CHAPTER TWO

REVIEW OF LITERATURE

Literature pertaining to research topic has been reviewed and presented under the following sub-heads.

2.1. Morphometric Characteristics of the Watershed Using Remote Sensing and Geographical Information System

The morphometric analysis of any watershed provides an account about the topography of the area, geological conditions and runoff potential of the watershed. Morphometric analysis is the measurement of a three dimensional geometry of the landforms and has traditionally been applied to watershed, drainages, hill slopes and other group of terrain features. The morphometric characteristics of a watershed represent its attributes and can be helpful in synthesizing its hydrological behavior. Remote sensing and GIS technique is a powerful tool for morphometric analysis. It provides efficient tool in drainage delineation and updation. It is effective in overcoming most of the problems of land and water resources planning and management on the account of usage of conventional methods of data process. Hence, morphometric analysis of a watershed is an essential first step, towards basic understanding of watershed dynamics.

Strahler (1964) stated that the morphometric analysis of a watershed provides the quantitative aspects of the characterization of watersheds. Various scholars have carried out morphometric analysis of river basins by using remote sensing and geographical information system techniques. Shrimali et.al. (2001) have worked on Sukhumi lake catchment in the Shiwalik hills for the delineation and prioritization of soil erosion areas by GIS and RS.

Narendra et.al. (2006) also studied the morphometric analysis of Mehadrigedda watershed, Vishakhapatnam, Andhra Pradesh using GIS and RESOURCESAT data. It was found that the morphometric study of the drainage basin is very useful for planning the soil and water conservation measures in the basin.

According to Epser (1998) the morphometric assessment helps to elaborate the primary hydrological diagnosis in order to predict approximate behavior of a watershed if correctly interrelated with the physiographic characteristics of the
drainage basin, such as size, shape, slope, drainage density and size and length of the streams etc. Hence, morphometric analysis of a watershed is an essential first step towards basic understanding of watershed dynamics.

Biswas et.al. (1999) stated that the watershed prioritization is the ranking of different sub watersheds of a watershed according to the order in which they have to be taken for treatment and soil conservation measures. Morphometric analysis could be used for prioritization of watersheds by studying different linear and aerial parameters of the watershed even without the availability of soil maps.

Nag et.al. (2003) defined morphometry as the measurement and mathematical analysis of the configuration of the earth surface, shape and dimensions of its landforms. The morphometric analysis is carried out through the measurement of linear, areal and relief aspects of the basin and slope contribution. Various morphometric parameters of the basin are computed through GIS technique.

Barber (2005) stated that morphometric analysis of any watershed provides an account about the topography of the area, geological conditions and runoff potential of the watershed. Morphometric analysis is the measurement of a three dimensional geometry of the landforms and has traditionally been applied to watershed, drainages, hill slopes and other group of terrain features. The morphometric characteristics of a watershed represent its attributes and can be helpful in synthesizing its hydrological behavior. Remote sensing and GIS technique is a powerful tool for morphometric analysis. It provides efficient tool in drainage delineation and updation. It is effective in overcoming most of the problems of land and water resources planning and management on the account of usage of conventional methods of data process.

Chitra et. al. (2011) used remote sensing and GIS techniques to study the watershed characteristics of Kundah sub basin in Karnataka. They found that higher the order, the longer the length of stream is noticed in nature. Longer length of stream is advantageous over the shorter length, in that the former collects water from wider area and greater option for construction of a bund along the length; the lower stream lengths are likely to have lower runoff.

Soni et.al. (2013) carried out the morphometric analysis of Mini Watershed-Rachhar Nala of Anuppur district in Madhya Pradesh through updated drainage. Drainage pattern of the study area was sub-dendritic and parallel with moderate drainage texture. Sub-dendritic drainage exhibits homogeneity in texture and lack of structural control but parallel drainage pattern suggest that the area has a gentle,
uniform slopes and with less resistant bed rock. The mean bifurcation ratio value is 3.94 which indicates geologically controlled drainage pattern. The average value of drainage density for the basin area was 3.30 km/km² while in grid method measurement the value varied from 1.08 to 4.88 km/km². In drainage density map analysis it was found that maximum basin area was covered in medium drainage density value which indicated medium surface runoff, moderate impermeable subsurface material, moderate sparse vegetation, steep to high relief and well developed network. It was found that streams originate from high relief or high slope region then comes to steep slope region and then flows in gentle slope area to meet the Narmada River. Due to medium drainage density and slope the area indicated moderate ground water recharge zone. The morphometric characteristics evaluated using GIS helped to understand various terrain parameters which were important for planning and management of the basin area.

Wandre et al. (2013) assessed the morphometric characteristics of Shetrunji River Basin using remote sensing and geographical information system. Using the IRS P6 LISS III and cartosat satellite images of the study area thematic analysis was made for the said themes using the ArcMap V9.2. Various morphometric characteristics of the Shetrunji river basin was assessed by applying GIS techniques. Strahler’s method was employed to assess the fluvial characteristics of the study region. The morphometric characteristics of the Shetrunji river basin as a whole and for each watershed will be helpful for the efficient planning of water harvesting and groundwater recharge projects on watershed base.

Gebre et al. (2015) studied the watershed attributes for water resources management using GIS of Chelekot watershed in Ethiopia. The results of the study indicated that the pattern classification of the micro-watershed was a dendritic type, which is characterized by homogenous subsurface strata. The watershed drainage pattern analysis indicated that the area had few structural or tectonics controls. The stream order of the watershed varied from first order to fifth orders. Large numbers of streams were found in the first and second orders. As the stream order increased the total number of streams decreased. The total number of stream segment was highest in first order streams and decreased as the stream order increases. The total length of streams in the watershed was about 177.1 km. The mean stream length (Lsm) and their ratio was computed using GIS software. The watershed had a classification of dendritic drainage patterns, despite stream lengths and other hydrological properties.
2.2. Land and Water Resources of the Watershed

Effective use of land and water is fundamental to growth and sustainable development. The concept of watershed management has evolved to ensure effective use of both natural and social capitals. Thus, the watershed development programmes include land, water and human resources as essential components. The watershed programme is primarily a land based programme, which is increasingly being focused on water management through increased in-situ soil moisture conservation and protective irrigation. In rainfed agriculture harvesting and management of water resources is of prime importance for conserving the runoff water for potential use during the season as well as in the off season. In the present scenario, water harvesting is the central issue in the watershed development programme.

Bali (1988) had given some basic recommendations with regard to watershed management. These consist of (a) to evolve a policy on watershed management, (b) water and land development should be the core and conservation production systems-the shell of watershed management policy (c) with bottom-up approach provide catalytic help through various interventions like water and land development measures (e) promote closure and grassland development plan only where you can protect and (f) split big watersheds into smaller ones of 300 ha or less; plan and execute intensively.

Pender et.al. (1998) stated that irrigation, however small, is an important complement to soil conservation development and adaptation of conservation measures in rainfed areas is an urgent need. Efforts to promote soil conservation structures must be designed according to local conditions. There is no ‘one-size fits-all’ solution to soil erosion problems. Standardized project designs that work in one location are likely to encounter unexpected constraints elsewhere.

Dwivedi et.al. (2000) studied the land cover and vegetation density in Adarsha watershed using satellite images to assess the impact of various interventions on these parameters. The IRS-IC and ID LISS-III images in April 1996 and April 2000, and the normalized difference vegetation index (NDVI) images generated from these were examined for change in land cover. Examination of the images from 1996 and 2000 revealed an increase in vegetation cover from 129 ha in 1996 to 200 ha in 2000.
Joshi et al. (2000); Kerr et al. (2000) reviewed the watershed projects in India, it was observed that most watershed projects did not address the equity issues of benefits, community participation, scaling-up approaches, monitoring and evaluation. Moreover, most of these projects relied heavily on government investments and were structure-driven (rainwater harvesting and soil conservation structures), and failed to address the issue of the efficient use of natural resources (soil and water). This is mainly due to the lack of technical support to such projects implemented by NGOs.

Ratna Reddy (2000) stated that the irrigated agriculture in India has probably reached its limit and further sustainable increases in food production must come from dry land farming, especially watershed development and management. This calls for an analysis of situations under which watershed technology becomes economically viable, socially acceptable and ecologically sustainable in the long run. To achieve the basic objectives of the watershed development project an effective implementation mechanism through integrated approach is indispensable by proper planning, implementation, administration and monitoring.

Rosegrant et al. (2000) concluded that water harvesting has the potential in some regions to improve rainfed crop yields and can provide farmers with improved water availability and increased soil fertility in some local and regional ecosystems, as well as environmental benefits through reduced soil erosion. However despite localized successes, broader acceptance of farmers for water harvesting techniques has been limited due to high costs of implementation and higher short-term risk due to the necessity of additional inputs, cash and labor. Water harvesting initiatives frequently suffer from lack of hydrological data and insufficient attention during the planning stages to important social and economic considerations, and the absence of a long-term government strategy for ensuring sustainability of intervention. The authors noted that greater involvement of farmers for planning and maintenance and provision of appropriate educational and extension support helped in expanding the contribution of water harvesting methods.

Arya and Samra (2001) studied the watershed management programmes in Shiwalik region. It was found that hill Resource Management Societies were constituted in 14 villages (out of 27) and the two most important common property assets were the forest lands and rain water harvesting tanks. The major investments by the Societies have been on repair and maintenance of dams and other infrastructure.
Wani et al. (2001) stated that the watershed management is increasingly being recognized as the ideal approach for integrated natural resources management in rainfed areas. About 51% of India’s geographical area (329 million ha) is categorized as degraded, most of which occurs in rainfed agro-eco systems. About 70% of the population is dependent on agriculture, and two thirds of the cropped area is dependent on rainfall without any protective irrigation.

Wani and Ramkrishna (2001) conducted a study at ICRISAT on-station watershed. The study revealed that after storing the rainwater in soil profile through in-situ conservation measures like broad bed furrow and flat on grade, the excess water was safely taken out of field and stored in above ground tanks and dugout farm ponds, which could be used as life saving irrigation and enhancing groundwater recharge. In rainfed agriculture conjunctive use through supplemental irrigation resulted in increasing crop productivities substantially.

Pathak et al. (2002) observed a significant reduction in runoff from the treated Adarsha watershed, Kothapally compared to the untreated watershed in 2000 and 2001. In the high rainfall year (2000), a significant reduction in runoff from the treated watershed (45% less than the untreated area) was observed. Even during a subnormal rainfall year (2001), a significant reduction in runoff volume (29% less than the treated area) was recorded. Daily runoff volumes and the effect of high intensity and large rains during 2000 on the treated and untreated watershed were also observed. Rainfall on 24 August 2000 alone accounted for about (78 mm) 70% of the total annual runoff (118 mm). Two years (1999 and 2001) out of three years were low rainfall years. In addition to low rainfall, most rainfall events were low intensity resulting in very low seasonal runoff during 1999 and 2001. In general, during low runoff years, the differences between the treated and untreated watersheds were very small. During a good rainfall year, i.e. 2000, a significant difference in runoff was observed between treated and untreated watersheds. Soil loss was measured from treated and untreated watershed during 2001, and a significant reduction in soil loss (only 1/3) was found from treated compared to untreated watersheds.

Reddy et al. (2002) reiterated that a watershed is an ideal unit for management of resources like land and water for mitigation of the impact of natural disasters for achieving sustainable development. Soil conservation is the most important measure taken to check the ravages of soil erosion in India. Land is a precious resource as it is the physical base of biomass on the earth. Conservation of such type of natural
resources is important to mitigate the increasing demand of food, fodder, fiber, water from the available limited precious land resources.

Sastry et al., (2002) coupled the concept of conservation of rainwater where it falls through watershed programme with support to farmers in production and marketing of produce of the crops. This would certainly bring revolutionary change in agriculture in rainfed agro-eco regions in the country. Thus, judicious management of soil, rainwater, vegetation and agricultural crops would usher the prosperity of the farmers in rural areas.

Sastry et al., (2002) studied the Watershed Development Programmes that has been taken up in large scale in Kuppam constituency area in Chittoor district of Andhra Pradesh. Many water harvesting structures such as check dam cascades, percolation tanks and farm/sunken ponds were constructed to augment water resources in addition to canopy development. It was observed that ground water recharge has increased tremendously. As a result many bore wells have been dug in the area and highly value added and exportable quality vegetable crops (Jerkin, baby corn, etc.) have been introduced and grown in this area under drip/ sprinkler irrigation systems. Thus water use efficiency has increased. The assured market for vegetables and high value crops made the farmer to adopt the technologies to net higher returns. The technical/scientific personnel of Israel project provided all guidance and support to the farmers in relation to the production and marketing of vegetables and products of other crops.

Shiferaw et al. (2002) conducted a survey in Adarsha watershed Kothapally before implementation of the watershed development programme. The results of the survey indicated that in Kothapally village: (i) drylands were more extensive than irrigated land; (ii) literacy was low; (iii) labour was scarce; (iv) crop yields were low, (v) there was not a single water harvesting structure in the village; and (vi) no income generating activities had been taken up by the villagers.

Wani et al. (2002) implemented farmer-based soil-water conservation measures on individual fields of the farmers in Adarsha watershed, Kothapally. They were broad bed and furrow (BBF) landform and contour planting to conserve in-situ soil and water; use of the tropicator for planting, fertilizer application and weeding operation; field bunding (38 ha); and planting Gliricidia on field bunds to strengthen bunds, conserve rainwater and supply nitrogen-rich organic matter for in situ application to crops. There were 15 bore wells before project initiation and 55 bore
wells were drilled during the project. There were 62 open wells in the Adarsha watershed. Based on the three years (1999-2001) of observations of groundwater levels in open wells, the estimated mean average rise of ground water was 4.15m. Thus the average contribution of the seasonal rainfall to the groundwater in the watershed was estimated at approximately 27% of the seasonal rainfall.

Wani et.al. (2002b) revealed that the watershed activities in Adarsha watershed Kothapally yielded promising results despite drought conditions during the last two years. The benefits were documented in the form of: (i) improved groundwater level: (ii) reduced runoff from 12% to 6%: (iii) reduced soil loss to < 1t/ha ; (iv) increased crop yields: (v) higher income from new cropping systems: and (vi) improved greenery in the watershed area. Water was the catalyst for improving the crop yields and enhancing the crop income, which was due to the soil and water conservation measures.

Sastry et.al., (2003) reported the opinion of most of the farmers across the country that the sustainability of agriculture is possible by harnessing rainwater and improving the ground water, which is possible through soil and water conservation measures. Farmers also reported that soil erosion can be minimized and irrigation potential can be improved through soil and water conservation measures. In addition suitable canopy development is a must for minimizing further soil loss. Forestry/agro-forestry/orchards system would improve micro-climatic conditions in the region.

Joshi et.al. (2004) studied the impact of watershed development programme in Hiware Bazaar situated 17 km from Ahmadnagar town in Maharashtra state. The total watershed area in the village is 977 ha, divided into three watersheds of 612 ha, 123 ha and 242 ha. The average rainfall in the village is 300-330 mm. The soil depth is 50-60 cm in the watershed area. It was found that the groundwater table has increased from a depth of 35-50 feet to 10-15 feet. Prior to project implementation water was available in the village at a depth of 35 to 50 feet during the monsoons and about 55 to 60 feet during summer. The number of wells in the village increased from 97 in 1993 to 217 in 2000. These wells are located near the village stream and near percolation tank constructed by the Agriculture Department. The farmers in this part of the village could harvest two crops a year and are able to cultivate high-value cash crops like onions, potatoes, other vegetables and fruits.

Reddy et.al. (2004) revealed that bunding, water/diversion channels, gully plugs, Gabion structures reduces soil loss and channelizes for proper flow of water
and water harvesting structures improve groundwater potential in addition to surface water, vegetation covering the land with grasses, trees, orchard plants would reduce soil loss, soil erosion, etc. and improves microclimate. Hence, systematic planning and mapping is required to prepare a plan to develop and maintain natural resources – soil, water and vegetation for sustainable growth of agriculture in rainfed agro-eco regions in India.

Sastry (2004) reported results of an evaluation study carried out in 31 different watershed sites across different states in India viz; Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Chhattisgarh, Uttar Pradesh and concluded that the impact of water resources development interventions is substantial in several WSM programs with significant increase of about 60% of area under irrigation. The irrigation by wells contributed maximum up to 71.9 % increase in irrigated area followed by tube wells and tank irrigation. He further observed that, watershed approach under different ongoing area development programmes created substantial impact on crop production, rural household income and employment.

Wangkahart et.al. (2005) reviewed the various watershed development works in North-East Thailand and discussed their approaches and impact on agricultural productivity and natural resources. In Tad Fa watershed, 17 farm ponds each of 1260 m$^3$ of volume were constructed that provided much needed supplemental irrigation to crops/fruit trees/vegetables particularly in the post rainy season. In large areas the field bunds were constructed along with the vetiver grass for controlling soil erosion. About 68% area was planted on contour on mild slopes. The cultivation increased the maize yield by 30-40 percent compared to conventional up and down cultivation. It also significantly reduced the soil loss. In Wang Chai watershed, the vegetative barriers were constructed to protect the roads and field bunds from erosion. Drains were constructed for safe disposal of excess run-off water. New crops and varieties were introduced in the watershed. The construction of farm ponds had significantly increased the cropping area and agricultural productivity in the post-rainy season.

Wani et. al. (2005) studied the Broad Base Furrow (BBF) and reveled that during 1995-2003 the improved BBF system recorded on an average 1 ha more grain yield than the flat landform. The BBF landform treatment stored 15 mm more rainfall in the soil profile than the flat landform treatment enhancing the green water flow and reducing the runoff. The run off in the flat land system (190mm) with a peak runoff rate (0.096 m$^3$/s/ha) compared unfavorably with the BBF system, which had lower
runoff (150 mm) and a lower peak runoff rate (0.086 m$^3$/s/ha) hence the BBF system was useful in decreasing runoff and increasing rainfall infiltration and green water use for crop production. The soil loss in flat land system was 2.2 t/ha versus 1.2 t/ha in the BBF system.

Pathak et.al. (2007) stated that integrated watershed development is the strategy adopted in the country for sustainable development of dry land areas. A recent comprehensive assessment of watershed programs in India undertaken by ICRISAT-led consortium revealed that integrated watershed can become the growth engine for sustainable development of dry land areas by improving the performance of 2/3rd watershed in the country.

Upadhye et.al. (2010) evaluated the Sawarde Bk. Watershed of Kagal Tehsil Dist. Kolhapur, India under NWDPRA using remote sensing and GIS. The parameters used to study the impact of WDP were land use, runoff and socio-economic status of the beneficiaries. The study revealed that the area under agriculture in the watershed increased in the post-development phase. The WDP works have resulted in decrease in the runoff from the watershed and slight increase in water harvesting.

Sherekar et.al. (2011) used the remote sensing and GIS technique to study the WGA-2A watershed of Wainganga river basin in Maharashtra. The various thematic layers like slope, land use, land cover, drainage, soil texture, soil depth, soil erosion and land capability were used for the preparation of water and land resource development action plan. These layers were overlaid using union operation and the suitable sites for the water conservation structures were suggested to reduce soil erosion and conserve the water as natural resource for the sustainable watershed management.

Osman et.al. (2013) reported that area under rainfed, grazing land, permanent pastures, current and other fallows, and cultivable wastelands registered decline in post project scenario and got converted into supplemental irrigated area to the extent of 115% in the post watershed development project compared to pre project period. The major impact of watershed was on bringing back of fallows and cultivable wastelands under cultivation.

According to Gebre et.al. (2015) the highest elevation in the Chelekot watershed is 2424 m from mean sea level and the lowest is 2019 m from mean sea level. This large elevation difference induced highest runoff and thus, less possibility for rainfall water infiltration. The slope map of the study was grouped into six classes
in percent. 0 - 3% (flat or almost flat), 3 - 8% (gentle sloping), 8 - 15% (sloping), 15 - 30% (moderately steep), 30 - 50% (steep) and more than 50% (very steep). Most of the area was classified as moderately steep slope. Gentle slopes were designated in the “excellent” category for groundwater management as the nearly flat terrain is favourable for more infiltration. Moderate slopes were also considered “good” due to slightly undulating topography which gave maximum percolation or partial runoff. Slope was a crucial factor which directly controlled the balance between runoff response and soil infiltration rates of the terrain. Slope of the terrain significantly controlled the development of the aquifers.

2.3. Impact of Watershed Development Programme on Groundwater Recharge and Irrigation Potential

The ground water is the major source of irrigation in the water scarce regions of the country. In the recent past, a sharp increase in groundwater use is recorded. About two-third of the total irrigation demand is met by ground water source. This expansion of ground water use has resulted in speedy decline in groundwater table in several parts of the country, this decline was recorded as about one to five meters every year under varying conditions. The evidences indicated that the lowering of water table was quite rapid in water scarce regions. This was resulted in the over exploitation of ground water and recommended an immediate attention towards this serious problem. Most of the farmers across the country are of the opinion that the sustainability of agriculture is possible by harnessing rainwater and improving the ground water, which is possible through soil and water conservation measures. Farmers also reported that soil erosion can be minimized and irrigation potential can be improved through soil and water conservation measures. In addition suitable canopy development is a must for minimizing further soil loss. Forestry/agro-forestry/orchards system would improve micro-climatic conditions in the region.

Gore et.al. (1998) conducted the groundwater modeling study of Wagarwadi watershed near Aundha Nagnath in Hingoli District of Maharashtra state using finite difference method that helped in assessing the GW recharge as 6.0 ha-m per year which resulted into 0.3 to 2.5 m rise in the wells located in 200 m on the downstream side of conservation structures.
Kerr *et al.* (2000) evaluated the development of watersheds dryland areas of India and revealed that due to variations in seasonal rains during the crops growing period, crops may face drought and sometimes water logging due to torrential downpours causing runoff. In order to conserve rainwater, minimize land degradation, improve groundwater recharge, increase crop intensity and crop productivity a watershed management approach is adopted.

Raju (2000) studied the status of the replenishable ground water. The groundwater resources were assessed as 43.19 million ha-m and utilizable ground water for irrigation is 32.56 million ha-m. The availability of water per capita per year is much lower in many river basins for the present population of more than one billion. Therefore, augmentation of ground water reservoirs through people’s participation is essential.

Goel and Samra, (2001) conducted a study at Rel Majra watershed in Shivalik region. It was revealed that soil and water conservation measures viz. contour and staggered trenches, nala bunds, cement plugs, loose boulder check dams, contour bunds, graded bunds, nala training works, diversion drains when implemented on watershed basis have definite impact on replenishment of ground water resources.

Khepar, *et al.* (2001) reported an increase in ground water table in open wells as high as 1.0 m and consequently, the irrigated area in the Kandi watershed project registered an increase of 172% compared to the pre-treatment period resulting in 70% higher crop yields. It was also observed that the soil and water conservation works implemented in the watershed project area resulted in an average increase in the ground water level of about 5.9 cm/year.

Osman et al., (2001) studied the rainwater use efficiency with supplemental irrigation and revealed that after storing the rainwater in soil profile through *in-situ* conservation measures, the excess water is safely taken out of fields and stored in above ground tanks and dugout farm ponds, which could be used as life-saving irrigation or enhancing groundwater recharge. In rain-fed agriculture, conjunctive use through supplemental irrigation from harvested run-off water or recharged groundwater results in increasing crop productivities substantially. The green-blue water (rain-fed systems with supplemental irrigation system) continuum proved to be more effective in terms of improving overall water-use efficiency.

Bisrat Alemu *et al.* (2002) conducted an impact assessment of Watershed Development Programme in augmenting groundwater resources in Basavapura
watershed of Kolar district in Karnataka state. Before implementation of the Watershed Development Programme, the sample of 40 farmers were having 52 irrigation wells, of which 16 were dug wells, 31 were bore wells, 2 were dug cum bore wells and the rest three were filter point wells. Among the 52 wells, 15 were non-functional and 37 were functional earlier to the implementation of Watershed Development Programme. With the introduction of Watershed Development Programme, the number of wells were increased to 72 (at a growth rate of 6.4 per cent per year). Among them 16 were dug wells, 51 were bore wells, 2 were dug cum bore wells and rest 3 were filter point wells. After implementation of Watershed Development Programme, the numbers of non-functioning wells were reduced to 5 from 9. Outside the watershed, the number of dug wells were increased to 34 from 22 during the same period, of which 13 (38 per cent) were non functional, wherein on an average, two wells were non-functioning per year.

Om Prakash, Sastry and Samra (2002) reported that the integrated watershed management programmes without village level institutions like, Watershed Association, Watershed Committee, User Groups and Self Help Groups cannot sustain for long in an efficient and effective manner nor the natural resources can be managed/ protected. The PIA/WDT members will act as facilitators to these Institutions. Further, it is also suggested that Gram Panchayat itself may not be considered as Watershed Association to avoid any political interference and ensure more people’s participation as a separate body particularly for conservation of natural resources on sustainable basis.

Pathak et.al. (2002) studied the effect of water harvesting structures in the contribution of seasonal rainfall received during normal year to groundwater in various watersheds in India. The various water harvesting structures (WHS) resulted in the average contribution of seasonal rainfall during normal rainfall year to groundwater ranged from 27 to 34 per cent. The contribution to groundwater was 27% in Adarsha watershed, Kothapally, Andhra Pradesh, 29% in Lalatora watershed, Madhya Pradesh and Rajsamadhiayala watershed, Gujrat was 34%.

Wani et.al. (2003) stated that the integrated watershed development is the strategy adopted in the country for sustainable development of dry land areas. A recent comprehensive assessment of watershed programs in India was undertaken by ICRISAT- led consortium revealed that integrated watershed can become the growth engine for sustainable development of dry land areas by improving the performance
of 2/3rd watershed in the country. In most of the developed watersheds with concerted efforts to manage rainwater, the groundwater availability is improved not only in the watershed, but the downstream areas also benefited with increased groundwater recharge. It was also observed that in Lalatora watershed in Madhya Pradesh, the groundwater level in treated area registered an average rise of 7.3 m, at Bundi watershed in Rajasthan 5.7 m increase was observed and at the Adarsha watershed, Kothapally in Andhra Pradesh 4.2 m rise in ground water was recorded.

According to Joshi et.al. (2004) the important reason for the success of Fakot watershed was continuous flow of new information and improved technologies by CSWCRTI. The institute is regularly monitoring technical, hydrological and socioeconomic changes by posting two regular technical personnel in the village. These also act as extension agents and disseminate improved technologies. Water is a binding force for the farmers to work together for regular maintenance of the check dams. Market opportunities induced to cultivate high value crops which require regular water for irrigation.

Sastry et.al. (2004) carried out an extensive survey to assess the impact of watershed management practices on sustainability of land productivity and socioeconomic status of 37 watershed locations developed under the National Watershed Development Programme for Rainfed Areas. The rise in water table was examined under arid, semi arid and humid agro climatic conditions over the 37 watersheds. It was found that the groundwater rise was 1.36 m in heavy soil areas as compared to 1.72 m in light soils. It was observed that on an average the water table was rose by 1.05 m, 1.57 m and 1.38 m in arid, semi-arid and humid agro climatic conditions respectively. The rise in groundwater was high in semiarid region. It was relatively less in the humid region. This could be due to high and variable slopes in the humid region. The surface water resources were developed to the tune of 9%, 18% and 20.5% in arid, semi-arid and humid agro climatic conditions respectively.

Sethi and Jena (2004) studied the impacts of watershed management on groundwater availability in various regions of the country. It was found that the impact varies in different agro-ecological regions. In Aravali hills of Rajasthan, the groundwater table rose by an average of 7.97 m after six years of watershed development programme. Due to increased availability of water for irrigation, there was an increase of 83 per cent in post-monsoon cropped area. In Yamuna ravine of Uttar Pradesh, the watershed management measures resulted in rise of ground water
table ranging from 1.53 to 6.05m depending upon monsoon rainfall. In Malwa region of Madhya Pradesh, the average annual post-monsoon increase in groundwater was 6.79 m due to implementation of watershed management measures compared to just 1.5-2.0 m in pre-project era.

Palanisami and Suresh Kumar (2005) examined the overall performance of watershed development programme in the state of Tamil Nadu. They reported that due to the soil and water conservation interventions carried out in the watershed the water level in the open dug wells increased from 2.5 m to 3.5 m in Kattampatti watershed and 2.0 m to 3.0 m in Kodangipalayam watershed, the groundwater recuperation in the nearby wells was observed to be increased, also the irrigated area and the irrigation intensity in the study area was found increased. The most important notable feature of the watershed development programme is that seven out of nine dug wells of the respondents during the household survey which were totally dry got recharged and became fully functional.

Sharda et.al. (2005) revealed that various water resources development activities in five watersheds located in different agro-climatic zones created additional water storage capacity ranging from 121 to 1584 ha-cm with an average of 474 ha-cm. It helped significantly in augmenting the groundwater recharge which was reflected through increase in recharge rate of 20 to 73 % wells located in the influence zone of the water harvesting structures. The irrigated area was increased by 65 to 585%, with an average of 206% resulting into the rise in crop production and boost in farmer’s income.

CGWB (2006) reported that the groundwater is an invisible and endangered open and common access resource. Overexploitation of the groundwater resources beyond the sustainability limits in several parts of the country had resulted in widespread and progressive depletion of its level in selected pockets of 370 (61%) out of 603 districts in the country. In 15% of the blocks, the annual extraction of the groundwater exceeds the annual recharge and in 4% of the blocks it is more than 90% of the recharge.

Sreedevi et.al. (2006) conducted a detailed study of groundwater scenario in the Rajsamadhiayala watershed, Gujarat. During pre-and post-watershed interventions, it was revealed that the mean total groundwater recharge has increased by three folds in different rainfall situations and the water requirement has doubled after the watershed interventions due to increased cropped area, cropping intensity
and change in the cropping pattern. The average water column was increased from 5.9 m in 1995 to 10.4 m in 2004. Not only increase in the water column is observed, significant improvement in the water yield in wells were also reported based upon the duration of pumping hours per day for irrigation. The average pumping duration of 5.25 hr per day in 1995 increased to 10.4 hr per day in 2004, which means that there is a net increase of 5.2 hr per day of pumping duration.

Government of India (2007) reported that the groundwater, which is 38.5 % of the available water sources of the country, plays a major role in irrigation, rural and urban drinking water supply and industrial development. Groundwater meets nearly 55% irrigation. 85% of rural and 50% of urban and industrial needs. The average rate of increase in number of wells per year in India was 2.3%. The number of tube and open wells increased at the rate of 6.3% and 2.4% per year respectively. It is estimated that currently there are 19 million wells in the country, out of which 16 million wells are in use and drawing about 213 BCM of water. The use of groundwater in the agriculture sector has expanded rapidly because of the short gestation lags with which it can be developed, control over irrigation that it provides, free or subsidized availability of power in some states, water requirements for the crop production during critical growth stages caused due to erratic rainfall in dry land agriculture and paucity of surface irrigation.

Wani et.al. (2009) studied the impact of the various watersheds development programme in India. In Lalatora watershed in Madhya Pradesh, the treated area registered a groundwater level rise by 7.3 m. At Bundi in Rajashtan the average rise was 5.7 m, and the irrigated area increased from 207 ha to 343 ha. In the Kothapally watershed, the groundwater level in open wells rose by 4.2 m. in the Rajasamadhiyala, the number of open wells increased from 255 in 1995, with very poor yield with an average water column of 5.9 m to 308 wells with mean water column of 10.4 m. overall, there has been an increase of 4.4 m of water column in 2004, as compared to that of 1995. The average pumping duration of 5.25 h per day in 1995 increased to 10.4 h per day in 2004, resulting in increased irrigated area by 58 per cent. Similarly, the number of bore wells also increased from 102 to 200 during the period. The number of bore wells in the watershed were doubled and was a cause of concern as in spite of farmers experience of defunct bore wells in 1995 and earlier they have again drilled more bore wells than open wells. The marginal positive
groundwater balance in lean and average rainfall years could tilt to negative side very soon if the farmers continued drilling bore wells.

Wani et al. (2009) studied the effect of soil water conservation and rainwater harvesting interventions on groundwater recharging in Bundi watershed in Rajasthan. It was observed that the interventions resulted in groundwater both in terms of duration of water available and the water yield from the wells. Before the watershed interventions, only 88 wells use to have water for 8 to 12 months in a year, whereas after the watershed interventions it increased to 187 wells. Before watershed interventions, 52 wells out of 227 wells were functional only for 1-4 months mainly during the rainy season, whereas after the watershed interventions particularly due to the construction of WHS, majority of the seasonal functional wells have become functional throughout the year. Similarly, the mean depth of water column in the wells before the watershed interventions was 4.5 m, compared to 9.5 m after the interventions.

Osman et al. (2013) reported a significant improvement in groundwater level in the watershed area resulting in increased area and number of irrigations per crop compared to baseline period (before WDP) leading to crop diversification. The average depth of groundwater level over a period of ten years in open dug wells from ground level before WDP was 9.5 m which got reduced to 6.1 m after WDP indicating a rise in water table of 3.4 m. The availability of groundwater also improved to 3.9 m even during summer which was earlier just 0.5 m prior to watershed development.

2.4. Various Performance Indicators of the Watershed

There are no single definitive indicators or measures and indices for overall impact measurement/assessment in view of complexities and diverse/multiple objectives of watershed development projects. In view of this, a set of quantitative and qualitative simple surrogate measures, indicators and indices may be evolved and/or used to assess changes as a result of watershed impact. Biophysical/technical, socio-cultural, economic, community participation, institutional and sustainability indicators are developed based on consultations with the project staff, farmers representative and other stake holders.
Drasana (2002) in a case study surveyed the impacts regarding the cultivation, environmental and socio-economic aspects of projects pertaining to the watershed management of the Tsiazompaniry region in Madagascar. Based on the results of the study, where the project was exposed to the three grounds mentioned above (cultivation, environmental and socio-economic), the results of the assessment proved successful. The most important cause for this was noted to be embedded in the public participation, the rural populace that was permitted to plant saplings in government owned lands, which also brought about a sense of reliance between the project authorities and the local inhabitants.

According to Kerr and Chung (2002), the quantitative and qualitative evaluation assessment methods that according to tradition have been utilized separately each have their weak and strong points. Therefore, a composition of these two methods, especially at times when curtailment is involved in the study plan, this evaluation can be more effective.

Samra et.al. (2002) calculated People’s participation Index (PPI) for a typical Shiwalik Watershed and observed to range from 28 to 84 per cent. The stakeholders participated in all the project activities right from the inception. With the increase in agricultural and animal husbandry components the women participation also increased considerably.

Lodha et.al. (2005) revealed that the livelihood indices are useful in addressing the issues of sustainability and policy making. For the Duhi watershed, the VDI index showed 8.7% and 10.1% improvement for the years 2001 and 2004 respectively from the base year 1997. The SCI improved by 417% by the year 2001 and 956% in 2004 from the base year 1997. The rate of growth for the year 2002 is observed to be about 18% from the base year 1997. The annual growth rate of the village was found to be around 1.2% which was lower than the average national rural growth rate of approximately 2% for India.

Sadeghi (2005) suggested two methods namely, quantitative and qualitative, in order to assess the impact measures of the watershed management. The quantitative method is extremely suitable and more accurate than the latter, on condition that, the statistics registered prior and after the implementation of the project are present. If this is not the case, it is essential that efficient and applicable methods are applied to qualitative methods in regions lacking registered statistics.
Sharda et.al. (2005) elaborated participatory watershed management for the six watersheds as per the Integrated Wasteland Development programme (IWDP) guidelines. The watersheds belong to different agro-ecological regions of the country having diverse physiographic, climatic and socio-economic conditions. Various indicators were employed to assess the impact of different activities showed significant improvement in biophysical, participatory and socio-economic attributes. The analysis of the data revealed that watershed interventions on arable and non-arable lands in a participatory mode significantly reduced runoff and soil loss which in turn improved crop productivity on an average by 28%.

Sharda et.al. (2005), assessed a cumulative effect of the interventions on agriculture improvement in the watersheds through the Cultivated Land Utilization Index (CLUI), which was based on the period of the year for which the cultivated area is under the different crops. The index value estimated for each of the six watersheds under study showed that land utilization improved by 2 to 81%. The CLUI of all the watersheds had increased from 0.26 in the pre-implementation to 0.33 in the post-implementation period as a result of increase in overall utilization of land.

Sharda et.al. (2005) revealed that the various agronomical interventions improved the yield of traditional crops by 9% (ladyfinger, Salaiyur) to 256% (tomato, Kokriguda). The overall crop productivity of the watersheds measured in terms of the Crop productivity index (CPI) increased from 12 to 45% depending upon the location and type of crops. The value of CPI improved from 0.50 to 0.64 after the post-implementation phase considering the five watersheds together from the different agro-climatic regions.

Sharda et.al. (2005) reported the increase in crop diversification index from 6 to 79% in all the watersheds except the Badakhera watershed. The increase in crop diversification index is attributed to the fact that earlier the farmers were practicing subsistence type of farming system with many crops but with better availability of resources, they switched over to lesser number of high yielding food and remunerative cash crops. The overall diversification of crops considering all watersheds together increased from 0.67 in the pre-project period to 0.82 after the project implementation.

Lodha et.al. (2008) developed an index to calculate the development of a village. The average of all HHDI values at village level will provide an index representing average development of the community at village level. This index is
termed the Village Development Index or VDI. Mathematically, it can be expressed as:

\[ VDI = \sum (HHDI_1 \times \ldots) \]  

Where \( x \) is the number of households in the village.

Lodha et al. (2008) developed an index to calculate the development of water resource in a watershed. An integration of all the village development indices at the watershed level would represent the general well-being of the community inhabiting the entire watershed in a holistic manner and such an integrated index is described as Watershed Development Index or WDI. A watershed may consist of several villages. VDI is calculated for each village in the watershed. The arithmetic mean of VDI values will provide the desired index WDI.

\[ WDI = \frac{\sum (VDI)}{y} \]  

Where \( y \) is the number of villages in the watershed.

The WDI is calculated using the village development indices based on the household data. Thus, the index is a realistic representation of the livelihood situation in the watershed area. The WDI can be observed during the implementation of the watershed development programme and hence the changes in livelihoods of the community can be evaluated.

Lodha et al. (2008) developed an index showing the stress on the community. The Stressed Community Index (SCI) is an index of stressed households with an HHDI index value of less than 0.20 at the beginning of the watershed development programmes. They are the most vulnerable group and have the fewest livelihood options. The average value of HHDI for such households will form the SCI. The numerical value of SCI can be traced throughout the implementation of the watershed program and is of great help in the evaluation of integrated watershed programmes or other such projects.

\[ SCI = \frac{\sum (HHLZ)}{z} \]  

HHLZ denotes households having an HHDI value less than 0.200 and \( z \) is the number of such stressed households.

Osman et al. (2009) developed CRIDA index, which accounts both area and income and used in their study to assess the impact of Watershed Development Programme (WDP) on land use diversification. However, most of the studies are confined to ex-ante analysis immediately after the completion of the project where impacts are clearly visible, but the question remains, to be answered is whether they
are sustainable in the medium to long run after the project period. The study focuses on ex-post analysis after a gap of one decade to understand the various aspects of sustainability and their drivers for drawing conclusions from the success of Kadwanchi watershed in Jalna district of Maharashtra state.

2.5. Impact of Watershed Development on Land Use Pattern, Cropping Pattern, Cropping Intensity and Crop Productivity

The watershed development programme is a natural resources-based programme, which is increasingly being focused on water, with its main objective being to enhance agricultural productivity through increased in-situ moisture conservation and protective irrigation. Thereby, increase in the cropping intensity and changes in cropping pattern will be observed.

Deshpande and Reddy (1990) reviewed watershed projects in Maharashtra originated and operated by State Department of soil conservation, Maharashtra (comprehensive watershed development programme). They noted changes in cropping pattern, intensity of cropping, proportion of wasteland brought under cultivation and yield per ha in the treated areas. The programme also helped in increasing the groundwater table. Impact parameters were analyzed in the context of scarcity zone, moderate rainfall zone and assured rainfall zone. It was observed that the impact parameters in the three zones were quite different.

Farrington et.al. (1999) provided an overview of the recorded impact of watershed development programs in the country. Results indicated that successful projects have in fact reduced runoff, increased surface water resources and recharged groundwater aquifers, improved drinking water supplies, increased the irrigated area, changed cropping patterns, crop intensity and agricultural productivity, increased availability of fuel and fodder, improved soil fertility and changed the composition of livestock. The impact of these projects on poverty alleviation and the long-term sustainability of project results were however less clear. Although some projects did seem to have paid attention to the needs of the landless poor but, their impact on poverty reduction was not assessed.

Joshi et.al. (2000) obtained results from a meta-analysis based on a large number of watershed studies. The study showed that watershed interventions in low income regions with rainfall levels ranging from 650 to 1000 mm performed better.
Based on the eco-regions, the same study also showed that the Western Himalayan regions and the southern zone of rainfed India performed relatively better than other regions. In the case studies Fakot (ICAR funded) and Sukhomajri watershed fall in Western Himalayan region, while watersheds under MYRADA and the consortium approach in Kothapally were in southern rainfed zone. These regions performed better with respect to productivity impacts than watershed located in other regions.

Government of India (2001) stated that the beneficial impacts such as increase in cropping intensity, change in cropping patterns, increase in crop productivity and increase in underground recharge as a result of conservation measures, reduction in soil and run-off losses with lesser siltation effect and reduction in sedimentation at watershed level were seen. These projects have also generated employment and increased family incomes through diversified farming system such as livestock development, dry land horticulture and household production activities.

Ramana (2001) reported results of an evaluation study carried out across different states in India and concluded that the impact of water resources development interventions is substantial in several WSM programs with significant increase of about 40% of area under irrigation. He further observed that, watershed approach under different ongoing area development programmes created substantial impact on crop production, rural household income and employment but, did not elaborate with regard to other issues such as out-migration and sustainability.

ICRISAT (2002) reported that several farmers evaluated BBF and flat landform treatments for shallow and medium-depth black soils using different treatment combinations. Farmers obtained 250 kg more pigeon pea and 50 kg more maize per hectare using BBF on medium-depth soils than from the flat landform treatment. Furthermore, even on the flat landform treatment farmers harvested 3.6 t/ha maize and pigeonpea using improved management options compared to only 1.7 t/ha maize and pigeonpea grain from their normal cultivation practices. The farmers with shallow soils reported similar benefits from BBF landform and improved management options for other cropping systems. The rainfall during 1999 was 559 mm, 30% below normal and that received in 2000 was 958 mm, 31% above normal. Despite this variation in rainfall, the productivity of the crop marked a sustainable increase during 1999-2000 and 2000-01.

Palanisami et.al. (2002) reported that watershed programs did not perform well in terms of controlling reservoir siltation, mitigating the impact of drought and
improving/ stabilizing the production of crops generally grown in rainfed areas like pulses and oilseeds. The production of many rainfed crops fluctuates depending on the pattern and quantity of rainfall. Also reservoirs are silting at alarming rates and droughts are causing hardships over large areas.

Pathak et. al. (2002) stated that a total of 200 ha were irrigated in post-kharif season and 100 ha in post rabi season, mostly vegetables, during the 2002-2003 cropping season due to additional groundwater recharge. Based on three years (1999-2001) of observations of groundwater levels in open wells, the estimated mean average rise of ground water was 415 cm thus the average contribution of the seasonal rainfall to groundwater in the watershed could be estimated at approximately 27% of the seasonal rainfall (assuming the specific yield of the aquifer material as 4.5%).

Rosegrant et.al. (2002) concluded that water harvesting has the potential in some regions to improve rainfed crop yields and can provide farmers with improved water availability and increased soil fertility in some local and regional ecosystems, as well as environmental benefits through reduced soil erosion. However, despite localized successes broader farmer acceptance of water harvesting techniques has been limited, due to high costs of implementation and higher short-term risk due to the necessity of additional inputs, cash and labor. Water harvesting initiatives frequently suffer from lack of hydrological data and insufficient attention during the planning stages to important social and economic considerations and the absence of a long-term government strategy for ensuring sustainability of intervention. The authors noted that greater involvement of farmers for planning and maintenance and provision of appropriate educational and extension support helped in expanding the contribution of water harvesting methods.

Wani et.al. (2002) reported that despite drought conditions in 1999 yield of maize increased to 3.25 t/ha in 1999 and 3.75 t/ha in 2000 from 1.5 t/ha in 1998. Similarly yield of intercropped pigeonpea went up to 0.64 t/ha in 1999 and 0.94 t/ha in 2000 from only 0.19 t/ha in 1998. Sole Sorghum yield went up from mere 1.07 t/ha in 1998 to 3.05 t/ha in 1999 and 3.17 t/ha in 2000. Yield levels were also substantially higher under farmer’s practices. Thus both availability of water and improved technologies contributed to such an impressive increase in the yield of different crops. Wani et.al. (2003) stated that rainfed arable lands are predominant (80%) worldwide and contribute 60% of the global cereal production. In developing countries up to 70% of the population depends directly or indirectly on agriculture, and 560 million
Poor people live in the semi-arid tropics. Most of the rainfed areas in developing countries suffer from one or another form of land degradation. Currently the average productivity of rainfed areas in the SAT is around 800-1000 kg/ha. Several studies have identified the main constraints for increased productivity in the tropics as low rainwater use efficiency for crop production (35-45%), inherent low soil fertility, inappropriate soil, water and nutrient management practices, low adoption of stress-tolerant cultivars of crops, insufficient pest management options and poverty (inability to invest for necessary inputs).

Wani et al. (2003) analyzed the data regarding the crop production activities and observed that average net returns per hectare for dryland cereals and pulses were significantly higher within the watershed. For cereals, the returns to family labour and land (net income) were 45% higher even with irrigation, while the net returns on rainfed cereal crops have more than doubled. Similarly for pulse crops, per hectare net returns within the watershed were more than double with irrigation and almost double without irrigation. This was mainly because the watershed development approach based on IGNRM includes improved cultivars of Sorghum (cereals), chickpea and pigeonpea (pulses) developed by ICRISAT, along with improved management of water and soil fertility. Adoption of improved varieties has not only increased crop yields, but also enhanced the economic profitability of other soil and water conservation investments, which might otherwise be economically unattractive to the farmers.

Wani et al. (2003) revealed that during 1998-2002 more pronounced impacts in terms of shift in cropping pattern were observed in a 500 ha Kothapally Adarsha Watershed. In this watershed the farmers grow a total of 22 crops and a remarkable shift has occurred in the cropping patterns from cotton (200 ha in 1998 to 80 ha in 2002) with simultaneous increase in area under maize and pigeon pea. The area under maize and pigeon pea increased more than three-fold from 60 ha to 200 ha and 50 ha to 180 ha respectively, and area under chick pea increased two-fold during the same period.

Joshi et al. (2004) studied the impact of watershed development program in Nalchha Milli Watershed (M.P.) and found that the bawdis (shallow wells) are the main source of drinking water. If there is enough water, it is used for irrigation of winter corps. Before implementation of the project, most of the villagers migrated during winter to Indore and nearby towns to do earthwork and work in brick kilns.
The most important indicator of success of the watershed program was increase in area under wheat and adoption of improved variety Lok 1 (requires light irrigation) resulting in a shift from pissi, an unirrigated variety. Another important benefit was shift from local to improved breed of buffalo and increase in number of buffaloes as compared to cows. Milk production has increased because of increased availability of fodder. Surplus milk is sold in nearby towns like Nalchha and Mandu. The other important income generation activity that has emerged is vermicompost. The district Rural Development Agency is the main buyer of this compost. Poultry has also emerged as an important source of income for the tribal population.

Rockstorm (2004) stated that current productivity of rainfed crops in the SAT hovers around 1.0 t/ha. However, numbers of studies have shown that productivity of rainfed farming system could be doubled or in some situations like West Africa could even be quadrupled through adoption of improved soil, water crop and nutrient management options.

Singh and Jain (2004) studied the Kandi Watershed and Area Development Project (KWADP) of Punjab where two periods were taken into account (1979-80 and 2000-01) which showed increase in cultivated area from 19.4% 53.3 % while cropping intensity was increased from 114 % to 143 % during the study period. Doubling of the total agriculture production was noticed during kharif and rabi, while the production from horticulture was several folds.

Sreedevi et. al. (2006) stated that the integrated watershed management through primarily water (surface and groundwater ) conservation and management compounded with other improved practices led to the significant increase in productivity, cropping intensity and income, while controlling degradation of natural resources. Compound growth rate (CGR) of productivity, net returns and benefit cost ratio were taken as the parameters for major crops. In case of Kothappally watershed, the increase in cropping intensity, B:C ratio and per capita income ranged between 30 - 55 %, 45 - 88% and 19 -78% respectively in community watershed after implementation of watershed interventions over the baseline data. In the Rajasamadhiayala watershed in Gujarat, per capita food secured was only 20 percent against requirement in 1995, while the food security increased drastically by 71 % in 1999, where as in 2003-04, the total per capita food security was attained (109%) owing to the overall development activities of the watershed programmes in general,
particularly due to additional water availability through rainwater harvesting and groundwater recharging structures.

Wani et al. (2006, 2009) observed that the increase in crop productivity is common in all watersheds due to watershed interventions in a short span of time. In the Adarsha watershed Kothapally, Andhra Pradesh, integrated watershed management technologies increased maize yield by 2.5 times and sorghum yield by 3 times. Overall in the 65 community watersheds, implementing best-bet practices resulted in significant yield advantages in sorghum (35 - 270 %), maize (30 - 174 %) pearl millet (72 - 242 %), groundnut (28 - 179 %), sole pigeon pea (97 - 204 %), and intercropped pigeonpea (40 - 110 %). The results also showed a similar trend in the Bundi watershed, Rajasthan. Due to additional groundwater recharge in the Adrasha watershed, Kothapally Andhra Pradesh, a total of 200 ha area was irrigated in the post-kharif season and 100 ha in post-rabi season, mostly to vegetables and flowers.

Parizanganeh et al. (2008) revealed that with the establishment of conservation structures in the Zanjan river basin and the control of the seasonal floods, the price of the land in the fringes of the river have witnessed a considerable increase. In this respect 87.5 percent of the farmers made a positive evaluation that the increase in the price of their land due to the project execution (r= 0.644). It also brings forth an increment of production and thereby the income for the farmers that are all positive evaluations. Furthermore, 65.63 percent of the farmers experienced an increment of land (r =0.61) and 76.56 percent pointed out to an increase of production and income.

Palanisami et al.,(2011) reported that integrated watershed management programme (IWMP) in India has made significant progress in rainfed regions through increase in productivity, improvement in resource quality, diversification of production systems and generation of additional employment. Watershed programmes resulted in yield increase significantly across the country and have shown a potential of 20 to 100% increase in the crop productivity from rainfed areas in addition to improving the natural resource base and environmental benefits.

Osman et al. (2013) implementation of watershed development programme (WDP) also witnessed the introduction of a number of cross-breed cows. At the same time, the number of indigenous breeds and draught animals were declined. Change in livestock composition was facilitated with introduction of improved varieties of fodder. Fodder production increased even when area under grazing declined from 102
ha to 32 ha which was attributed mainly to the cultivation of fodder crops and increased availability of crop residues particularly the cereals and pulses.

Osman et.al. (2013) reported the substantial increase in the cropping intensity from 132 % to 175 % after watershed development. Higher cropping intensity was attributed mainly to the increase in area under the existing crops like maize and wheat and also to the larger expansion of horticultural crops - mainly grapes (94 % area) in addition to pomegranate, sweet orange and other crops.

Osman et.al. (2013) stated that drought severity was found to be higher in pre-development period. All the farmers reported partial failure of crops in 2 out of 5 years while 62 % reported total failure of crops. During the post watershed development period, only 22.5 % farmers reported partial failure of crops in one out of 5 years while 2.5 % farmers reported total failure of the crops. Reduction in the drought vulnerability in the post watershed period was attributed to adoption of soil and water conservation measures and availability of water for supplemental irrigation during the dry spells.

Osman et.al. (2013) reported a substantial increase in area and production of Blackgram (29 and 47 fold, respectively) at the cost of pearl millet followed by chickpea (over 6 and 7 folds, respectively) substituting rabi sorghum, wheat (257 and 315 % respectively), cotton (74 and 94 % respectively) and greengram (25 and 75 % respectively). In Kadwanchi watershed major impact, that more area was brought under conventional crops such as cereals, pulses and cotton by bringing back fallows and cultivable wastelands under cultivation.

Pathak et.al. (2013) assessed the impact of watershed development programme at the Gokulpura-Goverdhanpura watershed at Bundi village in Rajasthan. The watershed development programme made significant positive impact on water resources. Increased availability of surface and groundwater significantly changed the land use pattern in the watershed area. The total irrigated area was increased by 66% (207 to 343 ha). The area under rainfed cropping declined by 36% (327 to 209 ha). The area under horticultural crops was increased by 35 ha and area under vegetable crops was increased by 11 ha.
2.6. Socio Economic Status of the Farming Community in the Watershed

The irrigated agriculture in India has probably reached its limit and further sustainable increases in food production must come from dry land farming, especially watershed development and management. This calls for an analysis of situations under which watershed technology becomes economically viable, socially acceptable and ecologically sustainable in the long run. To achieve the basic objectives of the watershed development project an effective implementation mechanism through integrated approach is indispensable by proper planning, implementation, administration and monitoring. Watershed monitoring and impact evaluation is essentially a part of the comprehensive process of watershed management.

Walker et al. (1989) reviewed the overall impact of the application of watershed based technologies at different locations in Maharashtra, Madhya Pradesh and Karnataka. The watersheds selected were Solapur, Kolhapur, Kolhewadi and Ralegan Siddhi (Ahmadnagar) from Maharashtra. Chitradurga, Gollahally, Bellary, Bijapur, Mittemari and Tiptur from Karnataka and Indore from Madhya Pradesh. Their results indicated incremental net income ranging between 49 and 203 per cent of the base level. The benefit cost ratio worked out in the range of 1.08 to 3.81 across the locations.

Deshpande and Ratna Reddy (1991) concluded that: (i) location specificity was an extremely important aspect of watershed planning since a population resource interaction generates varied situations under heterogeneous environments which were difficult to simulate a priority; (ii) watershed treatments alter the structure of income, stabilize income flows by avoiding over fluctuations and have positive impact on income distribution; (iii) people’s participation and scientific input were two most important components of watershed planning that enhance impacts.

Deshpande and Rajshekaran (1997) observed high tangible benefits for the landless like increase in household income and consumption expenditure, improved employment potential and reduced migration, improvement in household assets and wage rates. These studies not only vindicated the economic viability of the programme but also underlined the fact, that it is the only alternative to the development of rainfed agriculture in India.
Adhikari *et. al.* (1998) reported that in a red soil watershed in semi-arid region of South India (G.R. Halli watershed of Karnataka state) the income level of the farmers increased by about 4 times as compared to that of in the pre-project period, indicating the effectiveness of soil and water conservation interventions in the watershed area.

A majority of researchers agree that there is an increase in cropping intensity, household income, availability of fodder and groundwater status as reported by Narayana and Prahalladiah (1999) from Ralegan Siddhi of Maharashtra, Kumar *et.al.* (1999) from Bareilly district of Uttar Pradesh, Chandrakanth (2001) from Haikal watershed in Chitradurga district of Karnataka, ans Sripadmini *et.al.* (2001) from Venkateshpura and Taarehalla watershed in Chitradurga district of Karnataka.

Venkateshwarlu (1999) suggested that the training in watershed needs to be comprehensive aiming at social mobilization and technical competence and that can be best achieved by a proper blend of government organizations and NGOs as trainers.

Boyd and Slaymaker (2000) stated that the individuals must derive private tangible benefits from the watershed activities. These include raising agricultural productivity, augmenting income, meeting food security and controlling land degradation. It was noted that one of the key determinants for the success of the watershed activities was that the expected private benefits must substantially exceed the expected private costs. In many of the selected case studies like Sukhomajri in Haryana, Ralegan Siddhi in Maharashtra, Tarun Bharat Sangh (Alwar) in Rajasthan, Nartora in Chhattisgarh, the arrangements for sharing costs and benefits seem to have been satisfactory to the beneficiaries and encouraged them to willingly participate in the watershed programs. Sukhomajri watershed in Haryana was a unique case where the benefits were distributed equally to all the villagers. The benefits generated from grasses, fodder and water were equally distributed to each household in the village regardless of household size.

Hanumantha Rao (2000) emphasized capacity building for watershed development through training. It encompasses wide ranging tasks such as awareness building or imparting resource literacy, development of technical skills, and reorienting motivations and attitudes of officials and political functionaries at all towards the need for empowering the people through decentralization. The new guidelines emphasized this issue. The need for training has been emphasized at
different levels in hierarchy in the government and for the PIAs, NGOs, SHGs, Watershed committees village volunteers and villagers. The training program is designed for: (i) successful implementation of the watershed projects, (ii) understanding various aspects of the watershed development, (iii) skill upgradation, (iv) sustainability of the project, (v) confidence building and (vi) planning, implementing and monitoring of watersheds. The new guideline has also developed the criteria for selecting training institutions: these include: (i) experience in implementation of watershed development projects as PIA, (ii) good library and availability of communication, (iii) technology and other facilities for imparting training, (iv) faculty for training with adequate qualification and (v) linkages with other academic and research institutions involved in watershed development. The training course may include: (i) concept of watershed development, (ii) community organization, (iii) technical issues, (iv) accounts and administration, (v) issues of equity and sustainability, scientific inputs related to geographic information system (GIS) and role of remote sensing in watershed development, (vi) role of PRIs and (vii) involvement of women and weaker sections of society.

Joshi et.al. (2000) revealed from a meta analysis comprising 310 watershed that mean benefit cost ratio of watershed programmes in the country was quite modest at 2.14. The average internal rate of return was 22% which is comparable with many rural development programmes. The watershed programmes generated employment opportunities, augmented irrigated area and cropping intensity and conserved soil and water resource. The study added that performance of watershed programmes was best in low income regions with a rainfall ranging between 650 and 1000 mm jointly implemented by state and central governments targeted in low and medium income regions, and had effective people’s participation.

Kerr et al. (2000) studied the impact of watershed development programs in the rainfed areas. It was observed that few participatory watershed projects were successful and the impact of the program was limited. Also participatory watersheds performed better than the more technocratic. Top-down counterparts and the programs with a combination of people’s participation and sound technical input performed best. Similar observation was made by the Mid-Term Appraisal of the IX plan, which stated that projects have failed to generate sustainability because of failure of government agencies to involve the people.
Kerr *et al.* (2000) selected a few watershed implemented by NWDPRA, MoRD, NGOs and NGO-Government collaborated and control i.e. villages with no watershed project in the Maharashtra and Andhra Pradesh states only. The watersheds selected were Chittoor, Medak, Adilabad, Maheshwaram and Anantpur from Andhra Pradesh and Solapur, Kolhapur, Kolhewadi and Ralegan Sidhhi watersheds in Ahmadnagar from Maharashtra. For comparative discussions, a similar number of non-watersheds were also selected adjoining the watershed areas. The evaluation carried out indicated that, the projects in Andhra Pradesh focused much more on developing rainfed agriculture, whereas those in Maharashtra focused more on developing irrigation. Also he concluded that, long term maintenance of conservation structures was higher where farmers invested a higher proportion on their own funds; and finally rainfed plots under NGOs enjoyed higher net returns per ha than those under Government projects.

Kerr *et al.* (2000) distinguished two features that make NGO programs differ from government projects: scale of operations and staffing time. While government projects have huge budgets and work in hundreds of villages, NGOs mostly work in a handful of villages. They devote more staff time per village and they often work on a variety of activities in addition to watershed management. Although NGO projects are on average 20-40% more expensive, they are still more cost effective than the cheaper, but not so effective, top-down approaches. Also while government employees concerned with watershed management are almost exclusively trained in agricultural sciences and engineering NGO staff members include more non-technical staff trained in community organization. NGOs typically devote a lot of time to project preparation: in fact, many NGOs first get involved in other village development activities before entering into the watershed development.

Arya and Samra (2001) emphasized that the decision taken by all the villagers to stop animal grazing and strictly follow stall-feeding had drastically changed the livestock production and management pattern. The goats disappeared (declined from 246 in 1976 to 10 in 1986 and none in 2002), while buffaloes for milk became the principal source of income generation. The number of buffaloes increased to 291 in late 1990s from 79 in 1975. Milk production was remarkably increased from 334L/day in 1977 to 200 L/day in late 1990s due to shift in animal composition from sheep and goat to buffaloes, availability of grasses and better management. Cropping
pattern has also shifted in favour of maize, wheat and vegetables with the availability of water. These together substantially raised the income of the villagers.

According to Arya and Samra (2001) the effective people’s participation in Sukhomajri watershed in Haryana came as a consequence of numerous private benefits to the villagers due to conservation measures. Within the village, the regeneration of grasses and trees contributed in improving the irrigation water availability which intensified cropping patterns and expanded the livestock enterprise. The regeneration of grasses increased from 40 kg/ha in 1976 to 3 t/ha in 1992. The number of trees also increased from mere 13/ha in 1976 to 1292/ha in 1992. Mungri and babbar grasses were common in the village. While the Mungri grass was used for livestock in the village, the babbar grass was sold to a paper industry located in Yamunanagar approximately 100 km away from the Sukhomajri watershed project site.

Reddy et.al. (2002) revealed that the non-land based activities such as dairy, goatry, sheep rearing, poultry, duckry, mushroom cultivation, SHGs etc., were supported in watershed programme village with some support. The subsidy based activities had a set back after withdrawal of watershed programme. However, there are some activities that have been continuing even today.

Wani et.al. (2003), Ramakrishna and Osman (2004) revealed that people’s participation is critical for sustainable development and management of watersheds. A holistic approach converging the activities, which could improve livelihoods of rural people including landless dependent on natural resources is observed.

According to Reddy et.al. (2004) Government may create separate fund through public contributions with tax rebate only for preserving soil, water and vegetation for sustainable growth of agriculture in the country, as natural factors-viz: soil, water and vegetation are complimentary to each other and hence, plans should be made to sustain these factors for development in the present context of globalization, liberalization and privatization in the world. Capacity building is a prerequisite for effective implementation of Watershed Development Programmes.

Ratna Reddy (2000) has given the magnitude and spread of the Watershed Development Programmes, a number of studies were undertaken to examine the ecological and economic impact of these programmes. An over whelming majority of the studies have endorsed the programme in terms of costs and benefits. Some of the studies also highlighted the less quantifiable ecological benefits (Singh, 1994;
Deshpande and Reddy 1991; Chopra et.al., 1989; Deshpande and Rajshekharan 1995). These studies not only vindicated the economic viability of the programme but also underlined the fact, that, it was the only alternative to the development of rainfed agriculture in India. The studies indicated the prime importance of common pool resources in rural livelihood system and India’s rural economy and emphasized the urgent and greater attention to their restoration, development and management.

Hazra (2002) studied the economic condition of the beneficiaries in the watershed area. The grass from common lands in Tejpura Watershed was auctioned among the villagers of Tejpura only and the sale proceeds collected to the Pachayat fund. In 1992-1993, Rs. 35,000 were realized. About Rs. 1.00 per head load of firewood is charged to the villagers, which they often sell in the market for Rs. 7-10 per head load. The villagers borrowed money at nominal interest of 1-2% per year from the Panchayat fund. This provided much needed relief.

ICRISAT (2002) reported that of all the cropping systems studied in the Adarsha watershed, maize / pigeonpea and maize / chickpea proved to be most beneficial with benefit cost ratio 1: 2.67. Farmers could gain around Rs 16,500 and Rs 19,500 from these two systems, respectively. Sole sorghum, sole chickpea and sorghum/ pigeonpea intercrop also proved to be beneficial whereas, traditional cultivation systems of sorghum, maize and green gram were significantly less beneficial to farmers. The traditional management practices used for cotton cultivation resulted in a net loss.

Samra et.al. (2002) calculated People’s participation Index (PPI) for a typical Shiwalik Watershed and observed to range from 28 to 84 per cent. The stakeholders participated in all the project activities right from the inception. With the increase in agricultural and animal husbandry components the women participation also increased considerably.

Shiferaw et.al. (2002) conducted a survey in Adarsha watershed Kothapally before implementation of the watershed development programme. The results of the survey indicated that in Kothapally village: (i) dryland areas were more extensive than irrigated land; (ii) literacy was low; (iii) labour was scarce; (iv) there was an inverse relationship between land size and fertilizer/ pesticide use; (v) crop yields were low, (vi) there was not a single water harvesting structure in the village; and (vii) no income generating activities had been taken up by the villagers.
Wani et al. (2003) stated that during watershed development activities in Adarsha Watershed Kothapally, 2500 fruit trees and teak plants were planted on the field bunds as a part of village afforestation programme. Due to the improved landform treatment, the farmers harvested 3.6 t/ha maize and pigeon pea grains as compared to only 1.7 t/ha maize and pigeon pea grain from their normal cultivation practices. The area under vegetation was increased from 129 ha in 1996 to 200 ha in 2000.

Wani et al. (2003) observed the average net returns per hectare for dryland cereals and pulses are significantly higher within the watershed. For cereals, the returns to family labour and land (net income) are 45% higher even with irrigation, while the net returns on rainfed cereal crops have more than doubled. Similarly for pulse crops, per hectare net returns within the watershed are more than double with irrigation, and almost double without irrigation. Average household income from crop production activities within and outside the watershed is Rs.15400 and Rs.12700 respectively. The increased availability of water (and hence supplementary irrigation), and better employment opportunities in watershed development related activities, have contributed to the diversification of income opportunities and reduced vulnerability to drought and other shocks.

Joshi et al. (2004) revealed that in the Hiware Bazaar watershed, the controlled grazing has also raised the income of the farmers through production and sale of fodder and growth in milk production. The milk production has increased from 150 L/day for the village in 1993 to about 2200 L/day in 2000. The fodder grown on the forest and common land is sold to villagers on cut and carry basis (one person per family can cut and carry as much fodder as possible in one day) for which the payment has been fixed at Rs. 100. The remaining fodder is sold to the people from neighboring village. The income generated from the sale of fodder is used for improvement of facilities in the village school, and other services to the poorer families in the village.

Joshi et al. (2004) studied the impact of watershed development program in Fakot near Dehradoon (Uttaranchal) and revealed that the success of the watershed has induced adoption of similar models in surrounding areas. The whole region was converted into a vegetable and fruit belt with surplus milk collected by few middlemen. The success in raising yields of high value crops was due to the adoption of soil and water conservation practices. Individual farmers got tangible
benefits, which were realized in the form of raising agricultural productivity, food security and income rather than controlling land degradation. Regular availability of water and markets facilitated the process. As transformation progressed the importance of agriculture in rural livelihoods improved. The rural households were well integrated with the market system due to rising demand for vegetables, fruits milk, etc. and the increased value of vegetable crops provided strong incentives to invest in agriculture in some areas. Market access for vegetables and proximity to urban center was responsible for such a transformation. The nearest markets were available approximately 10 km away from the watershed area. Markets were also available in Dehradun and Haridwar at a distance of about 50 km in few cases. Contractual arrangements were made for sale of flowers in Delhi market.

Joshi (2004) reported that the annual income of the small farmers of Hiware Bazaar watershed in Ahmadnagar District, Maharashtra state has increased from Rs 4000-5000 in 1993 to about Rs 100,000-200,000 in 2000. The annual income of large farmers has now increased from Rs 15000 in 1993 to Rs 250,000-300,000 in 2000. The local migration of villagers in summer has completely stopped. About 31 families who had migrated out of the village permanently have returned to the village and resumed agricultural activities.

Several researchers have used different tools/techniques in their studies to evaluate the impact of watershed programmes in India and abroad. To document the efficiency, equity and sustainability benefits Joshi et.al. (2008) had reviewed 311 case studies and assessed the performance of watershed programmes by employing the meta-analysis using BCR and IRR. The studies revealed that the mean benefit-cost ratio of watershed development programmes in the country was quite modest at 2.14. The average internal rate of return was 22% which is comparable with many rural development programmes.

Parizanganeh et.al. (2008) pointed out that the social impacts of this plan are worthy of mention and that too if the impacts on the regional rural populace are distinct to a certain extent. The amount of local participation was only 32.8 percent. The type of participation was in two forms; financial (Cash payment and installments in participation shares) and, non-financial means (manual labour and assisting in the execution of operations of the project).

Parizanganeh et.al. (2008) observed the responses in connection to the Zanjan river management plan. The utmost impact of this plan is worth mentioning from the
economic point of view, such that, flood control measures decreases land
maintenance expenditures and restoration of land. An increment of area under
cultivation leading to an increase in production and a rise in the price of land arising
from advantageous land, are positive consequences of this plan, in addition to
securing the approval of the farmers and having a positive impact on their life-style
and economy. Ninety percent expressed approval and ninety five percent gave
positive responses regarding the execution of similar projects in other locations.

Singh and Prakash (2010) reported change in the livestock composition from
local to improved breed and increase in milk production in Khamenlok watershed
project in Manipur.

Osman et.al. (2013) reported that the annual household income derived from
fruits registered substantially higher income among different sources of income
accrued to farmers (Rs. 6.64 lakhs) in the watershed area which was Rs. 2.08 lakhs
before the WDP. The impact of WDP on horticulture (mainly grapes cultivation) was
found to be 219%. The annual income derived from arable crops after WDP was Rs.
2013 lakhs registering higher increase (621%) than fruits. However, the impact of
WDP on annual household income from milk production (dairy) was 83%. The
overall annual household income from different sources after WDP was higher (Rs.
3.21 lakhs) than before the project (Rs. 0.40 lakhs) and thereby the impact of WDP
on overall annual household income accrued was appreciably higher at 702%.

Osman et.al. (2013) reported that the farmers exhibited their keen interest and
belongingness towards the developed water storage structures. Out of 408 farm
families 207 got directly benefited. These storage structures needed no major repairs
and the sustainability fund of Rs. 8.00 lakh is intact. This was achieved because the
farmers were involved at every stage of the execution of the project and that helped
in skill enhancement of the farmers to attend the repairs and maintenance of the
structures on their own. The interest of the farmers towards soil and water
conservation works is attributed mainly to high profits from horticulture
interventions through convergence with other schemes under which 103 semi-dugout
farm ponds were constructed for protective irrigation. These ponds were filled by
lifting water from open dug wells mainly for storage and use during summer.

Osman et. al. (2013) observed that the implementation of watershed
development programme (WDP) in Kadwanchi watershed in jalna district
introduced a number of cross-breed cows. Number of indigenous breed and draught
animals declined. Change in livestock composition was facilitated with introduction of improved varieties of fodder. Fodder production increased even when area under grazing declined from 102 ha to 32 ha which is attributed mainly to cultivation of fodder and increased availability of crop residues particularly the cereals and pulses.

Pathak et.al. (2013) assessed the impact of watershed development programme at the Gokulpura-Governhanpura watershed at Bundi village in Rajasthan. The watershed development programme made significant positive impact on water resources, rural livelihoods and environment and ecology. The annual runoff from the watershed is reduced by 52% and soil loss by 64%. He observed that the watershed program is effective in conserving the rainwater and controlling the soil erosion, thereby minimizing land degradation. The programme converted the degraded wastelands into valuable and beneficial assets for community. The number of useful species of grasses and fodder increased due to Watershed Development Programme. Silvipastoral practices help in the conservation of vegetation, soil and nutrients and provide forage, fuel and timber on sustainable basis to the community. The socio-economic status of population significantly improved due to the impact of watershed development program.