of groundwater would be available to the groundwater manager. The management plans be based on the analysis of such data.

BEST PRACTICES

Assessment of groundwater resources, across the globe, is based on respective national policies. While advanced countries with strong databases like Australia, UK, South Africa have adopted the Sustainable Yield Policy, most of the countries including India have adopted Safe Yield Policy. In USA, both the Safe / Sustainable Yield Policy and Planned Depletion policy are in use. Regional Scale assessments have played a key role in National level decisions on groundwater management in many countries. The geographical unit for Regional Scale assessment in the USA is Regional Aquifer Systems, while in case of Australia and South Africa; it is basin or catchment area. GIS based approach has been adopted in most of the Regional and National Scale assessments in these countries. Techniques like Groundwater Storage concept, Water Balance, Soil moisture balance, Groundwater flow modeling are used for estimation of recharge, total groundwater availability and sustainable yield of aquifers

The existing state of water quality data in India is insufficient for providing perspectives with regard to public health, agriculture or other purposes. There is very poor dependability on the existing data sets since they are very sparse and have low frequency with respect to time. Instead, it is essential to arrive at a common minimum sampling density guidelines depending on aquifer conditions, type of problems, population density and access to drinking water and attempt to reach such a density in a specified time period. Moreover, there must be a convergence of quantitative and quality assessments of groundwater resources, which are constrained today due to the mismatch of scales on which these are collected. The aquifer based programme, will provide space in forging such convergence. Ideally, we should determine the required sampling network density can be determined by considering Aquifer type, Seriousness of Public Health Problem, Population Density and Density of drinking water sources and load on ground water irrigation.

The nature of sampling can be at different levels – indicative, numerical and analytical – which can be performed by different types of laboratories For example, an indicative Fluoride testing at a primary level testing for a high Fluoride level will indicate the numerical concentration of Fluoride at

Safe Yield, is broadly defined as the attainment and maintenance of a long term balance between the annual amount of ground water withdrawn by pumping and the annual amount of recharge to the aquifer. Safe yield is equated with annual re-charge. Sustainable Yield includes reserving a fraction of Safe Yield for the benefit of surface water flows and other water dependent ecosystems. Groundwater is a part of the Water Cycle; with-drawal of groundwater not only affects the aquifer but also the groundwater fed surface water systems (springs and baseflow) and the groundwater dependent ecosystems (wetlands and riparian vegetation).

a secondary level and further analysis on spread and transmission can be done by the tertiary labs on a selective basis.

CONCEPT OF AQUIFER MAPPING

Aquifers are basic units for understanding groundwater and attempting the sustainable management of groundwater resources. Aquifer mapping aims at defining hydrogeology and establish a framework of background information on geology, hydrology, and geochemistry of the Nation's important aquifer systems. This information is critically needed to develop an understanding of the major ground-water flow systems and to support better management of ground-water resources.

Hence, the first step is to construct a disaggregated picture by carefully mapping aquifers across different hydro-geological settings and understanding their storage and transmission characteristics. One of the outputs of aquifer mapping would be the estimation of the amount of water available within each aquifer. Bringing simple modeling techniques as an input, such estimation will be able to predict groundwater availability under various scenarios – degrees of exploitation of the resource, changing patterns of water use and climate change. This estimation can then feed into understanding the contribution of the aquifer to the overall water availability within a watershed or a river basin in a given hydro-geologic configuration.

Aquifer mapping will have to go beyond the production of specific aquifer maps at appropriate scales. Each aquifer map will, in many ways, bear similarity to District Resource Maps (Geological Survey of India) and Groundwater Prospects Maps (Rajiv Gandhi National Drinking Water Mission).

Aquifer maps, apart from thematic maps, will include:

- A narrative description of the maps themselves.
- Statement of the "sustainable yield management goal" for the aquifers, stating that the average withdrawals should not exceed long-term recharge, at least as a guiding principle.
- Inputs / guidance for implementing artificial recharge programmes effectively, indicating plans for implementing artificial recharge for the aquifers concerned.

Since the fundamental binding constraint on resource availability is on the demand side, aquifer mapping must lead to a groundwater management strategy, which includes appropriate demand-management strategies in addition to water use and recharge.

Once the aquifer is mapped and its storage, transmission and quality characteristics determined, a broad set of priorities of water use can be decided. Aquifer mapping should lead to location-specific protocols and agreements within the user community as well as arriving at a robust regulatory framework through legislation. Aquifer mapping will lead to carefully oriented strategies of using indirect regulatory instruments like electricity rationing or metering as a means of groundwater regulation.

GROUNDWATER MANAGEMENT

Aquifer mapping outputs should lead to a groundwater management plan in any hydrogeological setting. The output from an aquifer mapping plan would vary from setting to setting but should attempt to capture the following aspects as a groundwater management protocol, across all settings:

- Relationship between surface hydrologic units (watersheds and river basins) and hydrogeologic units, i.e. aquifers.
- The broad lithological setup constituting the aquifer with some idea about the geometry of the aquifer – extent and thickness.
- Identification of groundwater recharge areas – protection and augmentation strategies.
- Regulatory options at community level, including the nature of gram-sabha resolutions that will enable appropriate

regulatory mechanisms at the panchayat level. These may include (only an indicative list given here):

ü Drilling depth (or whether to drill tube wells or bore wells at all)

ü Distances between wells (especially with regard to drinking water sources)

ü Cropping patterns

- Comprehensive plan for participatory groundwater management based on aquifer understanding – domestic water security, food and livelihood security and eco-system security, bearing in mind principles of equitable distribution of groundwater across all stakeholders.

- Inputs to the use of indirect instruments of regulation, mainly power rationing and/or metering based on aquifer characteristics and degree of exploitation.

- Groundwater balance and water budgeting at the scale of a village or watershed

Groundwater assessment at the level of each individual aquifer should be attempted in terms of groundwater storage and transmission characteristics, including the aquifer storage capacity.

METHODOLOGY

The primary focus of an aquifer mapping effort should be all aquifers in the country, whether phreatic or confined. Most approaches hitherto have used a hydrogeomorphological approach along with geophysical measurements with the purpose of classifying groundwater prospects, or in simple words, to locate groundwater resources. The purpose of the proposed aquifer mapping being quite different – developing aquifer management plans – the methodology proposed here will essentially use three important criteria.

- Geological mapping at an appropriate scale, using primary and secondary information.
- Inventory of at least a representative sample of the 20 million odd wells that are supposed to be a part and parcel of India's groundwater infrastructure.
- Water level data at each individual location.
- Aquifer characteristics like transmissivity and specific yield / storativity.

These four layers of information are viewed here as constituting the basic information in mapping aquifers. The output from an aquifer mapping exercise should essentially be in the form of an "aquifer map" which will include the following:

1. An aquifer outcrop map on a geological map of appropriate scale (Geological Survey of India is currently taking up mapping exercises on the scale of 1: 10000; such maps can also be used as the basis for creating aquifer projection onto the surface. CGWB's current information in aquifers, at more regional scales, can also form a basis to begin work on aquifer mapping.

2. Vertical configuration of the aquifer(s) should be depicted through either appropriate cross sections or fence diagrams or other 3-D depiction models that can appropriately depict vertical boundaries.

3. Water level information (preferably a water table contour map for at least the pre and post monsoon seasons) which can be layered on top of the geological map.

4. Narrative on aquifer properties, mainly transmission, storage and groundwater quality. The narrative will explain, in simple terms, the map, cross sections and groundwater movement in the aquifer.

5. A supplementary map indicating natural recharge and discharge areas. This map will also indicate locations for carrying out recharge measures, best locations for siting

public drinking water sources, best locations for community irrigation wells etc.

6. Narrative on groundwater availability in the aquifer(s), possibly under different scenarios – normal recharge, droughts, groundwater exploitation etc.

7. Protocol for aquifer management – supply and demand side – including the possibility of imposing more centralized systems of legislation in a worse-case scenario.

GROUND WATER SALINITY AND URBAN AQUIFERS

As an integral part of the aquifer mapping effort, it is necessary to look at two specific aspects of aquifer mapping and groundwater, in the hydrogeological settings identified. Firstly, the context of groundwater salinity, which will include:

- Aquifers and their differential behaviour to inland salinity as well as sea-water incursion;
- Causes for salinity and sea-water ingress in light of aquifer characteristics;

Other associated water quality problems, if any; Groundwater recharge measures for mitigation; Groundwater management alternatives on different scales in context to aquifer salinity.

Aquifer mapping, especially in the case of coastal aquifers will include aquifer maps depicting physical state and characteristics of coastal aquifers; improved perspectives of recharge processes in such aquifers; inputs to scaled solutions on recharge for mitigating aquifer salinity and aquifer based protection of sources of drinking water supply.

Secondly, urban aquifers require a different perspective, over and above the hydrogeological setting in which an aquifer mapping and groundwater management effort is embedded. The urban groundwater perspective would need to look into specifics of aquifer-user profiles and the nature of evolving groundwater use in and around growing urban centres.

A reformed Groundwater Model Bill is also being discussed under the working group on Water Governance set up by the Planning Commission and the Bill has specific reference to urban groundwater, currently not under the purview of any regulatory framework. The overall perspective in looking at groundwater would require specific attention to questions of protecting recharge areas in and around growing townships including the question of peri-urban transitions on different aquifer settings, strategies of augmenting recharge and potential impacts on groundwater quality, mainly anthropogenic contamination. The outputs from such studies could include strategies of multi-aquifer groundwater management, including protection and conservation strategies.

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