Hydrological Investigation Challenges of Transboundary Watershed Aquifer in the Himalayan Region

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ABSTRACT

Trans-boundary may be defined by political, natural, geographical features or other anthropological activities or geo- referencing system. Further it may be defined by underneath geological strata and aquifers. A river has its own natural basin boundary consisting of multi sub-basins falling in or covering various local, regional, zonal, national or even international boundaries. Consequently, the river flows across all the concerned boundaries and the flow transportation can be realized as trans-boundary or inter sub-basin water transfer. The integrated study and investigation turn to be more challenging and complex. However, scientific and methodical planning makes this study of invisible processes more interesting, useful and applicable for sustainable and optimal development. Indian National Water Policy, 2002 has schedules for the planning and management of water resources and its optimal, economical and equitable use through hydrological unit planning such as drainage basin as a whole or for a sub-basin, which takes into account of surface and ground waters for sustainable use incorporating quantity and quality aspects as well as environmental considerations.

Snow and glaciers in the Himalayan regions took care of the flows in the river during the spring and summer by keeping it perennial. The lean flow of winter is necessarily from confined and unconfined aquifer. It may be possible that the ground flow of a watershed may appear in the stream of adjacent mountainous watershed and vice-versa. Few major Himalayan river basins of India have their upper catchment in the territory of other nations, having no snow and meteorological stations or data sharing platforms leading to problems of hydrological analysis. The paper discusses the trans-boundary nature and problems with prospects of hydrological analysis in typical Himalayan streams as well as the invisible aquifer contribution essential for flow in the stream at the time when each and every drop of water become precious due to climate change scenario. This flow is life sustaining flow as pious. There is a need of mutual cooperation and resolution of issues legally related to share and management of watershed, water resources and observations for the analysis and equitable developmental utilization.

Key words: Snow & Glacier, Lean flow, Groundwater, Inter basin aquifer, Base flow

1. INTRODUCTION

Effective utilization and efficient management of water resources are essential for the socio-economic development. Water resources management is neither complex nor simple due to its, generalized, diverse and stochastic hydro-geopolitical nature. The National water policy has provided sufficient guidelines to develop the resources. Several plan proposals and detailed project reports are still at the level of evaluation in paucity of fund, regional issues and environmental clearance. Direction of the court upon public litigation appeal is expected even to maintain the roadside drainage. Further, administrative trans-boundary development involves treaties and non-technical part. Whereas, inter or trans-boundary watershed/aquifer water transfer/flow is technical-cum-political to legal. Intra basin/aquifer water utilization and management deal with in-depth science, society, technology, initiative and equity issues. Privatization of natural resources may weaken the federal structure and demoralize the voluntary workers by keeping the stakeholders and poor population away. An individual dweller/user or agency has to know their watershed and aquifer basins potential and status to have fare share and participation. Non-commercial water right subsists with individual locals and the state. Only surplus surface or ground water or in conjunction temporally or spatially can be allocated or considered as commercial commodity. To develop the management practice of transboundary aquifer since 2000, the International Association of Hydrologist (IAH) and UNESCO's International Hydrological Programme (IHP) have established Internationally Shared (transboundary) Aquifer Resource Management (ISARM) and it is clear that case studies under different conditions will be needed (Puri, 2003; Puri & Aureli, 2005) as transboundary ground water overexploited by one state may be detrimental to another (Jarvis *et al.*, 2005) and pollutants might also migrate to contaminate a neighbour aquifer.

1.1. Transboundary basin a hydrological and national challenge

There is a need to define the boundary. The surface boundary may be defined by geo-referencing system based upon political, natural basin and geographical setup or any other anthropological activities. Further, it may be defined by underneath geological strata and synchronized with physical and political boundaries. A river has its own natural basin boundary consisting of multi sub-basins containing local, district, regional, state, zonal, national and international boundaries. Consequently, the river crosses all the concerned boundaries and the water transportation can be realized as trans-boundary if it crosses more states/nations; as inter basin if it crosses adjacent basins or as intra basin if it passes through sub-basins within a basin area. It is difficult to define or design the water availability for practical purposes on annual average basis or to designate an area of scarcity, if the availability of water is less than 1000 cum per capita per year. Himalayan rivers valley in India gets 80 to 90% precipitation in four monsoon months (June to September) only. The ground water recharge and aquifer potential developed during monsoon and latter through seepage of tank, reservoir and perennial streams augmented through snow and glacier melts help in meeting the demand from ground water resources. Ground water flowing downward through confined or unconfined aquifer or trapped in perched aquifer may not necessarily follow the basin or district boundary. It has its own geological strata and boundary to be relieved under pressure or to get released under gravity, if not trapped in between. Under world-wide hydrological mapping and assessment programme and hydrological map information system (WHY MAP/MIS), international hydrological map of Europe (IHME) having 90 transboundary aquifers were fitted (Struckmeier, 2007) with geo-referenced UN ECE data for conceptualizing hydrological model. Indeed, to assign the statistics for designating an area of scarcity a detailed and sound technical criteria are desired with reference to availability and risk involved with space and time. As an example, north-eastern states including Bengal, Bihar, UP and the state of Assam are not only prone to receive water logging and frequent floods but are also prone to recurrent drought and famine. To have non-monsoon period water supply and all weather fresh water, created surface storage or aquifer (unconfined and confined) waters are the last option.

Kathpalia & Kapoor (2006) discussed with an objective to transfer quality water for the people below poverty line. In order to keep the cost minimum, ground reserves are needed to be maintained. The springs and glaciers of the Himalaya keep the flow perennial in the rivers during the spring and summer are now drying up and receding due to climate change scenario. Thus, new storage scheme would have to take care of the flow deficiency. Analysis is difficult due to lack of observational network, especially in transboundary catchments. Having upper catchment of the river Sutlej in Tibet, remotely sensed imagery/data is the only source of any information at present. National Water Policy (MoWR, 2002) laid down specific policy prescription for an optimal development of the country water resources. Studies and investigations are supposed to be under taken through integrated basin-wise (Intra & Inter Sub-basin) development at war footing. The extracts of the water policy relevant to the topic are given below:

- PS3.3. Water resources development and management will have to be planned for a hydrological unit such as basin as a whole or a sub-basin, taking into account of surface and ground waters for sustainable use incorporating quantity and quality aspects as well as environmental considerations.
- PS3.5. Water should be made available to water short areas by transfer from other areas including transfers from one river basin to another adjacent basin.
- PS19.1 Priority should be given to reduce the vulnerability of drought prone areas through water conservation, water harvesting, water recharge, evaporation loss prevention and transfer of surface water required from surplus areas, wherever it is feasible and appropriate.
- PS27. Planning and management of water and its optimal, economical and equitable use are a matter of the outmost urgency. Success of the water policy will depend entirely on amicable national consensus and commitment to its underlying principles and objectives.

1.2. Transboundary and multilayer aquifers assessment

The runoff generated from hilly region is not always Hortonian (Beven & Kirkby, 1979). Proper infiltration factors on slopes (steep/gentle/flat) and depressions are needed to be assessed. The main limitation is the estimation of water holding capacity of aquifer and also estimation of withdrawal of ground water (GW) from different abstraction structures. Hilly areas may contain isolated pockets of storage. Sedimentary areas may have single aquifer or multi layered multi-quality aquifer systems. Hard rock watershed may have single water table aquifer. The inter-aquifer flow can be defined either by the subsurface vertical flow between two aquifers in a multi-aquifer system or by horizontal flow across the boundary between adjoining aquifers or in combination of both (Keshari, 2010). In most cases boundary of the study area does not coincide with the natural boundary. It may also be possible that assessment unit would have hydraulic connectivity with the surrounding aquifer systems. In these cases the horizontal subsurface flow moving out of the aquifer under assessment unit can not be neglected. Similarly in a multi-aquifer system there may be percolation or leakage to the confined or deeper aquifer from the unconfined aquifer. In general the inter-aquifer flow may not exist on a watershed scale unless there is some influence of geological features or hydro-fracturing. Delineation of vertical and lateral boundary of aquifer with type determination of recharge area and estimation or assessment of ground water is important.

Current national water policy recommends safe yield policy supported by GW recharge using water budget, soil moisture balance and mathematical model techniques. Planned depletion policy become important in declining conditions of GW reserve year after year due to over exploitation or less recharge and overall lowered water table. A case study of the Kosi project held at Patna in 1979 recommended that utilisation of GW in conjunction with surface water must be promoted to improve the irrigation performance of the project. In fact, it is the adhoc emergence of extensive GW use through cheap, improved bamboo tube wells in the Kosi command over the years that has covered up irrigated agriculture and saved the project from what would have been a catastrophic failure on the irrigation front (Prasad *et al.*, 1994). Models employed for estimation are sophisticated to simple depending upon the nature of data required. Methods generally used in India for the groundwater recharge estimation are Empirical methods (relate area specific GW recharge to Rainfall based on Chaturvedi, Amritsar and CGWB formula), Groundwater level fluctuations, Temperature based model (which utilizes sub-surface temperature profile), Hydrologic budgeting approach and Numerical method. Type of analysis includes pre and post monsoon water table or saturated thickness of the aquifer and water table fluctuation. Through repeated radiocarbon measurements, it is possible to understand the aquifer conditions by observing the changes in the radiocarbon ages. It provides valuable information in determining the recharge area, groundwater flow direction and ground water flow rates. When different aquifers exist in one area it is essential to determine aquifer to aquifer interaction in term of recharge and exploitation. In an unconfined aquifer, river and aquifer interaction are sensitive and need to be handled with care. The altitude of water table in the vicinity of stream should be lower than the altitude of stream water surface. Transboundary basins (watershed/aquifer) need to be managed and designed conjunctively as both ground and surface waters are complementary and supplementary to each other (Verdhen *et al.*, 1996). References on conjunctive management are indeed incomplete (Wilson *et al.*, 2006), as work under IDRC, USAID, IMMI/IWMI and Government of India conducted in early 1990's is commendable bench mark. MODFLOW is considered good but data requirement is massive.

1.3. Transboundary aquifer co-operation

To have sustainable and productive co-operation among co-basin states and countries for development of water resources a dynamic co-ordination, transparency and sound understanding are the pre requisite criteria. The natural and cultural bonding in terms of geographical affinity and historical events have positive role to strengthen the process of co-operation. Evolution and implementation of international law on scientific basis includes the principle of riparian rights, theories of prior appropriation, ideas of equitable distribution and issues of climate and environmental.

Typology conceptualisation (Eckstein and Eckstein, 2005) reflects the geo-political and hydro-geological features of transbounary aquifers. Transboundary relation of Nepal and India on north Bihar river basins is like model C, model D or E. Over the year Nepal feels deprived from its fair and rightful benefits while India considers the claim as unreasonable demands, intransigent attitude and deliberate stalling. Both are suffering under the syndrome of danger from big and benefit of small storage dams.

Presentation (Yamada, 2009) on international law of transboundary aquifers revolves around the preamble and general obligatory directions necessary and sufficient through Article 7: Aquifer states shall co-operate on the basis of sovereign equity, territorial integrity, sustainable development, mutual benefit and good faith in order to attain equitable and reasonable utilization and appropriate protection of their transboundary aquifers or aquifer systems. Consequently, aquifer states shall observe, analyze, monitor, manage, share, safeguard, operate and co-operate establishing independent and joint mechanism of cooperation.

2. RESULTS AND DISCUSSIONS

Transboundary watersheds and aquifers are needed to be monitored and managed simultaneously. However, likewise National Highways and Power Grid connectivity, inter basin water transfer grid or river interlinking is not a valid proposition as water does not flow against gravity at its own. Conflict-ridden project consists of 14 links (namely 1.Manas-Sankosh-Tista-Ganga, 2.Kosi-Ghagra, 3.Gandak-Ganga, 4.Ghagra-Yamuna, 5.Sarda-Yamuna, 6.Yamuna-Rajasthan, 7.Rajasthan-Sabarmati, 8.Chunar-Sone, 9.Sone dam-Southern tributaries of the Ganga, 10.Ganga-Damodar-Subaranarekha, 11.Subaranarekha-Mahanadi, 12.Kosi-Mechi, 13.Farkkha-Sunderbanas, and 14th an alternate to 1.) as Himalayan rivers component (Fig. 1) and 16 links as peninsular rivers component (Gopalakrishnan, 2009). Most of the concerned states are not convinced with the linking project.

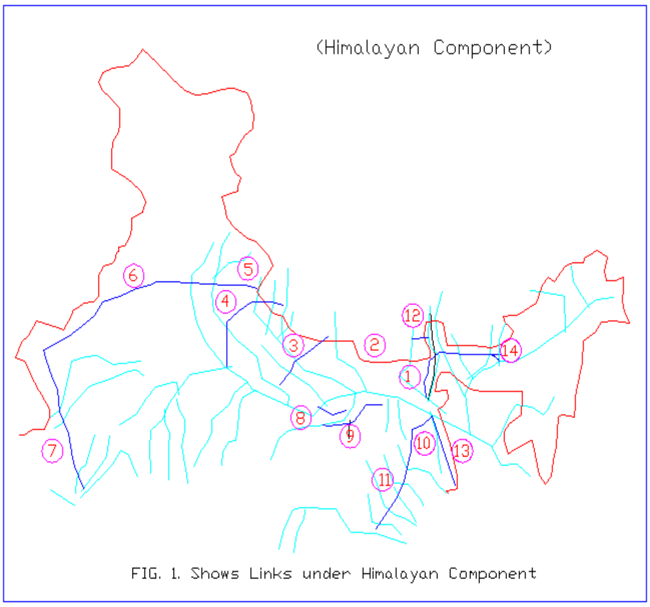

Fig. 1 The Himalayan Rivers link components.

Central government constituted a parliamentary standing committee understanding the deficiency in the approach, planning and design of the project and invited consent, comment and suggestion from all the concerned states, experts and stake holders in order to achieve socio-economic-effective and feasible solution. Inter-basin transfer entirely depends on the consensus amongst all the co-basin states and nations of the donor basin, in-route basin and recipient basin (Iyer, 2009). Hydrologic unit based intra-basin integrated water planning and management are the backbone of sustainable development.

Out of 12 identified transboundary aquifers in Asia (Ramasamy *et al.*, 2009), 7 to 9/10 are originating from the Himalaya, i.e. the Indus, the Ganga and the Brahamputra basins of India are transboundary in nature with Afghanistan, Pakistan, Nepal, Bhutan, Tibet (China), Bangladesh and Myanmar. Percentage of basin area and non-monsoon eight month's annual flow (Table 1) can be considered as a combined component of rain, drain, ground and glacier spawn flow, envisaged as 'Base Verdhen Flow (BVF)', which is 14 to 17%, distributed over non-monsoon period under the constraints of storage, recession and depletion. During monsoon it may increase twice to thrice, i.e. 30 to 40%. Summing up annually, it goes up to 55%. The Kamala and the Bagmati, being snow and glacier free basins, show only 7 to 8%. Above and all the fissure flow, Darcy's sub-surface flow and GW extraction have an influence on post to pre-monsoon ground water fluctuation. During subzero winter temperatures, the stream gets only ground and spring flow. A typical peak winter (Jan-Feb) weekly average discharge and monthly flow (Fig. 2) in Kothi/Solang nala of the Beas sub-basin with catchments area of 70/130 sq km are 1.3/3.5 cumecs and 0.06 mcm per sq km. Further, unit area monthly snow and ice melt flow with rise in temperature increases six times by the month of May. However, climate change impact shows rise in temperature and reduction in snowfall.

Table 1 Himalayan transboundary basins in India having internationally shared watershed and aquifer.

Name of the river basin/Sub-basin	Basin area (Sq. km)	%age area in India	Co-basin countries	Total length (km)	%age length in India	Annual flow (mcm)	%age monsoon flow	%age Non-monsoon flow
Indus	1165000	28	Afghanistan, Tibet and Pakistan	2880	37	209700		
Sutlei	75369	70	Tibet, Pakistan	1536				
Ghaghra	140606	50	Nepal and Tibet	1080	55	98438	84	16
Gandak	45942	24	-do-	630.4	40	53201	75	17
Burhi Gandak	12500	81	Nepal	550	99	7059	85	15
Bagmati	13690	44	-do-	593	67	5671	92	8
Kamla	5563	65	-do-	328	78	2156	93	7
Kosi	74500	15	Nepal and Tibet	468	53	78282	86	14
Mahananda	25043	70	-do-	376	85	13566	85.5	14.5
Ganga	1860000	46.3	Nepal and B. Desh	2525		525020	90	10
Brahmputra	580000	34	China, Bhutan, B. Desh	2900	32	607087	83	17

Indian Water Resources Society (Rangachari, 2005)) reviewed and presented critique on the effectiveness of Bhakhra dam and agreement to utilize it fully. The Indus Waters Treaty (1960) signed by India and Pakistan enabled the full development of the Sutlej waters by India. Article II says that all the waters of the eastern rivers (defined as the rivers Sutlej, Beas and Ravi) shall be available for the unrestricted use by India, except as otherwise expressly provided. Hence, India was not obliged to share any water of the Sutlej beyond the border, which facilitated Beas-Sutlej link effectiveness. Whatever needs are at lower are to be taken care of by themselves. Water surplus states at present are not irrigated significantly and almost all cities and towns in these states are having their own plan to develop hydrology and water resources. Also, the riparian states through which these rivers pass have their own plans to use the surplus water to develop their backward regions. Present performance of existing irrigation projects are not good enough due to various technical and non-technical reasons.

Generally, minor canals and water courses are incomplete resulting in ground water dependency for protective irrigation.

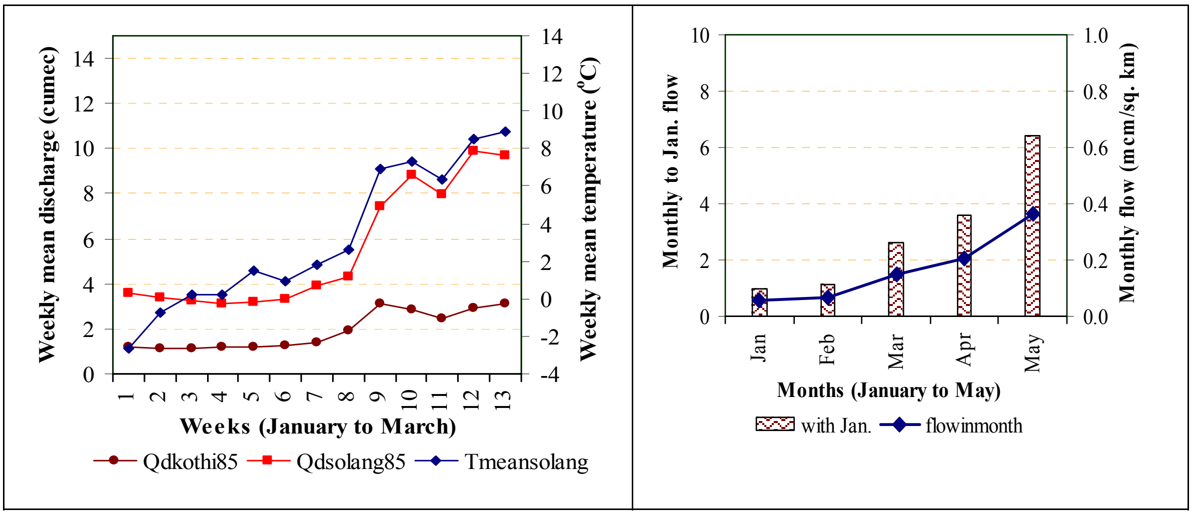

Fig. 2 at left shows weekly winter discharge(m^3s^{-1}) of kothi and Solang nalas of the Beas sub-basin with mean temperature at Solang, whereas at right it shows monthly flow (mcm km^{-2}) and relative to Jan.

Damaging or worst situation to an aquifer may arise by handing over the drinking ground water supply and irrigation operation under the hand of commercial group as concessionaire. To meet the cost, farmers are bound to be in debt and the government has to promise subsidiary or concession. We may need to pay the high economic and environmental costs of river inter-linking, as incomplete or inoperative (due to lack of water) Sutlej-Yamuna link canal was a cause of flood a. The international dimensions of sharing are equally critical. The holiest national river Ganga is at the centre of trans-boundary water management involving Nepal and Bangladesh. Legal issues may arise, as it pertains to local and natural issues. Recently, the country is witnessing differences among the states of Karnataka and Tamil Nadu over the sharing of water from rivers Kaveri and Krishna, even though both the states are riparian.

3. CONCLUSIONS

Certainly, scientific study, investigation and engineering design cum execution are required based upon technically sound and socially effective criteria keeping all the options open. The immediate need is to examine the basin watershed and water aquifer properties and interaction in conjunction with other adjacent basin and administrative boundaries. Studies on natural pattern and behaviour of surface and ground waters by having process based water balance within simulated boundary conditions are required. Assessment, utilization and management of surface water comparatively to ground water are apparent. However, mapping the aquifers boundary layers below surface and administrative boundary layers along with source of recharge, flow direction and discharge laterally as well as vertically are of prime importance. The aquifer planning and management strategies resolving the transboudary issues pertains to observation, analysis and utilization responsibility, share and legal agreement. Physically distributed model like SHE and MODFLOW are technically sound to have online decision under GIS environment provided process input variables and parameters are available. First step towards that is to have a complete framework for surface water optimal utilization resolving equity, sustainability and transboundary water share issues. The intra basin development of water resources is much more scientific and technical which should be taken up first (Verdhen, 2009) before the water utilization and distribution through links as a complex inter-basin transfer of unmanageable flood or scarce precious lean flow (base Verdhen flow) or ground water. Intra and inter aquifers basins together with transboundary aquifer management will backup as secondary but essential source to resolve the issues and to achieve a happy, healthy and amicable solution, minimizing legal conflicts.

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