

CHAPTER 1

Introduction

M. Dinesh Kumar^a, V. Ratna Reddy^b, A.J. James^c

^aInstitute for Resource Analysis and Policy, Hyderabad, Telangana, India

^bLivelihoods and Natural Resource Management Institute, Hyderabad, Telangana, India

^cEnvironmental & Natural Resource Economist, New Delhi, India

1.1 Introduction

As population grows, as food production increases, economic activities pick up and as societies become more affluent, demand for water burgeons. In very many places, demand has far outstripped supply—particularly so in seasons when supply is severely limited or in years of drought, or at times when demand is particularly high for large water-consuming sectors such as irrigation. Climate extremes compound the problem. As decisions on water allocation are going to be difficult under such situations (Molle and Vallée, 2009), water managers have to look for new management options, in a way that doesn't require compromises on social and economic development, ecological sustainability, and hydrological integrity of water systems.

Water management options for a locality or a region depend on three important factors, viz., hydrology, socioeconomic systems, and ecosystem (Mitchell, 1990; Voropaev and Zaitseva, 1996). Hydrological and topographical characteristics of the region determine the amount of water that is naturally available from the catchments or drainage basins that can be harnessed for meeting various water needs. Socioeconomic characteristics determine the demand for water for various human needs—domestic and productive. The ecological characteristics determine the amount of water required for maintaining the health of the ecosystem in the form of soil moisture storage, river flows and flow regimes, chemical and biological quality of river water, water storage and quality of water in wetlands, depth to groundwater table, groundwater flows, and wetland-groundwater interactions.

If the first two key parameters, i.e., availability of water resources within a hydrological unit and the demand for water various sectors of use within

that unit are known, the next important question, which confronts a water manager, is to know how much of the available water resources are already tapped through various interventions; how much of it is depleted, through various processes, and how much of the developed water resources in the basin remain un-utilized (or available for use); what are the unmet water demands, and how much of the water in the basin is untapped and joining the natural sink.

The interventions to tap the water to increase its utilization will comprise in situ water harvesting through field bunds and farm bunds, watershed treatment activities, small water harvesting systems, tanks, and large reservoirs and diversion systems. On the other hand, the processes, which cause depletion of water, are beneficial consumptive use (evapotranspiration, consumptive use by humans and animals), nonbeneficial consumptive use (evaporation from water bodies, barren soil, cropped land not covered by canopy, etc.), and nonbeneficial nonconsumptive use (return flows into saline formations, nonrecoverable deep percolation of water) and beneficial nonconsumptive use (recharge to groundwater and return flows from irrigated fields to streams) (Molden *et al.*, 2003; Perry, 2007).

Addressing these questions is crucial from the point of view of identifying the nature of future water management interventions (i.e., whether supply augmentation or end use conservation or both) possible in the basin, and analyzing the extent to which these interventions could help achieve a balance between water availability and water demand. Failure to do so would lead to suboptimal water management for the basin. If large amount of water in the basin is already developed through reservoirs, but capacity of the infrastructure created to transfer the water to the points of demand is insufficient, some parts of the basin might experience water shortages. A solution to this problem lies in expanding the water conveyance systems, rather than building new water storage facilities such as reservoirs.

1.2 Land use-hydrology interactions for catchment assessment and planning

As regards the first decision variable, i.e., hydrology of the catchment and basins, the land use and land cover have a significant bearing. Since both keep changing with time, in order to determine the amount of water that is naturally available from them, information on the following is crucial: (1) how the type of catchment land use influences the impact of increased vegetation cover on stream flows (including water quality), in different agro

ecologies (Idol, 2003); (2) how the nature of vegetation (whether shallow rooted grasses and shrubs or deep rooted trees) determines the impact of increased vegetation cover on the consumptive use of water from the soil profile and groundwater system of the catchment, and how these impacts can change across agroecologies (Oliveira et al., 2005; Idol, 2003); (3) the hydraulic interdependence between groundwater and surface water in a catchment and therefore the impact of change in groundwater withdrawal on stream flows downstream (Winter et al., 1998). Often, the sources of sedimentation can often be quite localized such as newly constructed roads, stream-bank cultivation, and movement of livestock around, to or from a water point.

Hence, there is a need for developing clear understanding of the catchment characteristics, current land use in the catchment, and the hydrological regime before interventions are planned for changing their hydrological regime. Of particular interest are the current stream flow regimes; the extent of base flow contribution to the stream flows; geological and geohydrological environment of the catchment, particularly the depth to water table and the thickness of the vadoze zone; area under natural forests, their condition, type of forests; area under cultivation, type of crops, their seasonality, and their geographical spread within the catchment; groundwater use in the catchment, its seasonality and location of wells; and amount of committed flows from the catchment for downstream uses.

A large number of catchment experiments conducted all over the world clearly demonstrated that deforestation of catchment implies an increase of water yield from it and, conversely, the establishment of a forest cover implies a decrease of water yield (Sahin and Hall, 1996). The application of this knowledge to designing sustainable water management practices, although necessary in water-stressed regions, has been largely delayed because of difficulties inherent to the change of any scientific paradigm, the limited experience on the hydrological consequences of land cover changes in large territories, and the disconnection between policy and science (Falkenmark, 2004; Calder, 2002).

1.3 Scale effects in water management

Scale effects in hydrology are well documented (Merz et al., 2009; Wood et al., 1988). The nature of hydrological interactions (surface water-groundwater interactions, infiltration-groundwater recharge) and hydrological relationships (rainfall-runoff relationships, rainfall-base flow, etc.)

within a catchment depends on the spatial unit of analysis. The rainfall-runoff relationship for a small (mini micro) catchment of say, 10 ha area, can be remarkably different from that of a hilly/mountainous catchment of say, 10 km² area, to which it becomes a part. The runoff coefficient for the latter will be much higher than that of the former, as in the latter case, it will also include base flows along with surface runoff unlike the former.

Similarly, the rainfall-runoff relationship for a small hilly/mountainous watershed, say of area, 10 km² can be different from a large watershed or river basin to which it becomes a part, even if there is no spatial difference in the rainfall. This can be because of many factors. First, the land use conditions could change drastically as one moves from the hilly/mountainous upper catchments to the plains. With the intensity of crop cultivation increasing toward the lower plains, a greater proportion of the runoff generated would be captured in situ, reducing the runoff coefficient. Another factor, which plays a crucial role in changing hydrological interactions spatially, is the topography. As lower catchments of basins will be relatively flat, the chances of natural outflow of groundwater to surface streams would reduce, with the result that the runoff coefficient will be less. The third factor is the climate. Generally, upper catchments of river basins are cold and humid, as compared to the lower catchments, which are hot and arid. This difference in temperature and relative humidity can significantly influence the rate of moisture depletion from the top soil through barren soil evaporation and ET losses from grasses and trees, and therefore infiltration and runoff generation.

As regards return flows, the effect of runoff from irrigated field and wastewater outflows from industrial areas and urban centers on the surface flows appears only in the lower parts of the basin and not in the watersheds and catchments from which the water is diverted for irrigation and other uses, essentially because of the terrain and drainage characteristics. But, return flows from irrigated fields to shallow groundwater from irrigated fields might appear in the lower part of the same agricultural watershed, though unlikely in the well of the farmer who irrigates.

As regards water demands, as one moves from upper catchment to lower catchments, not only does the water demand for competitive uses increase in aggregate terms, the nature of demand also varies. Generally, the upper catchments of river basins have low proportion of its land under crop cultivation due to the presence of forests, grass land, etc. This is compounded by cold and humid climate, which reduces the water demand for agriculture

significantly. Generally, upper catchments of river basins are less populated, and less urbanized as compared to lower basin areas. This means, the concentrated water demands for domestic and municipal uses are generally low. Further, barring the exception of mining, very few industries are located in upper catchments of basins that are generally hilly and mountainous, not ideal for manufacturing, which require heavy and quick transportation.

The situation changes dramatically as one moves to the lower basin areas, which are hot and arid and closer to the coastal plains. These areas are more heavily populated, with less area under forest cover and other natural vegetation, characterized by commercial farming, and display high degree of urbanization and industrialization. All these factors put together not only mean new areas of water demand (such as industrial, urban, and even thermal power and navigation), but also increased water demand in individual use sectors such as farming. Also, there can be significant differences in the pattern of water demand. The farms that are located close to urban areas would require water round the year to produce fruits, vegetables, and flowers, as compared to those which are in the remote villages located in the upper watersheds.

Water requirements for maintaining ecosystem health, over and above the water which is directly consumed by the ecosystem in the form of evaporation, will be higher in lower basin areas, as compared to upper basin areas that are generally characterized by thick natural vegetation and pristine stream flows. The relatively higher temperature and aridity and the presence of large build-up areas, and the significant alterations in flow regime of the rivers during their course, owing to the upstream diversions, increase the ecological water demand, comprising water for growing trees in urban areas, watering lawns and gardens and parks, maintaining the environmental flows in rivers and assimilating pollution. Added to this is the pollution of river water, which takes place during its course from the upper catchment to the lower plains, due to disposal of trade effluents, urban wastewater, and return flows from irrigation.

1.4 Traditional approach to water management decision making in river valley projects

The foregoing analysis suggests that our ability to arrive at effective water management decisions for any region would depend heavily on: (1) quantitatively analyzing the land use-hydrological interactions and surface water-groundwater interactions within a catchment or river basin, which is critical

for assessing the amount of water supplies available for meeting various needs, and its quality; and (2) choosing the right spatial scale for analysis of water availability and water demands, so as to capture the different types of interactions that are at play, affecting the effective water availability and water demands in different sectors and their spatial patterns. While the first is crucial for planning water resources management interventions, the second becomes important for all three activities, viz., water resources management, water resources development, and water allocation.

Historically, large water resource development projects, especially river valley projects in most developing countries, particularly in South Asia and Africa, were based on assessment of catchment water flows (yields), and normative demand for water in some other part of the basin, which experienced scarcity of water for meeting various needs, especially irrigation and domestic water supplies. This approach of considering a selected catchment as a source of water supply to meet the demand in another site lacked integrated basin-wide assessment of effective water availability and demands at any given point of time (Molle et al., 2010). The major technical challenge was in estimating the dependable (runoff) yield of the designated catchment, and sediment load, in lieu of the fact that for many rivers, stream-gauging data were not available for long time periods. This was by and large a piecemeal approach. The earlier criticism of the approach was on the inability of hydrologists to make realistic estimates of soil erosion from catchments, as in many situations the observed siltation rate was much higher than the values considered for reservoir design. Application of this catchment-based approach often led to creating conditions of water abundance in certain parts of the basin, and water scarcity, especially environmental water stress in certain other parts.

The catchment-based approach of basin development to meet water demands is segmented and often led to overappropriation of runoff in river basins. It also left no scope for exploring the range of alternatives in water management, particularly conjunctive management and water demand management. For instance, it is possible that within a basin, a large amount of water from a catchment is available as return flows to the shallow aquifers underlying the irrigation command area. Because of this, there could be build-up of water table over a period of time. Hence, it is important that well irrigation be encouraged in the region to prevent water logging, which would enable holding back a lot of water from the reservoirs and allocating it for meeting water requirements in other parts of the basin. Such an approach can, to a great extent, escape the need for investing in new water development projects. But, for embarking on it, we need to know what the

annual groundwater storage change in the basin is. Similarly, if we know how much of the developed water is lost in nonbeneficial consumptive uses in the basin in sectors such as irrigation (in the form of evaporation from the harvested fields), measures can be adopted to prevent them. But to gain insights into the changing dynamics of water availability and use across the basin, we need to do basin-wide resource evaluation and planning.

1.5 From large river valley projects to development and management of micro watersheds

In India and in many other developing countries of South Asia and Africa, watershed management is not merely a soil and water conservation work meant for protecting the catchments of large reservoirs, but a major developmental activity for the rural areas, aimed at improving rural livelihoods through agricultural productivity enhancement. India, which is a pioneer in the field, has a long history of watershed development and management programs, with schemes from three Ministries, viz., Ministry of Agriculture, Ministry of Rural Development, and Ministry of Environment and Forests of the Govt. of India operational since mid-1990s.

By as far back as 2005, India had invested around 3.1 billion dollars for watershed development programs, covering a total area of around 45.0 m. ha of rain-fed areas in the country (Parthasarathy Committee Report, 2006). But, these interventions had very limited success in terms of productivity impacts on agriculture. The problems identified vis-à-vis impacts include limited and temporary productivity gains; poor revegetation of common land; and fast dissipation of groundwater recharge benefits (Joshi et al., 2005; Kerr et al., 2004). There have been problems with watershed planning approach due to flawed criteria used for selection of catchments for watershed treatment (Kumar et al., 2017); and limited scientific inputs in planning catchment management interventions (James et al., 2015). This is compounded by poor implementation of work (Reddy, 2006). These are policy issues, which need urgent attention for investments in watershed development programs to yield sufficient returns.

1.6 Current approach to integrated watershed management

The current approach of integrated watershed management has a clear emphasis on improving the conditions of large majority of the people living in rain-fed areas who are dependent on land and water for their livelihoods.

The thrust is on implementing activities, which can be done by the local communities with minimum outside support on technical matters (Farrington et al., 1999; Kerr, 2002; Hope, 2007). The thrust is also on taking up physical activities, which will have immediate as well as medium and long-term impacts. In that respect, local employment generation is also given sufficient emphasis. These are the strengths of the program.

Improvement in water use efficiency and equity in catchment-wide distribution of water are two key long-term objectives of watershed management programs. In that respect, lack of sufficient information for catchment assessment and watershed planning is a major issue with the current approach. While the management is based on microwatersheds as the unit for planning and operation of watershed interventions, the hydrological data of the catchment are not available at that scale, particularly the annual stream flows, groundwater recharge and flow gradients, base flows and withdrawal, and the uncommitted flow from the catchment (James et al., 2015). Many small basins in India are ungauged, and in many large basins, gauging is done for large tributaries. In none of the small river basins, and smaller tributaries of large basins, flow measurements are done by the agencies concerned (Kumar et al., 2006).

Further, information is not readily available to the PIAs on the characteristics of the catchment. Generally, a decision to implement watershed management programs in a village is taken on the basis of limited data available from Survey of India toposheets. The information on cropping pattern and crop types, available at the village level, is never available on spatial reference and hence cannot be transposed on watershed boundaries. In the absence of such data, watershed planning as attempted by some NGOs purely on PRA approaches has not yielded required results. While good hydrologists with orientation for information technology might be able to generate data on land use/land cover and runoff for microcatchments, the issue is such trained professionals are very few in India. Even when they are available, the financial capability of PIAs to hire such skilled professionals is open to question (James et al., 2015).

The current approach to planning WSM interventions is based on a strong notion that if comprehensive treatment is done, it would improve the water availability and or soil moisture regime within the microwatershed along with reducing soil erosion, and that it can even increase the effective water availability for the downstream communities during the lean season. The underlying assumption is that a large amount of runoff during the monsoon goes uncaptured and eventually gets wasted as it joins the natural sink of

sea, ocean, or swamps. Since the geographical unit of planning is too small, the PIAs are not concerned with what happens to the runoff, which used to flow out of the microcatchment, and the social, economic, and environmental values it generated (Calder et al., 2008; Kumar et al., 2006, 2008). The approach tends to ignore the fact that there could be different values and interests, which communities within a large catchment attach to water but are all legitimate and need to be recognized (Jakeman and Letcher, 2003; Mitchell and Hollick, 1993).

The net result is that often there is overdoing of interventions within a watershed in terms of creating tree cover, building vegetative barriers to reduce the speed of runoff water, reduce soil erosion, and improve soil moisture conservation. Small water bodies are built to harvest monsoon runoff, without due consideration to storage efficiency. New crops are planned to utilize the augmented groundwater in the catchment, without due consideration to the water use efficiency ($\$/\text{m}^3$) of the newly introduced crops. In “closed” catchments, this reduces the overall economic viability of the interventions, and efficiency of water use at the catchment scale as downstream uses is adversely affected (Kumar and van Dam, 2013). While such practices are subject to criticism (Batchelor et al., 2002; Kumar et al., 2008), the current approach does not encourage proper assessment of changes in water use efficiency at the catchment scale.

Under the current approach, certain treatment activities within the catchment are promoted on the premise that they do not take much water from the hydrological system, and therefore, economic losses due to their adverse impacts are not taken cognizance of in the planning decisions (Batchelor et al., 2003). Such decisions tend to lose sight of the fact that within the same catchment, often there are downstream water systems like tanks and ponds, which depend on this runoff for uses such as domestic needs, supplementary irrigation of crops, and fisheries.

When the basins become closed, hydraulic interconnectedness of surface water and groundwater becomes marked (Molle et al., 2010). But, lack of recognition of the hydraulic interconnectedness of aquifers and streams in the catchment is another issue in watershed development programs. Groundwater recharge is promoted within the catchment under watershed management as a “positive value” with the assumption that it would increase the base flows, thereby making streams flowing in the lower catchment perennial through base flows during lean season. But, hardly any attention is paid to the fact that this activity is followed by indiscriminate drilling of wells by farmers in the area, which ultimately leads to increased draft,

threatening even the existing natural discharge of groundwater into streams and wetlands. But, there is virtually no control on groundwater abstraction planned under watershed management (James et al., 2015).

Lack of integration between micro and macro and local and regional watersheds is another major issue. The current approach to watershed management is also highly decentralized (Calder et al., 2008; Syme et al., 2012). Hence, the decision of an individual PIA about the degree and extent of treatment in a particular watershed is driven by “what is optimal for that watershed,” with the result that often the aggregate of the activities planned for all watersheds together is suboptimal for the large encompassing catchment.

Finally, the current approach is devoid of any measures for regulating the use of land and water resources within the catchment, particularly agricultural intensification and groundwater abstraction. Participation of the catchment communities is sought only for planning and implementing various physical interventions. The community organizations formed in the watersheds have no role, whatsoever, either in regulating land and water use or in allocating water among various uses.

1.7 Water accounting for exploring water management options

In developing countries, decisions to execute large-scale water resource development projects and projects to improve water use efficiency in agriculture are not based on realistic assessment of the opportunities that really exist at the basin-scale to augment the supplies and reduce water demands. In the case of water resource development, the individual catchment is the unit of analysis, rather than the basin. In many situations, the new developments such as construction of water harvesting structures and local groundwater mining, are undertaken in “closed basins,” inducing hydrological externalities for the existing ones located downstream (source: based on Kumar et al., 2008; Molle et al., 2010). To prevent such negative outcomes, in the case of water supply augmentation projects, the basin manager should be concerned with the amount of uncommitted flows in the basin and what fraction of it can be harnessed.

As regards projects to improve water use efficiency in agriculture (such as introduction of micro irrigation technologies), they are normally based on the concept of field level water saving, which considers the possible

reduction in the amount of water applied against the crop water requirement, through the use of those technologies, which help minimize the deep percolation of water applied in the fields (Perry, 2007). But in many situations, the deep percolation “losses” resulting from inefficient irrigation practice is available for reuse by well irrigators in the same catchment, and microirrigation technologies only reduce this beneficial, nonconsumptive use. Hence, using such concepts can lead to overestimation of water-saving benefits (Allen et al., 1998; Perry, 2007). Hence, to determine the “real water saving,” the basin manager should be concerned with reduction in the amount of “water depleted” (Kumar and van Dam, 2013).

Water accounting studies, based on an analysis of data related to various components of the hydrological system (e.g., rainfall, stream flows, ground-water recharge, evaporation from water bodies and swamps, storage changes in reservoirs and land use and water use) at appropriate hydrological units (e.g., basin, catchment or watershed-level) can give a range of useful information about potential water-related extreme events, how much of water in the basin is used in different sectors (drinking and domestic uses, municipal use, industrial use, livestock use, power generation, crop consumptive uses, and various in-stream uses), how much of the basin’s water goes uncaptured into natural sinks (e.g., saline formations, seas) and how much is lost through nonbeneficial uses (Molden et al., 2003). It could also help the water administration active in the basin to plan actions to mitigate the adverse impacts of hydrological stresses on the socioeconomic system, such as drinking water shortages for human and livestock populations in affected areas, crop losses, and reduced income and livelihoods of affected populations, and damage to water infrastructure.

From the point of view of water governance and management, water accounting studies is useful in the sense that it can provide insights into: (1) optimum level of investments in water augmenting measures (e.g., watershed development programs, water harvesting systems, large reservoirs and diversion systems); (2) possible measures to (a) increase effective water availability (e.g., reducing evaporation from surface reservoirs and preventing soil moisture depletion from rain-fed crop land), (b) reduce water demand (e.g., reducing nonbeneficial (both consumptive and nonconsumptive) use of water in irrigated fields) and (c) convert other nonbeneficial uses of water in the basin (e.g., evaporation from barren land) into productive uses; and, (3) better intersectoral water allocation, including from lower-value to higher-value uses.

1.8 Inadequate use of scientific knowledge in catchment management decisions

Most of the microwatershed management programs in India are grounded on inadequate knowledge of the relationship between changes in land use/land cover and catchment yield and soil erosion. They mainly concern differential impacts of various specific interventions on soil conservation and sediment control; differential impacts of grass buffer strips and retention ponds on sediment control; impacts of replacing crop land by tree cover, clearance of native trees from forested catchments, and replacing forest cover by crops on seasonal and annual yield of catchments; differential impact of grass and tree cover on erosion control and runoff reduction; and impact of use of efficient irrigation technologies on overall water use efficiency in the agricultural catchments and effective water availability for other uses in the catchment. Often, there are wide misconceptions, concerning their functions in different agro ecologies ([James et al., 2015](#)).

The knowledge on the dynamics of interaction between a particular land use and land cover and water use in the upper parts of the catchment, and the hydrology and ecosystems of a given catchment can provide pointers on the way in which the former needs to be modified to produce social, economic and environmental outcomes that are widely acceptable among the catchment communities. But, which land use or land cover-based intervention needs to be taken up and to what extent they need to be changed (scale analysis) to achieve the optimum outcomes in terms of water yield, sediment load reduction, meeting water quality standards and reduction in soil loss, etc. can only be assessed using complex mathematical models, which simulate the hydrological and biophysical processes. Such models basically integrate those used for prediction of soil erosion from the catchment; crop growth; rainfall-runoff; sediment transport; and groundwater flow. At the same time, the models used for predicting hydrological changes in catchments due to land use changes should be such that they can simulate the effects of irrigation efficiency improvement measures on degree of return flows from irrigated fields to groundwater and streams, and changes in groundwater withdrawals on magnitude of base flows from aquifers to streams.

In nutshell, scientific understanding of the relationship between catchment land use and land cover changes and hydrological and ecological processes is essential for identifying watershed management interventions that can achieve desired water management outcomes in social, economic, and environmental terms—improved livelihoods, drinking water security,

enhanced agricultural production, and protection of hydrological integrity of watersheds. The key research questions are: (i) what is the level of treatment on land—tree cover, vegetative barriers, crop rotations, soil and moisture conservation measures—, water harvesting and irrigation efficiency improvement measures that can ensure optimum runoff yield and sediment load reduction, while ensuring water for various competitive and in-stream uses within the catchment; and, (ii) what is the economic viability of these interventions?

1.9 Scope of the book

The book discusses the theoretical and operational aspects of integrated catchment management and integrated water management in river basins, through reviews of international best practices and case studies. While there are a set of concepts and principles in IWRM that are widely known, there is lack of clarity on what practices (both physical and institutional) work for achieving its goals in different situations.

The book synthesizes key scientific facts that are crucial for catchment assessment and planning, and river basin water accounting, from extensive reviews of international literature on catchment hydrology, forest hydrology, and other hydrological processes such as groundwater-surface water interactions. It discusses not only the science of catchment assessment and planning, but also the catchment planning process. It documents several of the positive international experiences with integrated catchment management and integrated basin management and distills the key learning from them, which are important from the point of view of shaping water management paradigms for the developing world. It presents detailed case studies from India and other parts of South Asia with integrated watershed/catchment management and illustrate how lack of scientific planning lead to a myriad of unintended consequences. It then presents pilot studies on integrated catchment management planning, and basin water accounting to show what kind of interventions would be required in the basins of those specific regions for enhancing that the social, economic, and environmental outcomes of ICM and integrated water resources management.

1.10 Contents of the book

Following this introduction, the second chapter of the book by Kumar, Batchelor and James presents a strategic review of international perspectives

and global experience with catchment management and basin management. It deals with various conceptual and theoretical aspects of catchment management, defining the principles and practice underlying it, as available from scientific research in the different parts of the world. It then discusses the technical aspects of catchment assessment and planning, including the use of hydrological simulation models. It then goes on to discuss the experience of some of the developed countries in operationalizing catchment management and river basin management concepts, on the institutional front.

The third chapter of the book by VR Reddy discusses the experience of Afghanistan in watershed management. It provides a basic policy and implementation framework for watershed management in that country based on a critical review of experiences in South Asian countries. The chapter reviews the evolution of watershed management in south Asian countries; examines the implementation and institutional modalities adopted in these countries; assesses the impacts (environmental and socioeconomic) of watershed interventions in varying agroclimatic conditions of these countries; identifies the implementation bottlenecks for sustainable watershed management; and draws lessons for Afghanistan.

The fourth chapter by Talati and Kumar illustrates the scale effects in watershed development using a case study from one of the sub-basins of Narmada river basin in central India, which experienced intensive and decentralized watershed development and water harvesting activities during the late 1990s to the early 2000s. The case study used analysis of field data on the geohydrological parameters at the level of microwatersheds, and the impact was analyzed by comparing sample (with watershed treatment) and control watersheds (with no watershed treatment). For the sub-basin level impacts of intensive watershed development activities in the upper catchment, secondary (hydrological) data were analyzed on a time scale in relation to rainfall. The impact analysis involved estimation of recharge coefficients for the treated and untreated watersheds, and analysis of rainfall-runoff relationship for the tributary draining the sub-basin, which experienced intensive watershed development.

The fifth chapter by James et al. discusses the findings of a catchment assessment and planning study carried out in South Gujarat, western India, using a simulation model based on SWAT (Soil and Water Assessment Tool). The model was calibrated using historical data of stream flow discharge from the catchment and validated to test its robustness. The validated model simulated the impact of various physical processes such as changes in rainfall magnitude and pattern, and land use/land cover on the catchment

runoff; and changes in rainfall and groundwater withdrawal on surface water-groundwater interactions, including the occurrence of lean season flows in a catchment. The chapter presents the findings of the study vis-à-vis how scope for and catchment wide impacts of various water management interventions would change from a wet year to a dry year.

The sixth chapter by Kumar & others discusses an innovative methodology developed by the authors for basin water accounting for a river basin with different competing uses of water, but with limited measurement of inflows and outflows. It also presents the results of a water accounting exercise carried out for a small, water-surplus river basin. The analytical tool for water accounting, which considered the factors such as inflows (renewable water resources), outflows (consumptive use in various sectors of use), and annual change in storage, was applied to Warna sub-basin of Krishna river basin in peninsular India. The water accounting study used data on reservoir mass balance, annual groundwater recharge and storage change, consumptive water use in agriculture and other sectors (such as domestic, livestock, and industry), and stream discharge at the last drainage point of the sub-basin to estimate the water accounts. The methodology helped quantify the total amount of renewable water resources generated in the basin, and the amount of water actually depleted for beneficial and nonbeneficial uses.

The methodology for water accounting will have to change as basin characteristics, defined by rainfall, climate, morphology, and geohydrology change. The seventh chapter presents the findings of a basin-level water accounting study done for one of the most arid and water-scarce river basins of India, i.e., Luni river basin in western Rajasthan, which suffers severely from lack of reliable data onstream flows. There is only one stream gauging station in the entire drainage area of 69,000 km², which is located near the last drainage point of the basin. Overappropriation of surface water, groundwater mining, and heavy transmission losses in the surface runoff are unique features of this basin. The aim of basin water accounting was to evolve integrated water resource Management Plan for the basin. Estimating the consumptive use of water in agriculture was one of the biggest challenges in the hyperarid river basin. The seventh chapter also discusses the viable technical options for improving water balance of the basin.

River basins are the most appropriate unit for planning most IWRM interventions, as the physical systems affecting water availability and socio-economic system affecting the demand for water can be integrated at that

scale (Jonch Clausen, 2004). However, the present situation in most countries is that these interventions have to be executed by agencies, which are not organized around river basins or their smaller hydrological units such as sub-basins and catchments. They operate at the state and district level or sometime even at the level of smaller administrative units. Therefore, interventions that are found to be effective at the basin scale for achieving IWRM goals in the Luni has to be downscaled, to arrive at the “scale” at which each intervention has to be carried out in the district. The eighth chapter discusses the analytical method and result of the process of downscaling IWRM plan for Pali, one of the districts of Luni River Basin.

The ninth chapter by Nitin Bassi and M Dinesh Kumar also uses a water accounting approach to assess the water security challenges of Kanpur Metropolitan Area (KMA), a city located in Ganga River Basin, which is under tremendous stress due to overappropriation and large-scale pollution. The chapter particularly focuses on the following: development of methodology for doing water accounting for cities; preparing water accounts for KMA; and identifying the present and future water-related risks resulting from the inadequacy of the quantity and quality of water supply for domestic and industrial consumers, and ineffectiveness of the regulatory framework related to water quantity and quality management in the KMA.

The scale effects in watershed management, particularly the downstream effects of upstream interventions due to land-water interactions, are well documented (Darghouth et al., 2008). Chapter 10 by Reddy and Syme discusses about addressing the scale issues in watershed development. One of the aims of using the IWRM approach is to internalize such effects.

That said, many of the concepts and principles underlying integrated water resources management are largely recognized and appreciated by basin managers. The challenge is in operationalizing the concept of IWRM through appropriate coordinating institutions at the river basin level. As discussed by Biswas (2008, p. 12), “... operationally it has not been possible to identify a water management process at a macro- or meso-scale which can be planned and implemented in such a way that it becomes inherently integrated, however this may be defined, right from its initial planning stage and then to implementation and operational phases.” There is also a lot of confusion about what an IWRM plan should contain in terms of interventions in different situations. As noted by Jonch Clausen (2004), there is no one-size-fits-all solution in IWRM. The solutions would change with the typology of areas, defined by the hydrological and socioeconomic reality, and the political and institutional setting.

In the eleventh chapter, the authors make an earnest beginning in this direction. The chapter suggests the following:

- (i) A framework for identifying the most vital interventions, which need to be carried out in a river basin for achieving IWRM goals, for different typologies;
- (ii) The tools for planning the interventions at the basin scale;
- (iii) The key technical and institutional interventions necessary for executing the physical interventions; and,
- (iv) The institutional mechanisms and processes that have to be put in place to monitor the effectiveness of IWRM interventions.

The chapter would also illustrate how the potential outcomes of some widely known water management interventions on supply and demand side could change at the basin level, as the basin characteristics change.

The concluding chapter summarizes the key findings and inferences from the previous chapters and discusses the areas for future research. It will also discuss some of the policy interventions that are required at the national and provincial level for promoting integrated catchment management and integrated basin management.

References

- Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, Italy. 1999.
- Batchelor, C., Singh, A., Rao, M.S.R.M., Butterworth, J., 2002. Mitigating the potential unintended impacts of water harvesting. In: Paper Presented at the IWRA International Regional Symposium 'Water for Human Survival', 26–29 November, 2002, Hotel Taj Palace, New Delhi.
- Batchelor, C., Rama Mohan Rao, M.S., Manohar Rao, S., 2003. Watershed development: a solution to water shortages in semi-arid India or part of the problem? *Land Use Water Resour. Res.* 3 (2003), 1–10.
- Biswas, A.K., 2008. Integrated water resources management: is it working? *Int. J. Water Resour. Dev.* 24, 5–22. <https://doi.org/10.1080/07900620701871718>.
- Calder, I.R., 2002. Forest valuation and water; the need to reconcile public and science perceptions. In: Verweij, P.A. (Ed.), *Understanding and Capturing the Multiple Values of Tropical Forests*, Tropenbos Proceedings. Tropenbos International, Wageningen, pp. 49–62.
- Calder, I., Gosain, A.K., Rama Mohan Rao, M.S., Batchelor, C., Garratt, J., Bishop, E., 2008. Watershed development in India. 2. New approaches for managing externalities and meeting sustainability requirements. *Environ. Dev. Sustain.* 227–240. <https://doi.org/10.1007/s10668-006-9073-0>.
- Darghouth, S., Ward, C., Gambarelli, G., Styger, E., Roux, J., 2008. *Watershed Management Approaches, Policies and Operations: Lessons for Scaling Up*. Water Sector Board Discussion Paper Series, Paper No. 11, The World Bank, Washington, DC.

- Falkenmark, M., 2004. Towards integrated catchment management: opening the paradigm locks between hydrology, ecology and policy-making. *Int. J. Water Resour. Dev.* 20 (3), 275–281.
- Farrington, J., Turton, C., James, A.J., 1999. *Participatory Watershed Development: Challenges for the Twenty-First Century*. Oxford University Press, New Delhi, India.
- Hope, R.A., 2007. Evaluating social impacts of watershed development in India. *World Dev.* 35 (8), 1436–1499.
- Idol, T., 2003. *Hydrologic Effects of Changes in Forest Structure and Species Composition*. Department of Natural Resources and Environment Management, University of Hawaii-Manoa.
- Jakeman, A.J., Letcher, R.A., 2003. Integrated assessment and modelling: features, principles and examples for catchment management. *Environ. Model. Software* 18 (2003), 491–501.
- James, A.J., Kumar, M.D., Batchelor, J., Batchelor, C., Bassi, N., Choudhary, J., Gandhi, D., Syme, G., Mile, G., Kumar, P., 2015. *Catchment Assessment and Planning for Watershed Management*. vol. 1. World Bank Group. Main Report.
- Jönch Clausen, T., 2004. *Integrated Water Resources Management (IWRM) and Water Efficiency Plans by 2005*. Global Water Partnership, Stockholm, Sweden.
- Joshi, P.K., Jha, A.K., Wani, S.P., Joshi, L., Shiyani, R.L., 2005. Meta-analysis to assess impact of watershed program and people's participation. *Comprehensive Assessment Research Report 8*. Comprehensive Assessment Secretariat, Sri Lanka.
- Kerr, J., 2002. Watershed development, environmental services, and poverty alleviation in India. *World Dev.* 30 (8), 1387–1400.
- Kerr, J., Pangare, G., Pangare, V., 2004. *Watershed development projects in India: an evaluation*. Research Report 127. International Food Policy Research Institute, Washington, DC.
- Kumar, M.D., van Dam, J., 2013. Drivers of change in agricultural water productivity and its improvement at basin scale in developing economies. *Water Int.* 38, 312–325. <https://doi.org/10.1080/02508060.2013.793572>.
- Kumar, M.D., Ghosh, S., Patel, A., Singh, O.P., Ravindranath, R., 2006. Rainwater harvesting in India: some critical issues for basin planning and research. *Land Use Water Resour. Res.* 6 (1), 1–17.
- Kumar, M.D., Patel, A.R., Ravindranath, R., Singh, O.P., 2008. Chasing a mirage: water harvesting and artificial recharge in naturally water-scarce regions. *Econ. Pol. Wkly* 43 (35), 61–71.
- Kumar, M.D., Reddy, R., Narayanamoorthy, A., Bassi, N., James, A.J., 2017. Rainfed areas: poor definition and flawed solutions. *Int. J. Water Resour. Dev.* 34, 278–291. <https://doi.org/10.1080/07900627.2017.1278680>.
- Merz, R., Parajka, J., Blöschl, G., 2009. Scale effects in conceptual hydrological modeling. *Water Resour. Res.* 45 (9), 1–15.
- Mitchell, B., 1990. *Integrated water management*. In: Mitchell, B. (Ed.), *Integrated Water Management: International Experiences and Perspectives*. Belhaven Press, London and New York.
- Mitchell, B., Hollick, M., 1993. Integrated catchment management in western Australia: transition from concept to implementation. *Environ. Manage.* 17 (6), 735–743.
- Molden, D., Murray-Rust, H., Sakthivadivel, R., Makin, I., 2003. A water productivity framework for understanding and action. In: Kijne, J. et al., (Ed.), *Water Productivity in Agriculture: Limits and Opportunities for Improvement*, Comprehensive Assessment of Water Management in Agriculture. CABI Publishing in Association with International Water Management Institute, UK.
- Molle, F., Vallée, D., 2009. Managing competition for water and the pressure on ecosystems. In: *Water in a Changing World*, United Nations World Water Development Report 3. UNESCO Publishing, Earthscan, London, UK.

- Molle, F., Wester, P., Hirsch, P., 2010. River basin closure: processes, implications and responses. *Agric. Water Manag.* 97 (2010), 69–77.
- Oliveira, R.S., Bezerra, L., Davidson, E.A., Pinto, F., Klink, C.A., Nepstad, D.C., Moreira, A., 2005. Deep root function in soil water dynamics in cerrado savannas of central Brazil. *Funct. Ecol. Br. Ecol. Soc.* 19, 574–581.
- Parthasarathy Committee Report, 2006. From Hariyali to Neeranchal: Report of the Technical Committee on Watershed Programmes in India. Department of Land Resources, Ministry of Rural Development, Government of India, New Delhi.
- Perry, C.J., 2007. Efficient irrigation, inefficient communication, flawed recommendations. *Irrig. Drain.* 59, 367–378. <https://doi.org/10.1002/ird.323>.
- Reddy, V.R., 2006. Getting the implementation right: can the proposed watershed guidelines help? *Econ. Polit. Wkly* XLI (40), 4292–4295.
- Sahin, V., Hall, M.J., 1996. The effects of afforestation and deforestation on water yields. *J. Hydrol.* 178, 293–309.
- Syme, G., Reddy, V.R., Pavelik, P., Croke, B., Ranjan, R., 2012. Confronting scale in watershed development in India. *Hydrol. J.* 20 (5), 985–993.
- Voropaev, G.V., Zaitseva, N. (Eds.), 1996. Environmental and Socio-Economic Consequences of Water Resources Development and Management, International Hydrology Programme. UNESCO, Paris.
- Winter, T.C., Harvey, J.W., Franke, O.L., Alley, W.M., 1998. Groundwater and surface water a single resource. US Geological Survey Circular 1139, Denver, Colorado.
- Wood, E.F., Sivapalan, M., Beven, K., Band, L., 1988. Effects of spatial variability and scale with implications to hydrologic modeling. *J. Hydrol.* 102 (1–4), 29–47.