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Review papers

Watershed management in South Asia: A synoptic review

V. Ratna Reddy [a,*], Yashpal Singh Saharawat [b], Biju George [c]

[a] Livelihoods and Natural Resource Management Institute, Hyderabad, India
[b] ICARDA, Kabul, Afghanistan
[c] ICARDA, Cairo, Egypt

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ABSTRACT

Watershed management (WSM) is the most widely adopted technology in developed as well as developing countries due to its suitability across climatic conditions. Watershed technology is suitable to protect and enhance soil fertility, which is deteriorating at an alarming rate with agricultural intensification in high as well as low rainfall regions. Of late, WSM is considered as an effective poverty alleviation intervention in the rain fed regions in countries like India. This paper aims at providing a basic watershed policy and implementation framework based on a critical review of experiences of WSM initiatives across South Asia. The purpose is to provide cross learnings within South Asia and other developing countries (especially Africa) that are embarking on WSM in recent years.

Countries in the region accord differential policy priority and are at different levels of institutional arrangements for implementing WSM programmes. The implementation of watershed interventions is neither scientific nor comprehensive in all the countries limiting the effectiveness (impacts). Implementation of the programmes for enhancing the livelihoods of the communities need to strengthen both technical and institutional aspects. While countries like India and Nepal are yet to strengthen the technical aspects in terms of integrating hydrogeology and biophysical aspects into watershed design, others need to look at these aspects as they move towards strengthening the watershed institutions.

Another important challenge in all the countries is regarding the distribution of benefits. Due to the existing property rights in land and water resources coupled with the agrarian structure and uneven distribution and geometry of aquifers access to sub-surface water resources is unevenly distributed across households. Though most of the countries are moving towards incorporating livelihoods components in order to ensure benefits to all sections of the community, not much is done in terms of addressing the equity aspects of WSM.

Contents

* Corresponding author.
E-mail addresses: vratnareddy@lnrmi.ac.in (V. Ratna Reddy), Y.Saharawat@CGIAR.org (Y.S. Saharawat), biju.george41@gmail.com (B. George).

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1. Introduction

Degradation affects over 2 billion ha of land worldwide, putting at risk the livelihoods of more than 1 billion people (ESC, 2001). South Asia is among the worst affected as 43 percent of its agricultural lands are degraded in one form or other (Perera and Fernado, 2004).

Watershed management is among the most widely adopted technology due to its suitability and appropriateness across climatic conditions. Watershed technology is also suitable to protect and enhance soil fertility, which is deteriorating at an alarming rate with agricultural intensification. More importantly, it caught the policy attention in some countries due to its potential to conserve soil and water in the dry regions as well.

1.1. Watershed management

Watershed is a topographically delineated area that is drained by a stream system. It is a hydrologic unit that has been described and used both as a physical-biological unit and as a socio-economic and socio-political unit for planning and implementing resource management activities. *Watershed Management (WSM)* deals with the changes in the institutional arrangements required for collective action situations. *Integrated Watershed Management (IWSM)* is the process of formulating and implementing a course of action involving natural and human resources in a watershed, taking into account social, political, economic and institutional factors operating within the watershed and its surroundings to achieve certain socio-economic and ecological objectives (Dixon, 1992). Though the terms watershed development (WSD) and watershed management (WSM) are often treated as synonyms, WSD could be treated as purely technical while WSM is broader as it concerns with technical as well as non-technical aspects of resource management. The approach of watershed management ought to be holistic and integrated involving hydrological, biophysical and socio-economic systems. Peoples' participation, is recognised as a key factor in effective implementation of the programme. Thus, WSM is a combination of 'science and art'/'technology and philosophy' (Tiwari et al., 2008 and Reddy et al., 2010). Throughout this paper the terms WSM and IWSM are used as synonyms, which incorporate WSD as well.

The size of watersheds ranges from two hectares (White and Runge, 1995) to 30,000 ha (World Bank, 2007). Based on the scale WSM is differently known or termed across the world - in the Americas it is termed as river basin management; in Europe it is termed as catchment management. The purpose of WSM varies from region to region or country to country depending on the regional and national priorities. It ranges from soil and water conservation (most countries) to rangeland protection (Afghanistan and Pakistan) protecting rivers / reservoirs (irrigation) (Afghanistan, Pakistan, etc.) to protecting reservoirs (hydel plants) (Nepal and Bhutan) to enhancing ecosystem services (Sri Lanka) and to improving land productivity in rain fed regions (India).

1.2. Objectives

This paper aims at providing a basic watershed policy and implementation framework based on a critical review of experiences of WSM initiatives in different countries of South Asia. The purpose is to provide cross learnings within South Asia and also lesson learning for the countries (especially the Africa) that are embarking on the WSM in recent years. Specific objectives of the study include:

a) Review the evolution of watershed management in South Asian countries,
b) Examine the institutional and implementation modalities adopted in these countries,
c) Assess the impacts (environmental and socioeconomic) of watershed intervention in varying agro-climatic conditions, and
d) Understand the implementation bottlenecks for sustainable watershed management.

The paper is based on exhaustive review of studies on WSM in South Asian countries viz., Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. The material reviewed include published research papers and unpublished reports. The paper is organised in six sections. The following section discusses the evolution of WSM in South Asia. Section three looks at the typology of WSM interventions across the countries. Section four reviews the impact of WSM in terms of socioeconomic, ecological and equity; section five examines the institutional and implementation modalities in the region. The last section draws lessons for WSM interventions in wider context of developing countries and provides some policy imperatives.

2. Evolution of WSM in South Asia

WSM is as old as agriculture. Manipulating water and soils for improved agricultural practices could be termed as a primitive form of watershed interventions. The importance of watershed interventions has increased with the advent of modern irrigation infrastructure of constructing storage reservoirs, which began around 3000 BC. Thus watershed interventions may be considered as 5000 years old (FAO, 2006). Though number of countries, including Asian countries, have adopted sophisticated watershed management model of vertical integration of different ecotypes, the potential of watershed technology started to be fully exploited in Europe between the sixteenth and seventeenth centuries. This coincided with the advent of new cultivation techniques (slow drainage and abundant fertilization), emergence of new crops (maize, potato, etc), private farming and higher yields. Sustaining these yield rates to meet the needs of growing population called for major public investment in irrigation, land reclamation and watershed management works (FAO, 2006).

In the context of South Asia, watershed management evolved in two phases. The first phase was triggered by the construction of big irrigation schemes and hydro-power dams during 1950s and 1960s. Protecting these systems from sedimentation consequent to the upstream-downstream runoff linkages has become a policy priority. Speedy saturation of reservoirs, increased incidence of flash floods in downstream areas has given rise to watershed planning – integrating economic and social aspects. The decade of 1970s, however, was occupied with the promotion of green revolution technologies and food security shadowed every other aspects related to agriculture.

WSM was back into policy agenda during the early eighties with the saturation of yield gains from green revolution, which was limited to irrigated regions. As productivity growth in the green revolution areas was showing signs of slowing down or stagnation

Table 1
Evolution of Modern Watershed Management in South Asia.

Country	Period	Bio-physical conditions	Purpose	National priority	Approach	Source
Afghanistan	1980s	Low rainfall and arid; High proportion of range lands; Heavy soil and range land degradation	Range land protection and catchments	Low (mostly external)	In the initial stages	Ahmad and Wasiq (2004)
Bangladesh	1970s	High Rainfall; Flood prone	Check soil erosion and forest protection in Hilly regions	Low Only hilly regions (mostly internal).	Forest and catchment focus (Integrated Watershed Management)	Misbahuzzaman (nd.)
Bhutan	1980s	High Rain Fall; Degradation in Mountain regions and catchments	Protection of reservoirs (Hydel)	Medium only mountainous (mostly external) areas	Integrated Watershed Management	Tsering (2011)
India	1970s	Arid and semi-arid with varying rain fall; large proportion of rain fed; Heavy soil and water resource degradation	Enhancing the productivity and reducing yield vulnerability in the rain fed regions	High. Covering crop and forest lands in all terrains of rainfed regions (mostly internal)	Participatory and integrated watershed management with a focus on enhancing livelihoods in rain fed regions	Reddy et al. (2010)
Nepal	1970s	High rainfall; Degradation of mountain regions	Protection of reservoirs (Hydel) forest protection and livelihoods	Medium to High. Covering mountainous regions (Mostly external)	Participatory and Integrated watershed management	Acharya (2000)
Pakistan	1980s	Low rainfall; large proportion of range lands; degradation of range lands; mountain regions and catchments	Protection of reservoirs (irrigation); protection of rangelands	Low Covering mountainous regions (mostly external)	Participatory and integrated watershed management	Ahmad (2001)
Sri Lanka	1980s	High rainfall; degradation of soil and water resources	Protection of Reservoirs (irrigation). upstream soil protection and water quality	Low covering upstream areas of the catchment (mostly external)	Participatory watershed management at the basin scale Reservoir protection (Irrigation)	Elkaduwa and Sakthivadivel (1998)

(Pingali and Rosegrant, 2001), future growth in agricultural production and food security is likely to depend on improving the productivity in the semi-arid and arid rainfed areas. From the economic angle there was evidence indicating that marginal returns to investments would be substantially higher in these regions when compared to the irrigated regions where potentials for productivity growth had been already exploited through the green revolution technologies (Fan and Hazell, 2000). Improving the livelihoods of the communities in the rainfed regions has also become a policy priority as these regions are politically getting more active and articulated in their demands over the years.

By the late 1980s environmental concerns, including land degradation, have gained economic significance with the publication of 'Our Common Future' by the United Nations. This followed by the introduction of the concept 'sustainable development' and the 'agenda 21' have clearly identified watershed development as a policy priority for natural resource protection. In fact, the 'agenda 21' stresses that successful watershed management must be based on local stakeholders' informed participation in natural resource management, economic growth and social change (FAO, 2006).

In most of the South Asian countries, evolution of WSM started early 1980s, though countries like India and Bangladesh had introduced WSM programmes during the 1970s. The purpose of WSM varies across the countries depending on their national priorities (Table 1). Of the countries, India, Nepal and Bhutan appear to have accorded high/medium policy priority for the WSM programmes. In most of the countries, watershed interventions are limited to mountainous terrains, range lands and forest areas. In India, watershed interventions are more widespread with a focus on rainfed regions, though not limited to. The main difference between India and other countries is that the emphasis is on crop lands in India, while range lands, forest areas and waste lands (mountain slopes, etc.) are mainly targeted in other countries. This differential coverage or focus has a natural division of covering private lands (crop lands) and public or common lands. Nepal also has to deal with treating private and common lands together due to the terrain. This has given rise to the need for people's participation for better implementation of the interventions, as number of private parcels of land are to be treated under the watershed. Thus, India and Nepal are among the first to introduce participatory WSM in the region and others adopted it later.

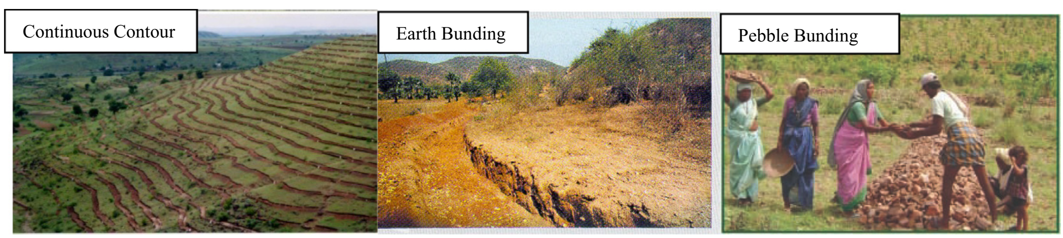
The purpose of watershed interventions determines the linkages between local communities and the interventions. That is the level of participation and involvement is dependent on the benefits directly accruing to the local communities. Direct benefits to the communities are more in the case of watershed interventions on crop lands, range lands and forest areas. Interventions on crop lands enhance land productivity and net returns from agriculture, range land improvement provides direct benefits through livestock development and communities in the forest fringe areas benefit from improved access to fodder, fuel wood, and non-timber products. On the other hand, interventions such as catchment protection, controlling soil erosion and protecting reservoirs, protection of hilly areas, etc. may provide valuable indirect benefits to the communities but the impacts are not strident enough and hence communities may not actively participate in the implementation process. In counties like Bhutan, Pakistan and Nepal, the main purpose is to protect the reservoirs from sedimentation (irrigation and hydel power projects) and hence communities are indirectly benefited. In order to achieve active involvement of people Nepal has integrated livelihoods components with watershed interventions. In some cases, the interventions take place far from the communities that benefit from these interventions. For instance, while communities in the upstream areas, where the interventions take place, may get limited benefits while downstream communities benefit more. In such cases, upstream communities have little incentive to participate and the downstream communities are not involved at all.

3. Watershed structures

The concept of WSM involves planning the development of a resource region. Resource region incorporates the private property as well as common property regimes. The focus of planning is the optimal and sustainable use of the resources viz., water and land. The approach of watershed treatment therefore ought to be holistic and involves quite a few hydrological, biophysical and socioeconomic aspects. WSM being a land based technology, it would help conserve and improve *in situ* soil moisture, check soil erosion and improve water resources, especially groundwater in the rainfed regions. It simply means improving the management of a watershed or rainfall catchments area through technical and non-technical interventions. Technical interventions are required in order to adopt the hydrological and biophysical conditions to the needs of the local communities. At the same time non-technical (socioeconomic) instruments are required to make the technical interventions more effective.

embankments constructed and graded so as to intercept rainfall and sediments and lead runoff away from the cultivated land.

These interventions (see pictures) are widely used across the countries though they are mostly implemented on the common lands and steep slopes. Besides, these approaches are commonly used in the centrally managed tea estates in Sri Lanka, where land is not in short supply and valuable topsoil can be sacrificed for the construction of bunds and terraces (Carson, 1989; Doolette and Magrath, 1990). Pebble bunding is also popular in the regions where soil quality is poor and crop lands are covered with pebbles. Clearing the crop lands of pebbles and using them to make bunds across gullies and small streams observed to serve double purpose of improving the quality of land and checking soil erosion (Reddy et al., 2010).



Large variety of interventions are being adopted in WSM, most of them fall within the field of soil and water conservation. These include both technical and non-technical measures, which in aggregate form help to limit the rate of soil loss and provide sustainable land and water use. Some measures may help prevent erosion whilst others may only control it, thus limiting the extent and timing of its impact. There are also interventions which are aimed at rehabilitating soils after erosion has negatively impacted the land, which include mechanical soil conservation practices; vegetative cover, afforestation, building contour bunds, water harvesting structures (farm ponds, check-dams), field *bunds* (raised edges), ridge bunds, etc. All these interventions are expected to facilitate higher land productivity through improved overall ecological conditions such as moisture and water availability for agriculture. It may be noted that all these interventions are not adopted in all the watersheds or regions. Nature and intensity of interventions vary according to the hydrogeology and biophysical conditions of the region or watershed. Here we discuss these interventions in brief. The technical watershed interventions can be grouped under three broad typologies i) soil conservation; ii) *in situ* moisture conservation and iii) water harvesting structures.

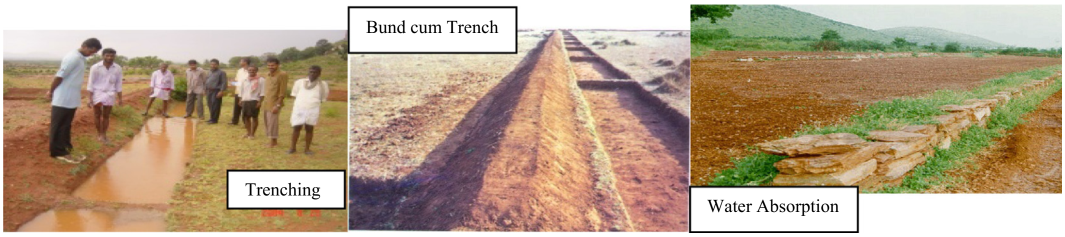
3.1. Soil conservation

Majority of soil conservation programmes instituted in the1970′s and 1980′s were dominated by engineered systems. These systems were originally developed for large land holdings in temperate regions (Doolette and Smyle, 1990). Some of them are adopted in South Asian countries. Most popular ones include: a) lock and spill drains- graded drain which is usually built along contours and acts by capturing runoff in small stilling ponds, which allows the rainwater to infiltrate slowly; b) Stone walls- constructed along contours in fields or road sides and provide an irregular form of terracing; c) bench terraces- construction of large benches on steep slopes and cultivation may be carried out on slightly downward or back sloping surfaces; d) bunds-artificial

Maintaining the vegetative cover is an effective way of reducing runoff and soil erosion. In fact, it has been observed that vegetative cover is more effective in checking oil erosion as well as improving water yields or stream flows. Calder (1991), has estimated that afforestation will reduce river flows by the order of 200 mm per year (or 2000 cubic meters/ha/year) in Sri Lanka. Afforestation is also widely adopted in the watershed management, especially at the ridge locations. Afforestation and forest conservation measures are extensively used in the hilly terrains of Nepal, Bangladesh, India, and Pakistan. Most of these soil conservation interventions are not very popular among the farming communities in South Asia. This is mainly due to small size land holding. These interventions are either capital intensive or land intensive or both. Often governments provide incentives or subsidies to promote on farm soil conservation activities. But they do not sustain once the incentives dry up. One activity that is observed to be very popular is the pebble bunding in many parts of the state of Andhra Pradesh, India. This is mainly due to the nature of the terrain.

3.2. In situ moisture conservation

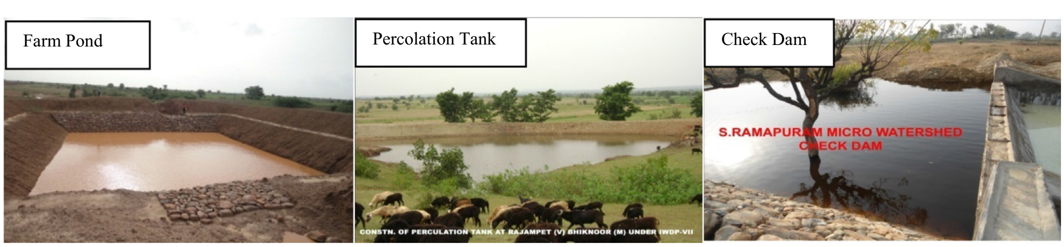
Increasing the water holding capacity of soils in the arid and semi-arid regions is a main concern for enhancing the agricultural productivity. Soil erosion further erodes the water holding capacity in these regions as, organic matter and clays contribute disproportionately more to water-holding capacity relative to other coarser soil fractions. Number of interventions are adopted to increase *in situ* soil moisture content, which are known as on farm interventions. These on farm activities are most widely promoted and adopted measures in the rainfed regions of India, especially during the initial years of 1970s and 1980s. These include on farm bunding, trenching and contour bunding (see pictures) to increase soil moisture within plots of land by reducing the run off. These interventions help retaining the rainwater within the farmers own field in the arid and semi-arid zones, where annual rainfall is low (200–600 mm). In India, these interventions are implemented with 90–95 percent government subsidy. These interventions, however, are land intensive and are not favoured by small and marginal farmers. In the case of very small plots, the loss of area offsets the yield gains.



Agronomically, there are a number of farming practices that can help increase soil moisture content and enhance yield rates. These recommended interventions include: vegetative soil cover, mulching, use of simple tillage practices, contour cultivation, ridging across the slope, vegetative barriers, ripped furrows, land levelling, level pans, terracing, etc. These practices, however, are only recommendations and not implemented as part of the watershed programme. Number of research studies have shown that these practices enhanced soil quality and yield (Doolette and Smyle, 1990).

3.3. Rain water harvesting

Of late rainwater harvesting is increasingly gaining popularity among local communities as well as policy makers. Often, this specific component draws a substantial share in the watershed allocations. For instance, in India the density and size of rainwater harvesting structures is on the rise during the last two decades. In the low rainfall arid and semi-arid regions, these structures provide a life line to protect crops and livestock during lean months. Rainwater harvesting structures can be constructed at the surface as well as subsurface level, though surface structures are the main interventions in the watershed programmes. The structures include check-dams; farm ponds; percolation tanks or pits; recharge wells and injection wells (see pictures). All these interventions help to recharge groundwater. While check dams and farm ponds are part of water spreading methods, which serve the purpose of recharge as well as direct use of water; percolation pits, percolation tanks, recharge wells and injection wells are used for recharging the groundwater.



The adoption of these methods depend on the location (upstream/downstream) within the watershed as well as the hydrogeology of the location. In a ridge to valley context of watersheds, it is often recommended that on-farm interventions (*in-situ* soil moisture conservation) and water spread methods (farm ponds and check dams) in the middle and downstream locations. However, understanding the hydrogeology is critical for determining the suitability of these interventions. From the hydrogeology perspective, moderate to deep weathering and fracturing zones are suitable for artificial recharge through water spreading methods (farm ponds and check dams); areas with deep fractures are suitable for artificial recharge methods by injection methods depending on the aquifer position; and areas with very shallow basement are not suitable for any interventions (Reddy and Syme, 2015). Based on the drainage order, mini-percolation and percolation tanks are effective on the first to third order streams. Check dams are more effective when the topography is plane. The interventions required for watersheds located on the weathered zone are different from watersheds located on the fractured zone. Water-spreading methods such as check dams, percolation tanks, and farm ponds are effective in weathered zones.

The impacts of rainwater harvesting methods are more conspicuous than any other interventions of watershed management. The visible collection of water at the check dams and the impact on the surrounding wells attract local community's attention. As a result, farmers demand more of these structures, as these structures can't be built by individual farmers due to their capital intensity. Besides, check dams needs to be constructed in the natural streams, which are common property. Even the implementing agencies are leaning towards creating more of these structures due to the demands from the communities and also due to their quick and visible impacts. These structures, however, provide location specific impacts and hence are not equitable in terms of distribution of benefits. Moreover, their impacts could be very limited when they are constructed in the absence of hydrogeological information of the watershed.

4. Impacts and equity

Impact assessment of the benefits from watershed interventions is complex, as the benefits from watershed management accrues with a lag of more than 5 years, as the interventions take time to enhance the resource base. Apart from time, extent and magnitude of the benefits also vary across space viz., upstream and downstream. Similarly, benefits vary with the scale of watershed. Benefits are expected to be more if the watershed scale coincides with the hydrological scale (Reddy and Syme, 2015). Given the externality nature of watershed benefits, if the watershed scale is smaller than the hydrological scale, it is likely that some benefits accrue beyond the boundaries of watershed. WSM projects are generally anticipated not only to provide local on-site benefits at the micro-watershed level, but also to offer positive externalities in the form of valuable environmental services downstream as well as to provide a means of correcting downstream negative externalities within the larger watershed. Therefore, investment in upstream cannot be justified by their on-site benefits alone and can only pass economic reasoning when downstream benefits are embodied. A larger watershed scale would facilitate the capture of externalities relating to groundwater and surface water flows. This calls for taking the impacts of positive and negative externalities across the streams into account while assessing the watershed impacts. This requires taking hydrogeological and bio-physical aspects into account. Very few studies have integrated these aspects into impact assessment.

Measuring the impacts is becoming more complex in the recent years as watershed development programmes have transformed from a soil and water conservation to a comprehensive rural development and livelihoods programme, especially in countries like India and Nepal. This would also create attribution problems, as there are other programmes related to poverty alleviation, livelihoods, etc., going on simultaneously in most of these countries. Hither to, watershed impact assessment studies have focused on the socio-economic and natural resource impacts (Reddy et al., 2010; Joshi et al., 2004). With the introduction of the livelihoods component along with participatory approach to implementation during the late 1990s, impact studies have started using the sustainable livelihoods (SL) framework to assess the impacts (Reddy et al., 2004, 2008). The SL framework is a more comprehensive approach that looks beyond income and employment aspects of poverty using the five capitals to assess the impacts. The framework incorporates the social, human and physical (capitals) dimensions of poverty, which are more long-term in nature. Despite the fact that the prime objective of watershed development is soil and water conservation and thus improving the productivity and resilience of the system, not much attention has been paid to assess the resilience aspects of watershed development in the literature.

Of late, resilience is gaining prominence as an important attribute of the farming communities, especially in the context of climate change impacts. In fact, the SL framework has resilience inbuilt. In most cases, impact studies do not have the backing of proper baseline information. This limits the validity of the impact assessment, as the data generated from the households suffer from memory lapse when "before and after" methods are used; while getting a perfectly-matching sample becomes a limitation when "with and without" methods are used. However, adopting a "double difference" method, in which both "before and after" and "with and without" approaches are combined, is expected to provide the best proxy in the absence of base line (Reddy et al., 2004). Impact assessments are also influenced by the timing of the study. While impacts are clearly captured in the immediate post-implementation phase given the lag, attribution of impacts gets blurred as the gap between implementation and assessment increases, especially when the structures are not maintained well. In this context, using resilience as an impact indicator would help in addressing the limitations to a large extent. Resilience is in a way directly linked to watershed interventions and hence, could be attributed directly to the current watershed condition. Furthermore, resilience is more long-term in nature and hence addresses the sustainability aspects of watershed development. When resilience is linked to the five capitals, it becomes robust and comprehensive in understanding the impacts in the absence of base line information.

The studies, thus, dealing with the impact assessment of watersheds and measuring the benefits should consider all these aspects. Though most of the impact assessment studies suffer from these short comings, a review of these studies provides an indication of the potential benefits and beneficiaries. Given the nature of national priorities, not all the countries have systematic impact assessment studies. Nature of impacts and benefits vary across the countries of South Asia, as their priorities and interventions differ (Table 2).

Table 2
Impacts of Watershed Management Across South Asia.

Country	Natural Resources	Economic	Social & Institutional	Overall Livelihoods Impacts (Magnitude)	Remarks
Afghanistan	Improved vegetative cover; number of tree species.	Improved fodder availability	Community managed grazing (social fencing)	–	Very few and not comprehensive
Bangladesh	Reduction Jhum cultivation; Improved forest protection	Improved livelihoods	Creation of Village community forest communities	–	Very few studies.
India	Improvement in the resource base, especially groundwater. Increased moisture availability and reduction in soil erosion	Positive benefit cost ratios; increase in net income and employment.	Strengthening of participatory institutions. Improved gender participation	Good impact on natural, financial and social capitals	Wide variations across the regions. Overall success rate is very low (20–25%)
Nepal	Checking forest degradation. Soil erosion and siltation declined. Vegetative cover improved	Crop intensities increased; Cropping changed to high value crops; yields increased	Education and health improved. Participation has increased; social cohesion increased	Improvement in all capitals. Household income doubled in some cases.	Not much variation across the studies
Pakistan	Reduction in soil erosion (21%) Reduced sediment (38%)	Improved yield rates of wheat, groundnut, fodder. Increase in income	Increased participation-including women.	–	Not many studies. There could be selection bias.
Sri Lanka	Reduced runoff and sedimentation in reservoirs	Improved power generation. High IRR	Low participation. Lack of institutions	Limited	The focus is not enhancing the livelihoods of the communities

Source: Based on the studies quoted in the text.

4.1. Hydrological impacts

Although hydrology is integral to WSM, hydrological impacts are not studied widely. Impact assessments are often focused on socioeconomic aspects or biophysical aspects. Most of the countries in South Asia have focused on upstream WSM in terms of improving the vegetative cover and afforestation in order to reduce runoff in the upstream and sedimentation in the downstream. Soil conservation and water harvesting measures and their impacts on surface and sub-surface hydrology are not given due importance in impact studies. As a result, watershed planning and designing have failed to integrate hydrogeological aspects. One reason could be the scale of watershed is not big enough to integrate hydrogeology, as in some of the South Asian countries the focus has been on micro watersheds, especially after the 1990s. Moreover, the purpose of WSM in most of the countries is reduction in soil erosion and sedimentation and the scale of these watersheds is much larger. Though hydrology (groundwater improvement) is integral to watershed management, hydrogeological characteristics are not taken into account while designing the watersheds (Massuel et al., 2013). For operating at the micro-watershed scale does not necessarily aggregate up or capture upstream-downstream interactions. A mix of upstream interventions would only have a considerable impact on downstream if prioritized and planned within the larger watershed perspective and with understanding of the spatial and hydrological links between the perceived externalities and their underlying factors (for example, land and water use).

Despite their apparent objective of improving natural resource conditions in a watershed, the WSM programmes or interventions may prove detrimental to downstream areas. Research has revealed that the micro-watershed approach may be producing hydrological problems that would be best addressed by operating at a macro-watershed scale. For example, in India, recent hydrological research cautions that watershed projects may be aggravating precisely the very water scarcity they intend to overcome. The study by Batchelor et al. (2003) noticed that successful water harvesting in upper watersheds came at the expense of lower watershed areas. On the basis of the data from the macro-watershed level (covering many villages), they documented cases where water harvesting in upper watersheds reduced water availability downstream. Even the interventions like rainwater harvesting structures could harm the interests of downstream communities, especially in the low rainfall regions (Ray and Bijarniya, 2006; George et al., 2011; Nune et al., 2014).

With the worsening of the groundwater table downstream, more intensive drilling of wells are needed, which the poor could often not afford, leading to inequitable distribution and use of water (Calder, 2005). Calder et al. (2006) term this as "catchment closure," whereby water harvesting upstream accumulates groundwater locally and then intensive pumping depletes the shallow aquifer. In this case, watershed development checks the movements of both surface runoff and groundwater towards downstream locations. As the size of watershed increases, the influence of land use on the upstream – downstream hydrology reduces while the influence of precipitation increases (FAO, 2006). A recent study at sub-basin scale has also observed that watershed interventions have caused water insecurity at downstream, though they have benefited the onsite communities (George et al., 2011). This indicates two adverse project outcomes: first, what is good for one micro-watershed can be bad for others in the downstream locations; and second, what is good for a watershed in the short term can be bad in the long term. Thus, while addressing socio-economic considerations favours small micro-watersheds as the unit of operation, approaching this hydrological problem calls for working in large macro-watersheds and the two may be inconsistent.

In the case of Sri Lanka land cover changes (from forest to tea gardens and home gardens) has altered the flow regimes. The observed adverse environmental impacts were directly related to changes in flow regimes. Rapid runoff was responsible for high soil erosion rate, loss of land productivity, and more frequent flash floods. The high rate of sediment supply due to accelerated erosion has caused degradation of stream channels, increasing the likelihood of flash floods, reduced land productivity in rice fields with deposition of coarse material and silting of irrigation canals. During dry spells, relative droughts and irrigation water shortages have occurred. Reduced low flows in downstream have threatened the dependable supply of good quality water and increased the salinity intrusion at the river mouth whereas increased high flows have aggravated the flooding (Elkaduwa and Sakthivadivel, 1998).

4.2. Impact on equity (who benefits)

In order to ensure equitable distribution of benefits from improved natural resource base or common pool resources, there needs to be effective property right regime and regulatory structures. This has so far proved difficult because in practice access to common resources is open and free for all in majority of the cases across South Asia. This is unlike the situation in countries such as South Africa, where landowners don't have automatic property rights to commons such as subsurface water. Although restrictions on over exploitation of groundwater exist, there is no restriction on how much of the common property subsurface water is 'privatized' through pumping onto private land.

Social organisation, its equitability and sustainability, links to questions of allocation of property rights and the distribution of benefits across different sections of the community. Whether property rights are clearly defined and equitably distributed is more important rather than who has the rights- individuals or groups. Unless property rights are defined clearly and equitably it is difficult to ensure sustainable resource management even under participatory watershed management. Allocation of rights and distribution of costs and benefits are the most important among the rules and regulations in managing the commons. These distributional aspects are important and affect the monitoring costs to a large extent. If solved to the satisfaction of all socio-economic communities in the group, they would reduce the costs of monitoring. For, free rider attitudes are more prevalent under institutional arrangements where costs and benefits are distributed unequally across households. Those who are on the other extreme (deriving least benefits) tend to assert their use rights inappropriately, such as encroaching. That is, when people view an established system as inequitable according to established social standards, they have incentives to undermine it (Hanna, 1996). For instance, grazing restrictions go against the interests of herders while they benefit the landholders (Reddy, 2000; Turton, 2000). On the contrary, small and marginal farmers tend to benefit from restrictions on groundwater exploitation while large farmers loose (Reddy, 2000). Such contradictions often result in non-cooperative behaviour among communities and hence need to be addressed in order to sustain collective action.

Sustainable WSM calls for participation of the whole community, which requires sharing of costs and benefits in a fairly equitable manner. Participatory WSM implies a fundamental concern for ensuring equity in benefits. While it is desirable to involve all sections of the community, watershed intervention by itself does not guarantee the distribution of benefit flows across the community. For, watershed is a land based technology and hence most of the benefits accrue to land owners – particularly those best placed to pump the increased groundwater – likely to be those who have land in the valley rather than at the ridge. Though landless households are expected to benefit to some extent, through employment opportunities and so on, the type and magnitude of benefits accruing to them are poorly understood. Even if the watershed covers the entire village lands, it might leave sections of dissatisfied households, due to the nature of interventions vary by location. Farmer prefers water-harvesting structures over soil conservation interventions. Unless benefits accruing to this section of the community are substantial in economic terms it is unlikely that they will participate or evince any interest in the programme. In the absence of such benefits, their apathy towards the programme might jeopardize the sustainability of the programme.

Thus, the distribution of economic benefits across socio-economic groups holds the key for the success of WSM. However, this important aspect is not often adequately addressed by the existing evaluation studies as they focus mainly on the issue of total benefits at the micro watershed level (Deshpande and Narayanamoorthy, 1999), rather than investigating the distribution of the benefits (Shah, 2001). Of late, the issue of equity in WSM has caught the attention of both the researchers as well as policy makers. The study by Joy and Paranjapye (2004) has presented a detailed discussion on the issue of equity and its specific relevance to WSM. The distribution of direct and tangible benefits is often observed to be discriminatory and limited, even in some of the most 'successful' projects (Shah, 1998; Deshpande and Narayanamoorthy, 1998; Kerr et al., 1998). The evidence not only indicates little impact on equity; sometimes, they point to increased deprivation for women/poor in terms of their access to resources in addition to further workload for project activities (Shah, 2009).

Many scholars observed that watershed development favours the land owners and those having land in the lower reaches as well as those who have the ability to invest in wells and pumps (Arya and Samra, 1995; Adolph and Turton, 1998; Kerr et al., 1998; Reddy et al., 2001). While the study by Reddy et al. (2004) in the context of Andhra Pradesh observes inequalities to be declining after the advent of WSM project. Another study (Singh et al., 1993) in the *Kandi* watershed of Punjab, inequity was found to be increasing. The recent study by Reddy et al., 2010a in the context of Rajasthan also points towards a disturbing fact that benefits from WSM in poor and backward regions are not only low, but are mostly cornered by large farmers resulting in the aggravation of inter and intra-regional inequalities. In a study in Orissa and Andhra Pradesh (Rout, 2013), participation was observed to have enhanced the benefit flows, but it could not ensure equitable distribution of the benefits. On the other hand, as pointed out earlier, equitable distribution ensures participation. The distinction could be absolute equity vis-à-vis relative equity. Equity issues arise even in the spatial context. Number of studies have observed that downstream locations benefit more from the watershed interventions when compared to upstream interventions (Reddy and Syme, 2015).

The review of impacts and benefits of WSM clearly brings out that the economics of watershed technology is unambiguously in its favour across South Asia, though the magnitude of its impact varies across the countries and locations. The impact of watershed technology is observed to be more effective in water scarce regions when compared to assured rainfall regions. At the same time, absolute benefits are more in the medium rainfall zones. For, adoption of the technology itself might be a difficult proposition in extreme scarcity conditions, as poor households living on the margin can hardly afford to adopt conservation practices such as losing part of their land for contour bunding, etc. Adding to this is the long gestation required for getting the benefits from the technology. This has led to the increasing demand for rainwater harvesting structures to the neglect of soil conservation in countries like India. In the absence of scientific approach (integration of hydrogeology into watershed design) the effectiveness of water harvesting interventions could be limited. Thus, while the potential of WSM in enhancing land productivity, livelihoods and resilience need not be reemphasised, adopting appropriate and scientific designing and implementation is the key for ensuring its effectiveness.

5. Watershed institutions and implementation

The dual character of WSM as a technology and its management as an art or philosophy makes the role of institutions critical in its implementation, management and sustenance. While the success of WSM as a technology is well established, the philosophy of its management is proving to be the main bottleneck for the wider success of the programme. Collective participation and action of the community is a critical ingredient for a successful WSM. This throws up a wide range of issues, such as social organisation and property rights, which require careful scrutiny. The problem of property rights arises in dealing with the treatment of common lands. Another distinctive feature of watershed technology is its relatively long gestation period. That is, farmers have to wait for 5–7 years to get benefits. The existing socioeconomic contradictions at the community level need to be addressed in order to sustain collective action. It is therefore necessary not only to involve them in the process but also show benefits (tangible economic) to all sections of the community in the short run as well. Evolution of appropriate institutions play a critical role in the implementation and management of watershed interventions. Institutions are required at various levels i.e., policy level to village level.

Evolution of watershed institutions varies across South Asia. Except in India and to some extent in Nepal, watershed institutions have not evolved much, though most of the countries have established specific departments for implementing watershed programmes at the national level. However, institutional evolution is evident in some countries where watersheds were implemented through donor support.

Except for India and Nepal none of the other countries in the region have formulated systematic guidelines from national to village level. In fact, the absence of such institutional set up is the main reason for low adoption of WSM projects in the respective countries (Baloch and Tanik, 2008; Gunawardane, Nd.). While Sri Lanka has a watershed policy and guidelines, Pakistan and other countries are yet to formulate their watershed policies. Sri Lanka though is moving towards people oriented policies, they are not backed by institutional arrangements. Even the establishment of watershed management committees doesn't fit into the overall government policy, which is against setting up new public institutions. As per the national watershed management policy the watershed management committees represented by rural committees and officers of the government institutions and watershed management units under chief provincial secretaries would coordinate the activities of all agencies at the rural, divisional, district, provincial and national levels (Gunawardane, Nd.). Afghanistan has introduced participatory management of watersheds during 1990 s but could not provide appropriate policy and institutional support for strengthening the social capital (Ahmad and Wasiq, 2004).

Thus, the countries in the region are at different levels of institutional arrangements for implementing WSM programmes. Even the countries with appropriate institutional arrangements, the implementation of watershed interventions are neither scientific nor comprehensive. All the countries are moving towards participatory approaches. Participatory approaches need to be backed by appropriate institutional arrangements in order to achieve the objectives. Implementation of the programmes for enhancing the livelihoods of the communities need to strengthen both technical and institutional aspects. While countries like India and Nepal are yet to strengthen the technical aspects in terms of integrating hydrogeology and biophysical aspects into watershed design, others need to look at these aspects as they move towards formulating watershed policies/guidelines and strengthening the watershed institutions.

Another important challenge faced at the implementation level in all the countries is regarding equity in the distribution of benefits. The main benefit from WSM, as perceived by the communities, is improved access to water. Due to the existing property rights in land and water resources coupled with the agrarian structure access to sub-surface water resources is unevenly distributed between households. Even when land is distributed more evenly, the distribution and geometry of aquifers may not be uniform. In most countries groundwater rights are linked to land rights, making access to water further skewed, as every piece of land is not endowed with good aquifer. In this regard, unless institutional arrangements are in place with clearly defined property rights, it would be difficult to ensure equitable distribution of benefits. Though most of the countries are moving towards incorporating livelihoods components in order to ensure benefits to all sections of the community, not much is done in terms of addressing the structural issues viz., property rights, sharing of water, etc. Countries are yet to find viable policy options in this regard. For instance, India is planning to move towards groundwater institutions during the 12th plan period but it has a long way to go in making them effective at scale (Reddy et al., 2014).

6. Conclusions

WSM is being followed across the globe for more than a century to address soil and water conservation and degradation problems. WSM in a comprehensive form is widely adopted in the developed countries of America and Europe and termed as river basin or catchment management for checking run-off and soil erosion in the catchments and protecting the rivers and reservoirs from siltation. Most of the South Asian countries adopted these models of watershed management to address similar problems (land degradation and reservoir protection) earlier. However, India has adopted WSM with a different objective and approach. It has moved away from the river basin or catchment management scale to protecting and enhancing the land productivity in the rainfed areas focusing at a much smaller scale. Further, WSM is viewed as a technological option (as green revolution for irrigated agriculture) for rainfed agriculture and accorded high policy priority and fund allocations. In the process the scale issues of WSM are largely neglected to achieve smooth implementation, as participation of local communities in the programme is recognised as critical for its success. Micro watersheds are taken up at the village level for better social organisation (participation). The focus on social aspects of WSM has led to evolution of the programme into a more comprehensive rural development approach of integrating livelihoods and production enhancement components as part of watershed interventions. Though number of watersheds covering large areas are being implemented, the technical aspects are not taken into account while selecting the watersheds for treatment. As a result, the effectiveness of these interventions has been limited despite better social or institutional outcomes.

Indian policy has transformed the WSM in many ways i.e., socially acceptable, economically viable and ecologically sound. India's experience in WSM is considered effective in addressing the rural livelihoods as well as resource degradation issues in rainfed areas. The participatory and livelihoods approach to WSM are now being adopted in most of the South Asian countries like Nepal, Sri Lanka, Pakistan, etc., though some of these countries are yet to evolve in terms of institutional aspects.

Thus the experience of South Asia in watershed management has proved that it can be adopted as an effective technology for addressing the broader aspects of soil and water conservation as well as productivity and food security issues of rainfed regions. Given the high proportion of rainfed agriculture in the region, WSM can provide a win-win situation when the broader aspects are integrated within the rainfed context. Countries like Afghanistan are well placed to adopt such an approach to protect soil and water resources and enhance production and productivity of rainfed regions.

Though each country is unique in many respects, they can draw lessons from more than 3 decades of different experiences of South Asian countries. The following aspects need to be considered in the context of WSM adoption on a wider scale:

- In low and medium rainfall regions watershed interventions should be targeted towards enhanced livelihoods rather than improving the productivity alone. This would ensure more broad based benefit flows and in turn would strengthen the social acceptance and participation.
- The scale of the watershed is another area where careful planning is needed. Learning from the experience of India and other countries placing watersheds at hydrological scale and boundaries would ensure sustainability and realistic impacts. This requires scientific delineation of watersheds in the first place. Implementation of watersheds should be taken up in such a way that it would address both local (soil and water conservation, improved productivity and livelihoods) and basin level issues (reduced run off and soil erosion). India's recent approach of Meso scale (5000 ha.) watershed interventions covering crop lands are relatively more effective in terms of impacts on livelihoods.
- Participatory approaches need to be made more science based-awareness building and improving their capacities to understand and adopt technically sound interventions rather than demanding quick and short term interventions. Given that the awareness about watershed management is low among the communities, concerted efforts are required to build awareness and gain acceptance for implementing the interventions. This specifically required considering hydrogeology and biophysical aspects in designing and implementing the watershed structures. Involvement of community and ownership is critical for implementing effective WSM. Any watershed programme with a recognised impact on downstream areas should strongly consider a public awareness component to provide community members a basic understanding of natural processes and how management can either positively or negatively influence these.
- Resource sustainability and equity need to be built into WSM approaches. While adopting scientific approach and scale in designing watershed interventions is necessary for addressing the sustainability but it is not sufficient. Any successful watershed intervention requires a combination of security/accessibility, clear land title and control, and appropriate geologic and climatologic conditions that will permit interventions to make a discernible difference (Groninger and Ruffner, 2010). Appropriate institutional arrangements for managing the resources i.e., access, demand and use across socioeconomic groups need to be evolved. Such institutions need to be built around the existing institutions that are embedded in the culture of the land.
- Countries with limited capacities in understanding and implementing the watershed management approaches need capacity building at various levels. Identifying right NGOs and encourage them to participate in the process would be a good starting point.

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References

Acharya, B., 2000, Watershed Management in Nepal Recent Experiences and Lessons, Office of Agriculture and Rural Development United States Agency for International Development Kathmandu, Nepal, July.

Adolph, B., Turton, C., 1998. Community Self-Help Groups and Watersheds, Partnerships and Policies Programme Series. Overseas Development Institute, London.

Ahmad Masood, Mahwash Wasiq, 2004, Water Resource Development in Northern Afghanistan and Its Implications for Amu Darya Basin, World Bank Working Paper No. 36; The World Bank; Washington D.C.

Ahmad Shahid, 2001, Watershed Management in Pakistan: Achievements And Issues; Paper presented in the National Seminar on "Water Resources" October, organized by FFC, Lahore.

Arya, S., Samra, J.S., 1995, Socio-Economic Implications and Participatory Approach of Integrated Watershed Management Project at Bunga, Technical Bulletin No. T-27/C-6, Central Soil and Water Conservation Research and Training Institute, Research Centre, Chandigarh, India, p 112.

Baloch Mansoor Ahmed, Ays¸egül Tanik, 2008, Development of an Integrated Watershed Management strategy for Resource Conservation in Balochistan Province of Pakistan Desalination 226, pp. 38–46, doi:http://dx.doi.org/10.1016/j.desal.0000.00.000.

Batchelor, C., Singh, A.K., Rama Mohan Rao, C.H., Butterworth, C., 2003. Watershed development: a solution to water shortages or part of the problem? Land Use Water Resour. Res. 3, 1–10.

Calder, I.R., 1991, Sri Lankan Link Programme – Hydrology component. Draft Tour Report ODG 9014.

Calder, I.R., 2005. Blue Revolution, Integrated Land and Water Resource Management. Earthscan, London and Sterling, VA.

Calder, I., Gosain, A., Rama Mohan Rao, M.S., Batchelor, C., Snehylatha, M., Bishop, E., 2006, Planning Rainwater Harvesting in India – 1) Biophysical and Societal Impacts. In National Workshop on Priorities for Watershed Management in India. Bangalore, 22–23 May, Government of Karnataka and the World Bank.

Carson, B., 1989, Soil Conservation Strategies for Upland areas of Indonesia. Occasional Paper No. 9 of the East-West Environment and Policy Institute, Honolulu.

Deshpande, R.S., Narayanamoorthy, A., 1998, A Policy Review of Irrigation Sector in Maharashtra., In: Bhanushali, S.G., Pujari, A.G., (eds.), Changing Perspectives in Indian Agriculture, published by R.R. Doshi Felicitation Committee, Kolhapur, pp. 120–136.

Deshpande, R.S., Narayanamoorthy, A., 1999. An Appraisal of Watershed Development Programme Across Regions in India, Artha Vijnana (whole issue), 41 (4): 415–515, December.

Dixon, J.A., 1992. Analysis and management of watersheds. In: Partha Dasgupta, Karl-Goran Maler (Eds.), The Environment and Emerging Development Issues, vol. 2. Clarendon Press, Oxford.

Doolette, J.B., Magrath, W.B., (Eds.), Watershed Developments in Asia: Strategies and Technologies, World Book Technical Paper No. 127, Washington DC.

Doolette, J.B., Smyle, J.W., 1990. Soil and Moisture Conservation Technologies: Review of Literature. In: Doolette, J.B., Magrath, W.B., (Eds.), Watershed Developments in Asia: Strategies and Technologies, World Book Technical Paper No. 127, Washington DC.

Elkaduwa W.K.B., Sakthivadivel, R., 1998, Use of historical data as a decision support tool in watershed management: A case study of the Upper Nilwala basin in Sri Lanka. Research Report 26. Colombo, Sri Lanka: International Water Management Institute.

ESC, 2001. Agriculture, Land and Desertification: Report of the Secretary General. Economic and Social Council, United Nations.

Fan, S., Hazell, P., 2000. Should developing countries invest more in less favoured areas? An empirical analysis of rural India. Econ. Political Weekly 35 (17), 1455–1464.

FAO, 2006. The New Generation of Watershed Management Programmes and Projects, FAO Forestry Paper 150. Food and Agriculture Organization of the United Nations, Rome.

George, B.A., Malano, H., Davidson, B., Hellegers, P., Bharathi, L., Sylvian, M., 2011. An integrated hydro-economic modelling framework to evaluate water allocation strategies I: model development. Agric. Water Manage. 98 (5), 733–746.

Groninger, J., Ruffner, C., 2011. Watershed Issues and Management in Afghanistan: Opportunities and Challenges. Presentation, Southern Illinois University.

Gunawardena Elgoda Ranawakage Nimal (Nd.) Evolution of watershed management: the Sri Lankan Experience. In: Proceedings of the Asian Regional Workshop on Watershed Management (chapter 14). <ftp://ftp.fao.org/docrep/fao/009/a0270e/A0270E11.pdf>.

Hanna, S., 1996. Co-Management in Small-Scale Fisheries: Creating Effective Links Among Stakeholders; International CBNRM Workshop, Washington, D.C., May <http://info.worldbank.org/etools/docs/library/97605/conatrem/conatrem/documents/hanna-Paper.pdf>.

Joy, K.J., Paranjape, S., 2004, Watershed Development Review: Issues and Prospects, Technical Report, Centre for Interdisciplinary Studies in Environment and Development (CISED), Institute for Economic and Social Change, Bangalore.

Joshi, P.K., Jha, A.K., Wani, S.P., Joshi, L., Shiyani, R.L., 2004. Meta-Analysis to Assess Impact of Watershed Programme and People's Participation, Comprehensive Assessment Research Report No.8. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India.

Kerr, J.M., Pangare, G., Lokur-Pangare, V., George, P.J., Kolavalli, S., 1998. The Role of Watershed Projects in Developing India's Rainfed Agriculture. Report submitted to the World Bank. IFPRI, Washington.

Massuel, S., George, B.A., Venot, J.P., Bharathi, L., 2013. Improving assessment of the sustainable groundwater availability with deterministic modelling – a case study of Musi sub-basin India. Hydrogeol. J. 21 (7), 1567–1580. Springer Verlag.

Misbahuzzaman, K., (Nd.); Problems and Prospects of the Hilly Watersheds in Bangladesh: Priorities for their Conservation; Institute of Forestry and Environmental Sciences, Chittagong University, Chittagong, Bangladesh <http://lib.icimod.org/record/12176/files/3539.pdf>.

Nune, R., George, B.A., Western, A.W., 2014. Relating trends in streamflow to anthropogenic influences: a case study of Himayat Sagar catchment, India. Water Resour. Manage. 28 (6), 1579–1595.

Pingali, P.L., Rosegrant, M., 2001. Intensive food systems in Asia: can the degradation problems be resolved? In: Lee, D.R., Barrett, C.B. (Eds.), Tradeoffs or Synergies? Agricultural Intensification, Economic Development and the Environment. CABI publishing.

Perera, N., Fernado, K., 2004. Sustainable Land Management: South Asia Perspectives. Colombo, Sri Lanka.: South Asia Cooperative Environment Program.

Ray Sunil, Bijarniya, M., 2006, "Upstream vs Down Stream: Groundwater Management and Rain Water Harvesting", Economic and Political Weekly, Vol. XLI, No. 23 June, 10.

Reddy V. Ratna, 2000. Watershed Management for Sustainable Agricultural Development: Need for an Institutional Approach, Economic and Political Weekly, Vol. XXXV, No. 38, September 2000.

Ratna, Reddy V. et al., 2008. Sustaining rural livelihoods in fragile environments: resource endowments and policy interventions- a study in the context of participatory watershed development in Andhra Pradesh. Indian J. Agric. Econ. 63 (2). April–June.

Ratna, Reddy V., Srinivasa Reddy, M., Sanjit Kumar Rout, 2014. Groundwater Governance. A tale of three participatory models in Andhra Pradesh, India. Water Altern. 7 (2).

Ratna, Reddy V., Syme, Geoffrey J., 2015. Integrated Assessment of Scale Impacts of Watershed Intervention: Assessing Hydrological and Bio-Physical Influences on Livelihoods. Elsevier, Amsterdam.

Ratna, Reddy V., Gopinath Reddy, M., Soussan, John, 2010. Political Economy of Watershed Management: Policies. Institutions, Implementation and Livelihoods, Rawat Publishers, Jaipur.

Reddy V. Ratna, Reddy, M.G., Galab, S., Springate-Baginski, O., 2001. Watershed Development and Livelihood Security: An Assessment of Linkages and Impact in Andhra Pradesh, India. Draft Report. CESS/University of Leeds.

Reddy V. Ratna, Reddy, M.G., Galab, S., Soussan, J., Springate-Briganski, O., 2004. Participatory Watershed Development in India: Can it Sustain Rural Livelihoods? Dev. Change, 35 (2): 297–326, April.

Reddy V. Ratna, Rout, Sanjit Kumar and Chiranjeevi, T., 2010a. The Impact Assessment Study of Watershed Development Projects in Rajasthan, Project Report, Livelihoods and Natural resource Management Institute, Hyderabad.

Rout, Sanjit Kumar, 2013. Collective Action and Natural Resource Management: A Study of Watershed Development in India, Unpublished Ph.D Dissertation, Centre for Economic and Social Studies (CESS), BRAOU, Hyderabad.

Shah, A., 1998. Watershed Development Programmes in India: Emerging Issues for Environment Development Perspectives, Economic and Political Weekly, 32 (26), July.

Shah, A., 2001. Who benefits from participatory watershed development? Lessons from Gujarat. IIED Gatekeeper Series No. 97, International Institute for Environment and Development (IIED), London.

Shah, A., 2009. Equity in the Impact of Watershed Development: Class, Gender and Regions, in Impact of Watershed Management on Women and Vulnerable Groups. Proceedings of the Workshop on Comprehensive Assessment of Watershed Programs in India (eds) Amita Shah, Wani SP and Sreedevi TK, ICRISAT, Patancheru 502 324, Andhra Pradesh, India.

Singh, K., Sandhu, H.S., Singh, N., Kumar, B., 1993. Kandi watershed development project: a critical evaluation. Econ. Political Weekly 28 (52), A122–A128.

Tiwari Krishna, R, Bajracharya, Roshan M., Sitaula, Bishal K., 2008. Natural resource and watershed management in south Asia: a comparative evaluation with special references to Nepal. J. Agric. Environ. 9. June.

Tsering, K., 2011. A Roadmap for watershed management in Bhutan: From policy to practice; Watershed Management Division; Department of Forests and Park Services; Ministry of Agriculture and Forests Thimphu Bhutan.

Turton, C., 2000. Enhancing Livelihoods Through Participatory watershed Development in India. Working Paper 131, Overseas Development institute, London, UK. Development. London: Routledge.

White, T.A., Runge, C.F., 1995. The emergence and evolution of collective action: lessons from watershed management in Haiti. World Dev. 23 (10), 1683–1698.

World Bank, 2007. Watershed Management Approaches, Policies and Operations: Lessons for Scaling-Up (Draft Report). Agriculture and Rural Development Department, World Bank, Washington, DC.