SPECIAL PUBLICATION OF THE GEOLOGICAL SOCIETY OF INDIA
No.5, 2016, pp.145-153
DOI: 10.17491/cgsi/2016/95961

Conjunctive Use of Surface and Ground Water in India: Need to Revisit the Strategy

J. Harsha
Central Water Commission, Ministry of Water Resources, River Development & Ganga Rejuvenation,
Government of India, JALASOUDHA, HMT Post, Bangalore – 560 013
Email: infoharsha@yahoo.com

Abstract: Conjunctive use of surface water and ground water is a complex water management strategy that involves management of surface water and groundwater as one resource under diverse geological, hydro-geological, hydrology and geophysical setting. India has adopted this concept as management strategy since 1970s, but the progress of the same hasn't been encouraging as on date. The strategy has been a setback in Indian context, despite prioritizing 40 years ago, due to the limitations and lacunae of research and institutions. The paper identifies the causes and impediments that has slowed implementation of conjunctive use of surface and groundwater in India and recommends measures to reset its strategy in the 21st century.

Keywords: Conjunctive use, Surface water, Groundwater, Hydro-geology, Hydrological districts.

INTRODUCTION

Conjunctive use of Surface and Groundwater in India was conceptualized as a water management strategy way back in 1970s. This adaptive resource management strategy was considered by Irrigation Commission of 1972 and National Commission of Agriculture in 1976 (Central Water Commission, 1995). Subsequently, conjunctive use of surface and groundwater was adopted in National Water Policy – 1987, 2002 and 2012 considering water as single resource. National Water Policy – 1987 & 2002, *inter alia*, states, "*Integrated and coordinated development of surface water and ground water and their conjunctive use, should be envisaged right from the project planning stage and should form an essential part of the project*". Whereas the National Water Policy – 2012 is less explicit or evince less interest in conjunctive use of surface and groundwater as a water management strategy; it focusses more on holistic water management and integration of multi-disciplines, multi-stakeholders for efficient water management in accordance with IWRM principles.

According to Central Water Commission (1995), conjunctive use of surface water and groundwater in India is conceptualized as,

> "*Unified nature of use of water resources as single resource taking advantage of surface and groundwater phases of hydrological cycle involving integration at different temporal and spatial settings*".

This water management strategy has been envisaged for application in irrigation water management (also urban water management and coastal management) across waterlogged areas and water scarce regions for optimizing water use, create water security and create buffer in sub-soil for use in different spatial and temporal setting. The focus of this paper is restricted to investigation of the feasibility of conjunctive use of surface and ground water in India in the irrigation sector against the backdrop of a number of impediments; and the remedies to be adopted so that this adaptive management strategy can break the shackles of policy papers, and find its application in India's watersheds or command areas of water resources projects.

INDIA'S KNOWLEDGE GAP

Conjunctive use of surface and groundwater involves complex setting with respect to geology, hydrogeology, hydrology, agronomy and geophysical processes (Fig.1). India's geology, hydrogeology, hydrology and geophysical setting are not uniform throughout the country. For example, Alluvium being higher water bearing aquifer is dominant in Indo-Gangetic plains, whereas in the Maharashtra-Karnataka region basalt and banded gneissic complex are dominant. Whereas, basalt is higher water bearing rock variety amongst igneous rocks, banded gneissic complex has low water retention capacity (Heath, C.R. 1984). So, the buffer in the form of ground water available in the sub-soil is not the same across

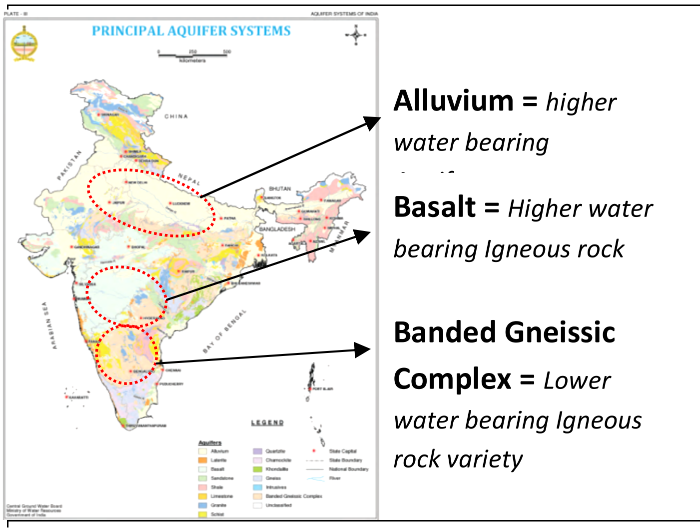


Fig.1. Different hydrogeological settinf of India (Source: CGWB (2012) & Heath, C.R. (1984))

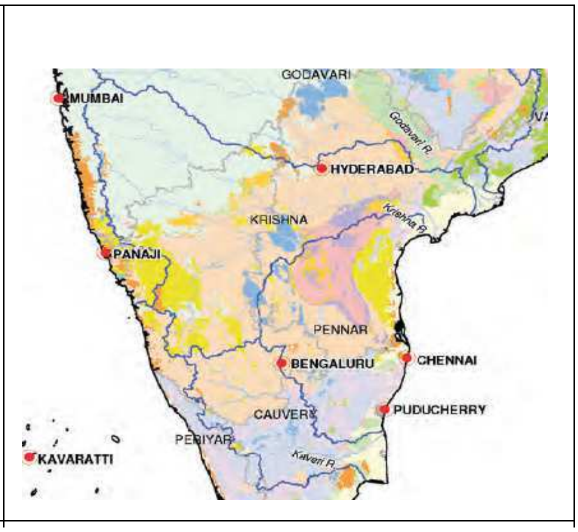


Fig.2. Surface water basin and aquifer basin mismatch (Krishna, Cauvery and Godavari river basin). Source: CGWB (2012)

the regions. Then, India's surface water basins do not always coincide with the aquifer basins beneath the ground. Figure 2 shows Krishna river basin with half of the basin largely underlain with basalt rock variety and the other half with banded gneissic complex and both have different water recharging ability and water retaining capacity. The different types of aquifers extend beyond the boundaries of surface river basins. Within river basins, the topography, terrain slope, soil types, cropping pattern, climate and water table vary. For example, within Krishna river basin there exists about 2 different agro-climatic zones i.e. Western Plateau and Hills region, and Southern Plateau and Hills region (Indian Agricultural Statistical Research Institute, 2015). The elevation of the basin varies from 1000 m above mean sea level (amsl) in the West and reaches sea level in the East. Therefore, while policy papers make grandiose conceptualization of water as a single resource, the reality is that groundwater responses across regions rarely compliment the surface water in both spatial and temporal setting.

Water resource projects generally possess command areas that are tiny in comparison to a river basin or sub-basin or watershed but then the command areas too are diverse with respect to level of water table beneath the ground, the terrain slope, precipitation magnitude, vegetation types, surface water-groundwater interaction, aquifer-stream interaction, geology, soil types and political boundaries. It is very rare to find a command area with surface water and groundwater interaction being uniform and complement to each other in the entire area. Figure – 3 shows the command area of Karanja major irrigation project overlaid on the district map of Bidar in Karnataka. As seen in figure, the command area is spread over diverse water bearing stratums with different yields, different levels of precipitation within same command, different geological lineaments and different political boundaries of *tehsils/taluks*. Therefore, any plan of conjunctive use strategy in Karanja command area across different spatial/temporal setting, demands comprehensive information system of this diverse setting and different integration strategies across the same command. The scenario in large number of command areas in India is similar to the Karanja command area. Figure 4 also shows indicatively, how water table, terrain slope, topography can vary within command areas. Hence, the information about baseline status of the diverse setting of geology, hydro-geology, hydrology, agronomy, terrain slope etc., within basin or sub-basin wise or watershed or project-wise are vital and a pre-requisite for even conceiving conjunctive use of surface and groundwater. But India's data repository of these diverse setting of surface and groundwater watershed-wise or river basin-wise is utterly miserable to the extent that it serves as the first level of impediment to plan conjunctive use in a command area.

RESEARCH GAP

Of late, there have been several examples in India where mathematical models of conjunctive use of surface and groundwater have been developed in the computers and run by several scholars. But, in India, the examples of the success of such mathematical models applied to command areas where surface water and groundwater behaved exactly as per the model is rare, if not nil. The reason is that every mathematical model representing any scientific phenomena does not represent the

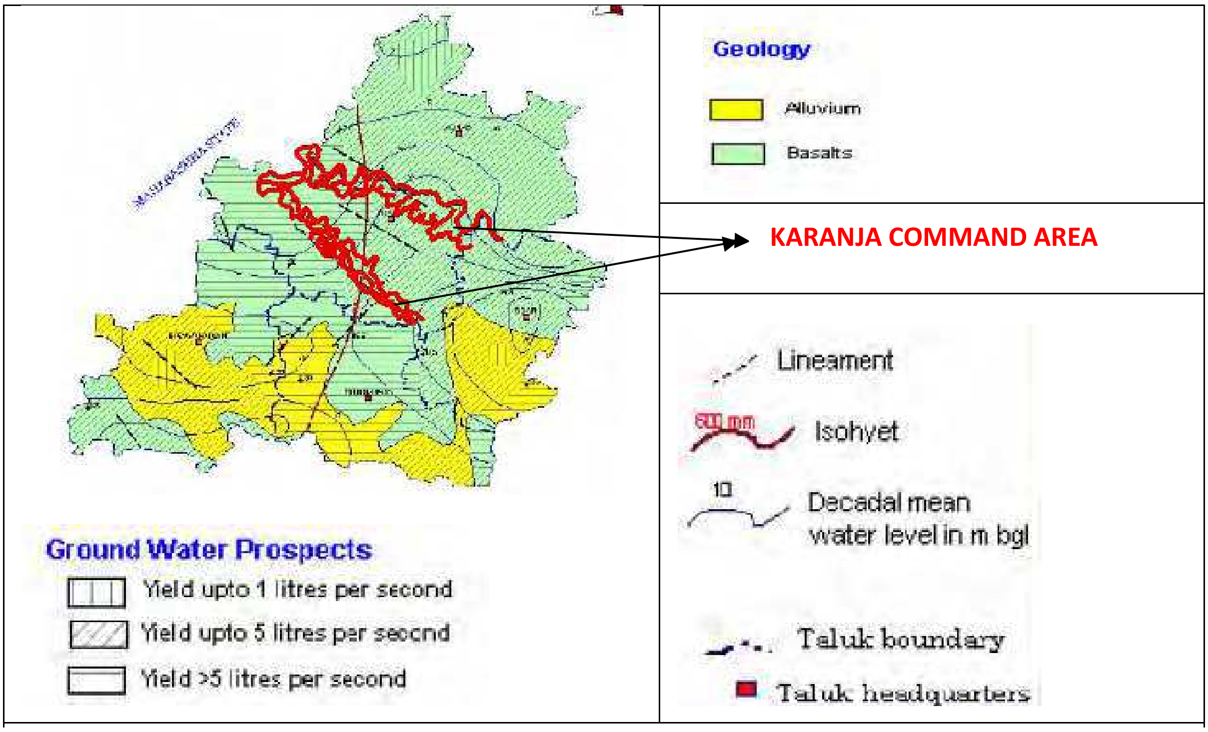


Fig.3. Command area (marked in red) of Karanja Project in Bidar District, Karnataka encompassing diverse water bearing stratum, water levels, slope, political boundaries and direction of flow of groundwater. (Source: CGWB (2012), India-WRIS (2012) & Author)

phenomena exactly. There will be shortfall in representation. But the case of mathematical models with respect to conjunctive use is different due the diversity of scale within the hydrological cycle and the disciplines involved. Often, models developed for a particular geologic or climate setting are difficult to run in different geologic and climate setting (Lundin, L.C et al, 2000). Mathematical models like MODFLOW (groundwater flow model), SVAT (soil-vegetation-atmosphere interaction model), MIKE-SHE (simulates runoff in a river basin) etc., are available, but then India lack the requisite data - project-wise or watershed-wise - ready to feed these models and couple them.

Even if database is collated and the mathematical models are run successfully, their results diverge because the command area in India belong to private owners and the operation of bore wells or open wells is dependent on the flickering power supply of India that upset both spatial and temporal phases of conjunctive use of surface and ground water (see Fig.5 for ideal case of conjunctive use in temporal setting and spatial setting). The model error therefore goes horribly astray. A mathematical model has been attempted by Vedula et, al., (2005) at the irrigation canal command of Vani Vilas Sagar Dam at Chitradurga district of Karnataka. The model assumes surface water availability and groundwater recharge as deterministic ignoring the uncertainty (stochastic); the groundwater response that is spatially varied is assumed as lumped; the type of aquifer is assumed as isotropic, homogenous, 2-dimensional and unconfined throughout. The mathematical model therefore is too reductionist of the complex setting involved in surface water and groundwater interaction. The ideal scenario that the model envisages does not exist at all in the reality of Vani Vilas Sagar command area. And, Vedula et al., does not provide any error of the model vis-à-vis crop yields achieved after implementation of conjunctive use in the command area. No wonder farmers in Vani Vilas Sagar command area are still deprived of water, there is scarcity of water in the reservoir and skepticism has been expressed over success of even micro-irrigation (Water Resources Department, 2013).

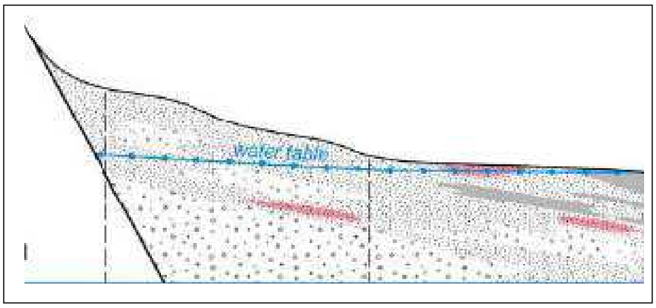
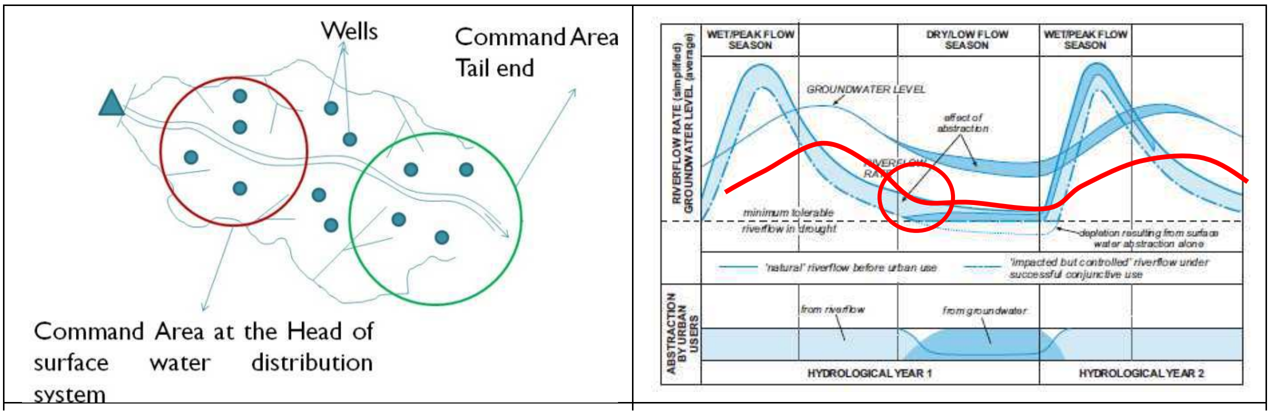


Fig.4. Indicative section showing the diverse geological setting, terrain, topography and water table. Source: Evans, W.R. and Evans, R. (2011)



Spatial Setting (Source: Author) **Temporal Setting** (source: Foster, E., Steenbergen, F., Zuleta, J. and Garduno, H. (2010))

Fig.5. Ideal case of conjunctive use benefits in spatial and temporal setting (The conjunctive use strategy may not work in regions where groundwater variation follows the red line instead of blue line in temporal setting)

INDIA'S PRACTITIONER-ACADEMICS DICHOTOMY

The absence of any validation and error of mathematical models in comparison with the results on ground is always discouraging for its adoption by practitioners. Apart from the severe reductionist view of mathematical model, the complete lack of co-ordination of academicians and the practitioners (i.e. authorities engaged in irrigation activity largely in state governments, authorities involved in data collection, planners and policy makers) has disconnected research with reality. Practitioners are deprived of familiarization of the research or getting accustomed to deficiencies of mathematical models, learn the same, run the model and validate the same by themselves. Despite the inevitability of the model error, had the practitioners been able to run mathematical models, validate or compare the model results with actual output in the command area, probably that would have enhanced the confidence of practitioners and furthered the science of conjunctive use. This experience hasn't exactly happened in India in the past 40 years. There have been few or no examples of credible co-ordination/ collaboration between the academics, practitioners and private owners of command area for realistic implementation of conjunctive use. Whereas governments largely maintain the database, say for example, discharge data of river Indus or river Ganga, the academics are literally at their mercy to acquire the database (Harsha, 2013). Hence, in addition to the unrealistic mathematical models confined to computers, the disconnect between ongoing research between academics, practitioners and private owners has been an hurdle for the poor progress of this management strategy of conjunctive use as on date.

TECHNOLOGICAL BACKWARDNESS

Conjunctive use strategy is a technology intensive strategy. The strategy is different from mere augmentation of groundwater through unlined canals where unknown quantity of water seeps without any control thus raising the groundwater table. Uncontrolled seepage of surface water through unlined canals may again cause water-logging, or may be inadequate to achieve the requisite crop yields or it may suit only particular cropping pattern. Therefore, surface water and groundwater variations have to be measured, monitored and database created before envisioning any unification of these two water resources. Stream flows, reservoir inflows, reservoir operations, reservoir outflows, surface water quantity in main canal, the quantity of water diverted in different distributaries, minors, field channels, water reaching the command have to be measured and compiled periodically over different seasons. Water leakage in the canal network has to be detected as any leakage would cause water-logging in adjacent command area disrupting the entire conjunctive use strategy. The rainfall over the surface water basin, watershed and command area has to be measured; similarly, the evapotranspiration levels, quantity of infiltration, groundwater levels, water table variation have to be measured or monitored periodically to enable unification of the water resources. While India demonstrated its giant technological leap in "*Mangalyaan*" in 2014, it is yet to take a few baby steps in the creation of new indigenous technology or at least adopt existing technology for the purpose of conjunctive use of surface and groundwater.

Attempts have been made in India in the last few decades to measure the canal conveyance and delivery system for irrigation scheduling through canal automation and SCADA (Supervisory Control and Data Acquisition). Some of the projects in India that have attempted to install canal automation are Chambal, Khadakwasla, Majalgaon, RAJAD, Sardar Sarovar and Tungabhadra project (Mandavia, A. B., 2015).

Bhima Lift Irrigation Scheme, Karnataka (2015) Bennithora Field Irrigation Channels, Karnataka (2015)

Fig.6. Unaccountable surface water due to dilapidated canal infrastructure (Source: Author).

However, their results are varied, not satisfactory and does not intend to couple groundwater management. According to Mandavia (2015) in Chambal project, the discharge is unreliable in the canals despite canal automation that has left farmers guessing about the allocation and timing of water delivery. Similarly in Khadakwasla project, the success of the canal automation has been dependent on the reliability of supplies at the head reach of distributaries. But in many of the projects that this author visited in Karnataka/Goa like Bhima Lift Irrigation Scheme, Karanja, Tillari, Bennithora, Amarja, Lower Mullmari Project, even manual water measuring devices at the end of distributaries were absent which mean conjunctive use with groundwater is impossible in these projects. Then, for conjunctive use of surface and groundwater, canal automation is insufficient or mere half-solution, as the strategy demands command area automation or watershed automation too. But Indian command areas or watersheds are hardly equipped with devices like rainfall measuring devices, rainfall shutoff sensors, soil moisture sensors, groundwater level sensors and telemetry for the purpose of integration with canal automation of surface water to enable co-ordination in spatial and temporal scales.

INSTITUTIONAL ISSUES

Conjunctive use envisages use of water resources as a unified resource instead of managing separately as surface and groundwater. Prior to 1970s water resources in India were largely managed disjunctively as surface water and groundwater. While '*Temples of Modern India*' i.e. large dams, reflected utilization of surface water through construction of dams and canal network, later the tube well revolution in India demonstrated groundwater usage as an alternative source of irrigation, scoring over surface water as the largest source of irrigation in India. The first documentation of treating water as unified resource, as a management strategy was adopted by Irrigation Commission in 1972 and later in National Commission of Agriculture in 1976 (Central Water Commission, 1995). Subsequently, National Water Policies in 1987, 2002 too adopted the strategy of conjunctive use of surface and groundwater whereas NWP-2012 has been implicit in using water resource as single resource. But none of these policies have any legal support, whereas the constitutional position of India remains outdated particularly with reference to envisaging water resources as unified resource. The *entry-17* of List II of Constitution of India was framed during late 1940s reflects the scenario of an era when water resources remained disjunctive i.e. surface water and groundwater. Therefore the constitutional position of 21st century remain outdated as far as conjunctive use strategy of water concerned, thereby relegating the idea of "unified resource" to a mere fanciful idea in the policy papers.

Despite conjunctive use being adopted as a water management strategy 40 years back and finding itself a predominant place in policies, the strategy itself has been overlooked - as seen in the case of Government of India's "*Command Area Development & Water Management Programme* (CAD & WM)" - a grave error and lapse on the part of the government itself. It is astonishing that the CAD & WM program began in 1974 (Ministry of Water Resources, 2013), around the same time when conjunctive use of surface and groundwater was recognized in India as an adaptive management strategy, however little interest was shown for conjunctive use in the CAD & WM program. While, the CAD & WM continued to receive funding for an envisioned command area of 15 million hectare since 1974, there was little incentive for extending the same beyond surface water and integrating with groundwater in India's command area. Therefore, there has been only sporadic case studies with respect to adoption of conjunctive use of surface and groundwater in India's command areas; and the one that is often widely cited as a success story in India is the case study of

Madhya Ganga Canal, Uttar Pradesh (Sakthivadivel and Chawla, 2002) where it is reported that groundwater levels increased due to the introduction of canal network carrying surface water. But then, a large number of failure stories are never cited at all.

BASELINE STATUS OF SURFACE AND GROUND WATER COMPONENTS

The next institutional impediment is the poorly managed individual components of surface water and groundwater phases in India. The baseline status of individual components of surface water management and groundwater management in India is appalling. Indian Institute of Management Lucknow (2014) has reported that India's surface water distribution network largely suffers from loss of water during distribution, incorrect recording of irrigated area, insufficient water distribution and unequal water distribution between farmers at different points. Central Water Commission in its own findings has reported poor maintenance of canal and distribution network, siltation of canals, damage to lining, leakages of gates, non-availability of control structures and lack of awareness of farmers. As part of inspection of irrigation projects, this author himself had visited a number of irrigation projects in Karnataka like Bhima, Karanja, Amarja, Bennithora etc., and found that at number of locations along the canal network, there were cracks in canal lining, silting in the canal, extensive growth of weeds, lack of measuring devices for discharge at the outlets and passive water user associations (Figs.6 and 8). Therefore, when the surface water flowing in various canal networks in India itself is largely mismanaged and unaccounted, then the prospects of integrating surface water with groundwater gets diminished. The scenario of groundwater phase is no different from that of surface water. About 25% of the groundwater blocks in India are already semi-critical to over-exploited as on 2009 according to Central Ground Water Board Annual Report (2013). The semi-critical to overexploited blocks are largely concentrated across the arid and semi-arid regions of India where surface water availability is also less (Fig.7). These semi-critical and overexploited blocks are asymmetrically placed with respect to the surface water basins, sub-basins, watersheds and even command areas thus posing a challenge for any conjunctive use plan with surface water in spatial and temporal setting.

DISMAL PARTICIPATORY IRRIGATION MANAGEMENT IN I NDIA

The creation of surface water infrastructure in India is largely a public investment and controlled by government agencies, whereas the command area is owned by private

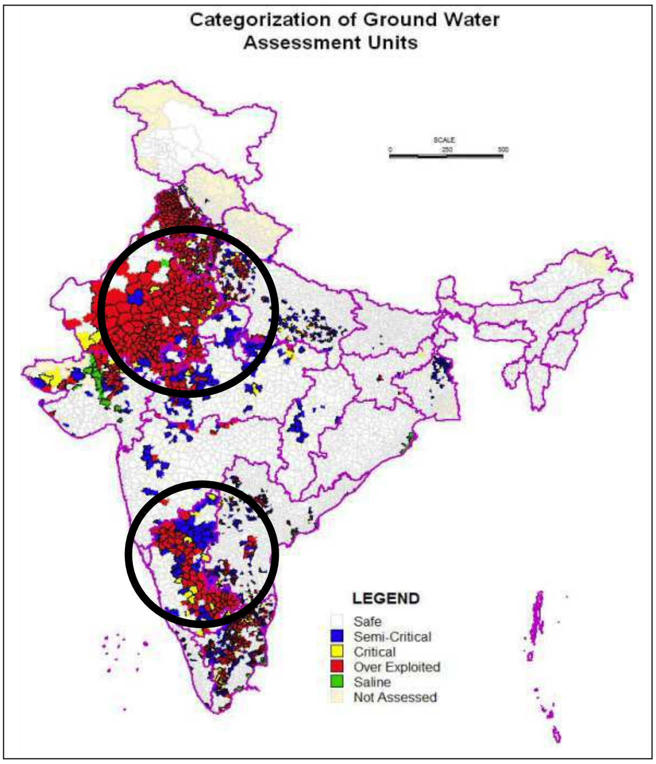


Fig.7. India's semi-critical to overexploited blocks of groundwater.

owners i.e farmers with whom the responsibility of drilling of wells/tube wells and drawal of water from under the ground is vested with under Indian Easements Act 1882. Therefore, even if the surface water phase is best accounted or managed by a government agency, it is unrealistic to expect that it could be unified successfully with the ground water phase because of the control of command area by private owners whose participation in the management of water as a unified resource is crucial for its success. On the contrary, the participation of water users in the command area in India has been dismal as on date, though the degree of participation varies from region to region across India (Sinha, P., 2014). The implementation of conjunctive use is thus largely dependent on the level of participatory irrigation management; which again does not seem to be that encouraging in India. Also, the command area owned by farmers is caught in the energy-irrigation nexus, where the control of the output of groundwater is largely dependent on the fickle power supply from electricity agencies. Then, farmers have little awareness of the hydro-geologic setting of the region, water table status, water table variation, timing of surface water availability, the quantum of availability etc., within their land holding and beyond unless it is shared by the concerned agencies involved in conjunctive use. The economic condition of Indian farmers is varied thereby causing hurdles to invest by themselves in drilling and operation of the recharge wells only for the purpose of creation of buffer inside aquifers during

Amarja Project, Karnataka (2014) Karanja Project, Karnataka (2014)

Fig.8. Dilapidated surface water infrastructure (Source: By Author)

periods of higher surface water flows in the command area. Therefore, unless the institutional setting of India is supportive of the management strategy of conjunctive use, there is little doubt that the *status quo* of conjunctive use that is largely confined to policy papers now, would be continued in future.

DISJUNCTIVE SURFACE AND GROUNDWATER ORGANIZATIONS

The organizational setting of water resources in India is defective. Conjunctive use or viewing surface and groundwater as unified resource should be preceded by a similar unification of the disciplines and exchange of expertise between organizations controlling surface water and ground water. Instead the institutional setting in India seems to have been skewed more towards surface water than groundwater with little interaction and exchange of expertise between organization controlling surface water and groundwater. The policy making in India's Ministry of Water Resources, River Development & Ganga Rejuvenation is dominated by the experts of surface water that is reflected vastly in successive water policies wherein the groundwater is relegated to a few statements of intent like optimum utilization of groundwater etc. Then, India's water management discourse propagates river basin management as a scientific method of water management, but in the last 4 decades, there has been not a single river basin organization of multi-disciplinary character constituted. Whatever basin organizations are existing in India as on date are largely dominated by engineers, in particular, the surface water specialists with a narrow objective of surface water management alone (Example: Brahmaputra Board).

CONCLUSIONS

Given the extensive gaps in knowledge & research; institutional impediments, technological backwardness, it can be rightly concluded that India's conjunctive use of surface and groundwater is imply a non-starter in its vast river basins, watersheds and command areas. And, the strategy is largely confined to policy papers or reduced to mere rhetoric given the fact that India's deployment of state-of-the-art technology in watershed and command areas is poor, the relation between government agencies, water users and academics remain disjunctive while the constitutional position remain outdated.

With climate change phenomenon looming large over India, mere advocacy of this strategy or confining the strategy largely in policy papers or be content with a few case studies for the purpose of citation in future will not suffice, as large parts of India is already facing severe water scarcity. Hence, Indian is left with no option but to reset and revisit the strategy of conjunctive use in 21st century or even 22nd century based on following recommendations.

Recommendations

1 Political boundaries have been the bane of India's water management. Therefore, hydrological districts with watershed or sub-basin ridges as boundaries should be created with autonomous multi-disciplinary organizations managing these districts. Without multi-disciplinary organizations within these hydrological districts any idea of "unification" of water resources or holistic approach of water management as described in policy papers will continue to remain *fantasy*.

2 India's current weakness for any holistic management of water resources is the lack of integration of information system within watersheds or project command areas. Information system within hydrological districts with respect to varying hydrology, hydro-geology, geology, agronomy, soil types, and socio-economic conditions have

to be collated and maintained by multi-disciplinary organizations managing hydrological districts. The “gap” in the knowledge should reduce as much as possible.

3 The individual components of surface water infrastructure and groundwater management which are in poor shape at present have to be improved as a pre-condition for even conceptualizing conjunctive use of surface and groundwater. Unless, surface water is accounted and groundwater is better managed, there is no question of any unification possible between surface and groundwater phases and eventually derives any benefits out of it in spatial and temporal scale.

4 India is technology poor when it comes to deployment of indigenous or existing technology in the water resources sector. Canal automation and SCADA is still limping in canal commands even after visualization of conjunctive use 4 decades ago. Canal automation and SCADA should unify with similar automation in command areas, watersheds and river basins to measure and monitor groundwater, precipitation and evapo-transpiration.

5 Incentives for water users or rent per land holding in acres should be provided to encourage participation of poor farmers, to facilitate monitoring of groundwater levels in their land by government agencies, to overcome the hurdles existing for academics-practitioner-private user, deployment of technology in the land and capacity building of farmers for the purpose of realization of conjunctive use of surface and groundwater.

6 Latest research conducted by academics should be accessible for planners and practitioners. Similarly, database required for research should be available to research scholars without hindrance. Such a co-ordination can only happen in autonomous multi-disciplinary organizations within hydrological districts. Mathematical models of conjunctive use strategies developed by academics should be tested by practitioners in the field under various objectives so that the science of conjunctive use strategy is improvised.

7 No recommendation is successful without adequate funds..! India’s water management has also been a victim of a mere allocation of 0.8% of GDP to overall Research and Development (R&D) according to World Bank data for 2012. Putting water infrastructure in place but without adequate maintenance funds is like *purchasing a car but ignoring the regular service*. Therefore, the share of allocation for water sector should increase within R&D allocation and also R&D as a percentage of GDP should make a realistic leap to meet realistic target of new strategies.

8 India’s surface water projects are largely dominated by engineers who are trained to “*build*” but not “*manage*”, this deficiency has to be erased through urgent capacity building. The domination of engineers should be replaced by a team of multi-disciplinary experts of earth sciences and engineering in proposed multi-disciplinary organizations. Existing water resources organizations and ministries should be more balanced with both surface and groundwater specialists. Dominance of either bureaucracy or surface water specialists or groundwater specialists in water resources organizations is a disincentive towards any holistic water resources management..

9 One of the primary causes of poor progress of conjunctive use of surface and groundwater is the weak constitutional position reflecting the realities of late 1940s. While the policy papers are legally not binding, the constitutional position like *entry 17 & entry 56* too does not contain the 21^{st} century paradigms of water management like conjunctive use of surface and groundwater, Integrated Water Resources Management, River Basin Management etc. Last but not least, the colonial law Indian Easement Act – 1882 needs to be replaced by a law reflecting 21^{st} century realities, so that arbitrary exploitation of groundwater is denied to private owners of land.

Therefore, if India has to come out of its business-as-usual scenario in implementation of conjunctive use of surface and groundwater, realize its unification and improve its water management amidst growing scarcity, then it urgently needs to completely overhaul the strategy in its entirety with respect to implementation of the conjunctive use of surface water and ground water. With that intent, it is recommended that India urgently needs to revisit its conjunctive use strategy against the backdrop of a number of impediments and hurdles before its water mismanagement spiral out of control in 21^{st} century.

References

Central Ground Water Board (2012) Aquifer Systems of India. Ministry of Water Resources, River Development, Ganga Rejuvenation. Faridabad: Government of India.

Central Ground Water Board (2013) Groundwater Year Book-India. Ministry of Water Resources, River Development, Ganga Rejuvenation. Faridabad: Government of India.

Central Water Commission (1995) Guidelines for planning conjunctive use of surface and ground waters in Irrigation Projects. Indian National Committee on Irrigation and Drainage. New Delhi: Government of India.

Evans, W.R., Evans, R. and Holland, G.F. (2011) Conjunctive use and management of groundwater and surface water within existing irrigation commands: the need for a new focus on an old paradigm. Groundwater Governance: A Global Framework for Country Action. Thematic Paper. 2. Sinclair Knight Merz. Australia.

Foster, E., Steenbergen, F., Zuleta, J. and Garduno, H. (2010) Conjunctive Use of Groundwater and Surface Water from spontaneous coping strategy to adaptive resource management GW-MATE. World Bank: Strategic Overview Series.2.

Harsha, J. (2013) Needed dismantling of data 'license-permit raj' to boost India's research and innovation in India. Curr. Sci., v.105(9), pp.1207-1208.

Heath, C.R. (1984) Ground-Water Regions of the United States. USGS science for a changing world. Geological Survey Water – Supply Paper 2242.Washington, D.C: U.S.Government.

Indian Agricultural Statistical Research Institute (2015) ICAR. Government of India: New Delhi. Retrieved at http://iasri.res.in/agridata//12data%5Cchapter1%5Cdb2012tb1_2.pdf.

India-WRIS. (2012) River Basin Atlas of India. RRSC-West. NRSC. ISRO. Jodhpur: India.

Indian Institute of Management Lucknow. (2014) Study on Issues Related to Gap between Irrigation Potential Created and Utilized. Final Report. Retrieved from http://wrmin.nic.in/writereaddata/ProgrammesandSchemes/IIM_Lucknow99657331.pdf

Lundin, L.C., Bergstrom, S., Eriksson, E. and Seibert, J. (2000) Hydrological Models and Modelling. Chapter-11. Sustainable Water Management in the Baltic Sea Basin. The Waterscape. Uppsala University. Retrieved from http://www.balticuniv.uu.se/index.php/teaching-materials/818-swm-1-the-waterscape

Mandavia, A.B. (2015) Modernization of irrigation system operational management by way of canal automation in India. Food and Agricultural Organization. Retrieved at http://www.fao.org/docrep/003/x6626e/x6626e06.htm.

Ministry of Water Resources. (2013) Guidelines on Command Area Development & Water Management Programme. New Delhi: Government of India. Retrieved at http://wrmin.nic.in/forms/list.aspx?lid=410.

Sakthivadivel, R. and Chawla, A.S. (2002) Innovations in Conjunctive Water Management: Artificial Recharge in Madhya Ganga Canal Project. IWMI-TATA Water Policy Program. International Water Management Institute.

Sinha, P. (2014) Status of Participatory Irrigation Management (PIM) in India. National Convention of Presidents of Water User Associations. MoWR RD & GR. Retrieved at http://wrmin.nic.in/writereaddata/PIM02.pdf.

Vedula.S., Mujumdar, P.P. and Chandra Sekhar, G. (2005) Conjunctive use modeling for multicrop irrigation. Agricultural Water Management. Elsevier: 73. 193-221.

Water Resources Department (2013) Annual Report:2012-13. Bangalore: Government of Karnataka. Retrieved at http://waterresources.kar.nic.in/docs/Annual%20report%202012-13%20-%20Eng.%209.7.2013.pdf.