Watershed and Its Management

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1.1 Concept and Definition of Watershed

The word ‘watershed’ has different meanings. In British English it means a ridge line or a line which shows slopes in two different directions on its either sides. A ridge line is also a line connecting the points of highest elevation in a terrain. Therefore, ridge line is also known as ‘watershed line’ or a ‘surface water divide’. In colloquial language the word ‘watershed’ is used to describe a path breaking event.

In American English, the word ‘watershed’ is used as a synonym for ‘catchment’ or ‘basin’ wherein rainwater or storm water gets collected from an area enclosed by a ridge line. This water eventually flows through the various drainage channels which merge with one another to form one or rarely more than one outfall(s) of a stream. Thus, ‘watershed’ is defined as an area enclosed within a watershed line. In this course, the word ‘watershed’ is used for a small basin or a small catchment representing a hydrological unit which drains all its rainwater into a stream. Therefore, it is independent in terms of its water in general and surface water in particular.

To distinguish a watershed -which generally implies a small catchment or a basin, Bali (1980) suggested an upper area limit of 2,000 km^2 for a watershed. This classification is an extension of the classification suggested by Rao (1975) for large river basins -with an area greater than 20,000 km^2, medium river basins –with an area between 2,000 and 20,000 km^2 and small river basins commonly referred to as watersheds.

Bali’s classification of watersheds was probably reflected in the watershed classification by the All India Soil and Land Use Survey (AISLUS) in 1990. According to this classification, watersheds are further classified into 5 categories based on their areas as ‘macro-watersheds - with area between 500 and 2,000 km^2, ‘sub-watersheds’ –with area between 100 and 500 km^2, ‘milli-watersheds’ –with area between 10 and 100 km^2, ‘mini-watersheds’ –with area between 1 and 10 km^2 as well as ‘micro-watersheds’ –with area less than 1 km^2.

A watershed is a physical entity consisting of the natural elements in it such as plants of various sizes and types which grow over various types of soil or rock layers. Additionally, watershed also comprises of all the artificial elements such as roads, bridges, tunnels, buildings, and burrow holes etc. which are mostly introduced in it by human beings and sometimes by other animals. In the next section, we shall discuss about the scope of watershed management.

1.2 Scope of Watershed Management

As we have already seen in the previous section, watersheds represent small basins. By delineating the ridgelines in a medium or a large river basin, the entire basin can be subdivided into a number of watersheds, each with an area within 2,000 km^2. Because of their compact size, it is always easier to manage watersheds rather than a river basin. In a well-managed watershed, all the natural resources such as soil, water, vegetation, etc. are conserved.

Vegetation or plants play a vital role in conserving the natural resources of a watershed such as soil and water. The underground components of the plants such as roots spread within the soil and thereby stabilize and reinforce the soil. This generally leads to soil conservation. The water infiltrates below the ground through the voids in the soil as well as through the interface between the root surface and the soil. The terrestrial components of plants such as stems, branches and leaves prevent the soil below it from getting directly exposed to sunlight as well as to the impact of raindrops. Thus, a significant part of the momentum and energy in rainwater is absorbed and thereby inducing/ accelerating the downward movement of rainwater through stem flow and infiltration. On one hand this process creates water bodies like the groundwater reservoirs and rivers, which are good sources of water and nutrients required for plant growth. On the other hand, this process also substantially reduces the soil erosion and the surface flow velocity of storm water.

Additionally, there will be release of ample amount of oxygen, generation of colorful and fragrant flowers, fresh leaves as well as fruits through the process of photosynthesis. This makes the entire watershed very pleasant for human beings, migratory birds, flying insects as well as all other animals. The fruits and leaves also serve as food for human beings and animals.

A watershed containing large amounts of vegetation is considered as a healthy watershed. It is also called a well-managed or a 'green watershed'. It has no or very limited soil erosion and also it has large reserves of groundwater as well as surface water. In general, it has most of its natural resources conserved.

Thus, the scope of watershed management involves all the actions and programs aimed at achieving an overall balance between utilization and conservation of natural resources in a watershed. It represents a sustainable approach for resource conservation through watershed management. In the next section, the Indian and global perspective to watershed management is discussed.

1.3 Watershed Management: Indian and Global Perspective

India has the second highest population of over 1.2 billion among all the nations [i.e., 17.1% of the world population], a seventh highest land area of 3.29 million km^2 among all the nations [i.e., 2.4% of the world area] and an annual river flow of 1869 km^3 out of an annual rainfall of about 4000 km^3 [i.e., 4% of the world water]. The rainfall distribution is highly uneven spatially with the highest annual rainfall of 11,690 mm in the north-eastern state of Meghalaya and the least annual rainfall of 150 mm in the western part of the north-western state of Rajasthan. The number of rainy days [i.e., number of days with a minimum recorded daily rainfall of 2.5 mm] varies from 5 to 150. The rainfall distribution is also very uneven temporally with about 75% of the annual rainfall occurring only in the four monsoon months of June to September. The average annual rainfall is 1160 mm which is slightly higher than the global average of 1110 mm. In the year 2010, the annual per capita water availability was estimated at 1588 m^3, which is considered as water stressed [i.e., between 1,000 and 1,700 m^3] as per the international norms. The per capita water availability was 5200 m^3 during the year 1951. The annual potential evapo-transpiration (PET) varies from 1,500 to 3,500 mm.

Although India has a well-developed precipitation pattern in the form of monsoons and an equally well developed drainage network consisting of 14 large river basins, 44 medium river basins and hundreds of small river basins, there is a huge stress on water and land resources due to continuous overexploitation. This has led to many adverse hydro-meteorological impacts like large scale soil erosion, excessive lowering of water table, extensive river/ ground water pollution due to municipal/industrial wastewaters, widespread loss of forests/ grass lands/ crop lands/ wetlands/ water bodies, silting of existing water bodies, frequent occurrence of floods/ droughts, alarming reduction in Himalayan glaciers etc. All these phenomena have generally made the Indian perspective in watershed management very vulnerable to climatic and anthropogenic factors. Thus, achieving sustainable water resources development and integrated watershed management are two major challenges in the Indian context.

In spite of this alarming scenario, there are hundreds of best management practices (BMPs) – adopted both in the government sector and the non-government sector over the entire length and breadth of India, which have been the bright spots in water and land resources management. These BMPs employ technologies which are either traditional or modern or a combination of both. Some of these BMPs -which were effectively implemented in different parts of India, are as follows:

1) An effective implementation of the ban on tree cutting policy by the local government authorities in the north-eastern state of Sikkim resulted in an increase in the forest cover from 44% in 1995-'96 to 47.59% in 2009 [Hindustan Times, 2010].

2) During 2000 to 2006, voluntary work by hundreds of people led by a spiritual saint near Jalandhar in the north Indian state of Punjab, resulted in the near total cleaning and rejuvenation of 35 km of Kali Bein River, which was heavily polluted by industrial effluents and garbage [The Times of India, 2007].

3) Over a 20-year period starting from 1974, a severely drought prone village of Ralegan Siddhi in the western Indian state of Maharashtra –even with an annual rainfall of about 200 mm, had transformed into a village with ample drinking water, food and fodder. This was possible due to the adoption of ridge to valley approach in watershed management through social forestry, grassland development, continuous contour trenching, loose boulder structures, brushwood dams, nulla bunds, percolation tanks, underground dams, gabion bunds, check dams, farm ponds, staggered trenches for arresting soil erosion and ban on free grazing [Hazare, 1994].

Global perspective on watershed management is having many similarities and some differences with the Indian perspective. Moreover, there are even bigger spatial and temporal variations in water/ pollutant distribution. It is also very much affected by soil erosion, excessive lowering of water table, extensive river/ ground water pollution due to municipal/industrial wastewaters, widespread loss of forests/ grass lands/ crop lands/ wetlands/ water bodies, silting of existing water bodies, frequent occurrence of floods/ droughts, alarming reduction in glaciers etc. These phenomena have resulted in major constraints due to water scarcity and land scarcity. However, in majority of the developed world and in many parts of the developing world, sufficient watershed management activities have been initiated in the government and non-governmental sectors.

The impact of these watershed management programs is varied ranging from failures with undesirable environmental and socio-economic consequences to significant benefits. To make the watershed management programs sustainable, land and water resources need to be managed together with an interdisciplinary approach. There is also a strong need to develop regional training and networking programs at all levels, especially when government agencies are not fulfilling their role in watershed management. The emergence of citizen-based watershed organizations in the United States and many other countries is a very positive development.

1.4 Timeline of Watershed Management Programmes in India

The watershed management concept in India starts from the pre-historic times. In the Shanti Mantra or the peace hymn of Yajur Veda –one of the four Vedas or treatises of knowledge in the ancient Indian philosophy –which is written/ codified in Sanskrit, there is a phrase which states that '…..prithivih shantih aapah shantir oshadhayah shantih…'. The meaning of this phrase is '…let there be peace on earth, water, vegetation…'. This is possibly one of the oldest references to watershed management. Additionally -in that hymn, peace is also sought in heaven, sky, Gods and in all natural entities/ living organisms -starting with the person reciting this Mantra.

The actual timeline of watershed management programmes in India starts from the 1950s during the First Five Year Plan, with the establishment of a number of Soil Conservation Research Demonstration and Training Centres (SCRDTCs) by the Ministry of Agriculture (MoA) of the Government of India (GoI). In 1956, 42 small [i.e., less than 1 km^2] experimental watersheds were established for monitoring the impact of land use changes and conservation measures on surface hydrology, soil loss reduction and biomass productivity improvement. In 1961-'62, the MoA, GoI sponsored a scheme for soil conservation in the catchments of River Valley Projects (RVPs) for preventing siltation in major reservoirs.

In 1974, all the SCRDTCs were reorganized under the Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun. A real breakthrough was achieved by CSWCRTI when watershed technologies were demonstrated under natural field settings using community driven approaches through four model Operational Research Projects (ORPs) in different regions of the country. The world famous Sukhomajri model in Haryana was also one of them. The Ministry of Rural Development (MoRD), GoI launched major nationwide watershed development programs like the Drought Prone Area Programme (DPAP) in 1973-'74 and Desert Development Programme (DDP) in 1977-'78. The MoA, GoI launched watershed programs in 10 catchments under the Flood Prone Rivers (FRP) Project.

During 1983, encouraged by the success in the earlier four model ORPs, CSWCRTI, Dehradun developed 47 model watersheds in the country in association with the Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad. MoRD, GoI also started adopting watershed approach in 1987. The Planning Commission, GoI also started adopting integrated watershed approach in 1987-'88 for its Western Ghats Development Programme (WGDP) and Hill Area Development Programme (HADP) covering 16,000 km^2 area in Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu. In 1989-'90, the Ministry of environment and Forests (MoEF) initiated National Afforestation and Eco-development Projects (NAEP) scheme following integrated watershed approach.

In the 1990s, many watershed development programs externally funded by the World Bank, European Economic council (EEC), Danish International Development agency (DANIDA), some Indo-German, Indo-Swiss and Japanese organizations were undertaken in various parts of India. Around the same time, MoA initiated a massive project on National Watershed Development Programme for Rainfed areas (NWDPRA) in 1991. In 1995, MoRD launched another big project called Integrated Wastelands Development Project (IWDP) with well formulated guidelines.

In 2001, the Planning Commission, GoI drew up an ambitious plan of treating 88.5 Mha of degraded/ rainfed lands in India, by the end of the 13th Five Year Plan in 2022 involving a huge financial investment of Rs. 72,750 crores. To strengthen the participating institutes, MoRD revised the watershed development guidelines as 'Haryali' [i.e., greenery] guidelines in 2003. The GoI established the National Rainfed Area Authority (NRAA) under the Planning Commission in 2006. MoA also started the projects on Reclamation of Alkali soils (RAS), Watershed Development Project for Shifting Cultivation Areas (WDPSCA), Indo-German Bilateral Project (IGBP) and World Bank assisted Sodic Land Reclamation Project (SLRP). MoRD has initiated watershed projects under Mahatma Gandhi National Rural employment Guarantee Act (MGNREGA), Investment Promotional Scheme (IPS) and Technology Development Extension and Training (TDET), Wastelands Development Task Force (WDTF). Till March 2005, an area of 28.53 Mha was treated at an investment of Rs. 1,457 crores by MoA, MoRD, MoEF, out of a total degraded land of 146.82 Mha –as per the estimates of the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), Nagpur. From 2008, the new watershed projects are being implemented as per the latest common guidelines for watershed development projects, developed by the NRAA.

1.5 Problems and Prospects in Watershed Management

Watershed management encounters many problems and constraints. Some of the major problems and constraints in watershed management are listed below.

1.5.1 Problems and Constraints in Watershed Management

(a) Land degradation in rain fed areas due to soil erosion from runoff is one of the major problems. In India it was estimated that the soil erosion in the 1990s was almost double that of soil erosion in the 1980s. Rainfall uncertainty and poor economic conditions act as a major constraint and thus prevents the farmers in rainfed areas from making investments. This leads to improper watershed management.

(b) Equitable benefit sharing of watershed management within the farming communities as well as within the different locations of watershed is a huge problem. Generally, women, marginal farmers and landless laborers gain very little or nothing at all from the watershed management activities. Several case studies in water scarce states of Gujarat and Madhya Pradesh in India have showed that overdevelopment of water harvesting structures in the upstream portion of watersheds had significantly reduced the inflows into the downstream reservoirs. On the other hand, it is also noticed that building of large reservoirs resulted in the submergence and hardship in the upstream parts and benefits for people in the downstream parts of the same watershed or a neighboring watershed generally having an urban or an industrial area.

(c) Acute shortage of water in general and drinking water especially in summer has been observed in many watersheds with inadequate watershed management which may result in severe/ recurrent droughts. It may often result in limited and temporary food productivity gains.

(d) Many a times, common lands do not get treated adequately and re-vegetation does not take place as expected in spite of the watershed management programs. As a result of this, domestic/ ecosystem water needs and livestock water/ fodder needs are either inadequately addressed or are made to suffer due to increased water withdrawals by other uses or due to overgrazing.

(e) Problems exist or new problems crop up due to improper understanding of the interaction between biophysical and socio-economic processes in watershed management.

(f) Conflict among various government ministries such as those related to agriculture [with emphasis on food production], rural development [with emphasis on employment generation & poverty alleviation], forests [with emphasis on maintaining biodiversity & wildlife], as well as conflict between government bureaucracy and elected representatives in their zeal to control funds, is a major problem in watershed management programs -which requires to be resolved on a priority basis.

(g) It is hard to conduct meaningful impact assessment studies on watershed management programs for lack of baseline data for monitoring and comparison of the current conditions. The whole exercise of watershed management is undertaken without properly estimating the water supply scenarios under drought/ normal/ surplus years as well as without proper demand management especially during drought years.

(h) Large areas inhabited with tribal population lack facilities to harvest water and to stabilize their food/ crop/ fodder production due to reduced forest yields, deterioration in land quality, lack of tribal agriculture policy and population pressure. This leads to a sustained misery, socio-political unrest and insurgency among the tribal population.

1.5.2 New Prospects and Opportunities Associated with Watershed Management

In spite of the above-mentioned problems and constraints as well as some other problems and constraints, watershed management is associated with new prospects and opportunities. Some of them are listed below:

(a) There is a need to produce more and better food without further undermining the environment/ ecology, especially the land, water, forests, wildlife and atmosphere. This may include adoption of best management practices (BMPs) such as organic farming, de-silting for reservoir capacity restoration as well as for crop productivity increase, sprinkler and/ or drip irrigation to avoid excess use of water, no tree felling policy, afforestation and arboriculture through high oxygen yielding & other medicinal plants etc.

(b) There is a need to ensure that gains due to groundwater recharge are not dissipated by excess groundwater extraction. To achieve this, groundwater over-extraction should be avoided through public awareness and also through regulation.

(c) There is a need to consider the downstream impacts of intensive upstream water conservation. For this, watershed associations with representations from all the stakeholders in the watershed should be made operational. These associations can take decisions in the best interest of all the people concerned.

(d) Decreasing the costs at which the gains are achieved and thereby increasing the modest benefit-cost ratio should offer new prospect and opportunity in watershed management. To realize this, low cost technologies which may involve local materials, labour at practically no cost, technologies which are traditional and time tested should be employed to generate more benefits spread over the entire watershed among all the stakeholders.

(e) Increasing all sections of people's participation beyond the project implementation stage to ensure sustainable watershed management should be a top priority. Only this can ensure progress on a sustained basis overcoming the hydro-geological, socio-political and other uncertainties.

(f) Many successful watershed management programs -especially in India, have been implemented on a small scale in a few villages by collaborated efforts among the government departments, non-governmental organizations (NGOs) and research organizations. They represent sporadic BMPs. Hence there is a need to scale up the watershed management activities over large areas which could include remote and/or difficult terrains, so that many problems affecting our agricultural, rural and forest sectors can be effectively addressed.

(g) Since there have been no or very few institutions built for research & development on collective management of watersheds, there is a need to build centers of advanced learning employing the modern tools of remote sensing, geographic information systems, decision support systems, computer based planning tools, poverty & socio-economic analysis etc.

(h) There is a need to preserve and improve common pool resources (CPRs) of land, water, fodder, forest, fisheries, wild life and agriculture which significantly contribute towards people's livelihood especially in the rural areas.

(i) There is a need to minimize migration to urban areas by creating opportunities in agriculture, natural disasters like floods/ droughts, forest/ mountain economies and by arresting fall in agricultural prices, gap in urban/ rural wages, gaps in urban/ rural employment opportunities.

1.6 Applications of Remote Sensing and Geographical Information System (GIS) in Watershed Planning

Remote sensing and GIS two of the important modern tools which have many applications in watershed planning. In this section, the remote sensing applications in watershed planning are discussed followed by the GIS applications.

Doppler RADAR (i.e., Radio Amplification Detection and Ranging) is used in the enhanced meteorological collection of data such as wind speed and direction within weather systems. By measuring the bulges of water caused by gravity, features on the seafloor to a resolution of about a mile are mapped. By measuring the height and wavelength of ocean waves, the altimeters measure wind speeds and direction and surface ocean currents and directions. Light detection and ranging (LIDAR) is used to detect and measure the concentration of various chemicals in the atmosphere, while airborne Heights of objects and features on the ground can be measured more accurately by LIDAR than radar technology.

Remote sensing of vegetation cover is a principal application of LIDAR. Simultaneous multispectral platforms such as the images from the Landsat remote sensing satellite have been in use since the 1970s. Maps of land cover and land use from thematic mapping can be used to find minerals, detect or monitor land usage and deforestation and examine the health of indigenous plants and crops, including entire farming regions or forests.

Within the scope of the combat against desertification, remote sensing allows to follow up and monitor risk areas in the long term, to determine desertification factors, to support decision-makers in defining the relevant measures of environmental management and to assess their impact on watershed planning. After the successful launching of India's remote sensing satellites viz., Bhaskara 1 and Bhaskara 2 in 1979 and 1981, respectively, India began developing an indigenous Indian Remote Sensing (IRS) satellite program to support the national economy in the areas of agriculture, water resources, forestry and ecology, geology, watersheds, marine fisheries and coastal management.

The Indian Remote Sensing satellites are the mainstay of National Natural Resources Management System (NNRMS) for which Government of India's (GoI) Department of Space (DOS) is the nodal agency, providing operational remote sensing data services. Data from the IRS satellites are received and disseminated. With the advent of high-resolution satellites, new applications in the areas of urban sprawl, infrastructure planning and other large-scale applications for mapping have been initiated. Remote sensing applications in the country, under the umbrella of NNRMS, now cover diverse fields within the domain of watershed planning and management such as pre-harvest crop area and production estimation of major crops, drought monitoring and assessment based on vegetation condition, flood risk zone mapping etc.

GIS has been widely used in characterization and assessment studies which require a watershed-based approach. Basic physical characteristics of a watershed such as the drainage network and flow paths can be derived from readily available Digital Elevation Models (DEMs) and data such as the United States Geological Survey's (USGS) National Hydrography Dataset (NHD) Program. This, in conjunction with precipitation and other water quality monitoring data from sources such as the Environmental Protection Agency's (EPA) BASINS (i.e., Better Assessment Science Integrating Point & Non-point Sources) database and USGS, enhances development of a watershed action plan and identification of existing and potential pollution problems in the watershed.

Data gathered from Global Positioning System (GPS) surveys and from environmental remote sensing systems can be fused within a GIS for a successful characterization and assessment of watershed functions and conditions.

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