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REVIEW ARTICLE

Studies on Water Resource Management: Approaches and Strategies

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Abstract

The alarming growth of the world population and unlimited demand for water contribute to the degradation of water resources worldwide. Global warming, depletion of natural resources and vegetation cover, climate change, pollution of water bodies, soil erosion and recession of water table are grave global issues related to water crisis. Sound programs and policies should be implemented to ensure equitable accessibility of water for ensuring the prosperity of present and future generations. The present paper is an attempt to review the studies on various strategies adopted elsewhere for water resource management and its sustainable utilization.

Introduction

Water is a precious and limited resource that plays a crucial role in maintaining the stability of the environment. After industrial revolution there has been remarkable increase in the destruction of the environment by poisoning the air we breathe, the water we drink and the food we eat with hazardous chemicals and pesticides. Consequently, environmental awareness with particular reference to water contamination and the need for implementing stringent water conservation strategies have been subjected to intensive debates and discussions among administrators, environmental activists, politicians, academicians, students, non-governmental organizations and general public. As Agarwal and Narain (1999) rightly pointed out, forty percent of the world's population currently experience serious water shortage. India is one among the 80 countries of the world bearing heavy social, political, economic and environmental costs of this crisis. Water quality problems affect some 44 million people around the world. The presence of fluoride, arsenic and iron besides the intrusion of seawater is polluting the groundwater aquifers. With the impact of climate change being a reality, there has been increasing demand for water and hence sound policies and programs should be implemented to ensure equitable accessibility of water for ensuring the prosperity of present and future generations. The present review paper is an attempt in this direction and it aims to document and discuss the prospects of various water conservation strategies for sustainable development.

1. Integrated Water Resources Management: A strategy to tackle water scarcity

Integrated Water Resources Management (IWRM) is a recent approach that promotes the management of water, land and related resources, in a well co-ordinate way to maximize economic and social welfare without compromising the sustainability of vital ecosystems. In different countries and also in different states of India, a wide variety of water conservation and rainwater harvesting techniques have been practiced since ancient days. Many of these water conservation structures were constructed and operated through public participation. It should be noted that successful implementation of water resources management is not an easy task without public awareness and participation.

Integrated water management is vital for poverty reduction, environmental sustenance and sustainable economic development (Goel and Patel, 2006). Proper watershed management to support livelihood requirements viz., domestic, irrigation, industries and sustainable groundwater development requires water augmentation programs through appropriate water conservation and pollution abatement strategies. Watershed management in India has been defined as rational utilization of land, water and water resources for optimum and sustained production with minimum hazards to natural resources. The new guidelines for watershed development provide a paradigm shift in the traditional approach, where the role of Government is changed from that of governance to facilitation. This approach of watershed development, in a holistic manner, strikes a prudent balance between environmental concerns and developmental aspirations. It envisages proper land use, protecting land from all source of degradation, preserving soil fertility, conserving water for agriculture, management of water for drainage, flood protection, sediment reduction and increasing productivity of land use (Borthakur, 2009). Integrated Wasteland Development Project scheme (IWDP) is yet another people's own programme of the Government of India which aims development of waste land by checking land degradation. Here also people have a key role in decision making viz., project implementation and fund dispersal.

River water management is another important area of natural resource management. It requires public intervention through appropriate institution. Considering the important water related problems of India, Venkatweswarlu (2001) stressed the importance of a scientific and technical approach towards water management. The important water related problems, as suggested by the author are: frequent floods and draughts, saline intrusion in the streams and coastal aquifers, drying up of lakes, pollution of water sources, soil erosion and water logging. Mondal and Singh (2004) conducted a study of unconfined aquifer response in terms of rise in water level due to precipitation and evolved a rapid and cost-effective procedure in hard rock terrain. A case study on Yamuna River water conservation through management intervention was reported by Nallathiga (2008).

Narain *et al.* (2005) studied the water harvesting and conservation potentials of the state of Rajasthan against drought. The study reports that despite water resources depletion, the state still has significant potential for harvesting and conserving water if an integrated water resources management approach is adopted, and proper policies and investment actions are implemented using recent technologies.

2. Role of Peoples' participation in natural resource management

Community based system of natural resource management is a novel concept in rural development**.** Water is a vital component that determines the full potential of the agriculture sector of any country. According to Gokhale *et al.* (2004), self-organized systems of conservation of living as well as non-living resources depend on effective community organization and devolution of authorities to communities. Services of voluntary organizations play a crucial role in implementing water conservation and irrigation management strategies by ensuring people's participation. Water harvesting initiatives, especially those by NGOs, are often driven by considerations other than economic efficiency, the most important of which are social equity and environmental justice (Dinashkumar *et al.*, 2006). Development of Humane Action (DHAN) foundation is one such organization working in rural areas of south India with a focus on water resources development and their local management. This organization was registered as a Trust under the Indian Trust Act-1882 on October 2, 1997. A group of highly motivated professionals live and work in developmental activities of the villages with a deep concern for poverty alleviation and help people to become self reliant. During the past thirteen years DHAN foundation has undertaken rehabilitation works of more than 750 minor irrigation tanks with people's participation in the five districts of Madurai, Ramanathapuram, Theni, Tiruvallur and Kancheepuram in Tamil Nadu; in two districts of Chittoor and Nalgonda in Andhra Pradesh and in Tumkur district of Karnataka. Besides, it has undertaken many tank-based watershed development works and construction of community wells in many districts of Tamil Nadu. The funds to carry out these works were pooled from various National and International funding agencies. The DHAN foundation availed only 75% of the cost of work from these agencies and the rest 25% were mobilized from beneficiaries. The foundation organized about 950 water users (WUAs) and watershed development associations with 60,000members in order to enable them to carry out the development works and manage them thereafter (Dhan Foundation, 2006). During the last three decades, several community-based proposals were suggested in response to the water management crisis. Some of these policies were implemented to transform ecological poverty into sustainable economic wealth.

The efficacy of integrated approach to village resource development has been pointed out by Chopra *et al.* (1990); Agarwal and Narain (1999a). According to these authors, the current rural development efforts in India are extremely fragmented focusing mostly on agriculture, and often efforts are contradictory and counterproductive. In India, the 'village ecosystem' is a composition of several integrated components viz., crop lands, grazing lands, forest areas and trees, local water bodies, livestock and various energy sources. What happens in one component invariably influences the other components, and all is maintained in a delicate ecological balance. Hence, the developmental activities must focus on the holistic enrichment to increase the productivity of all components of the village ecosystem.

There are a few isolated and scattered instances regarding the transformation of rural ecosystems with people's participation led by social workers / NGO leaders. Mr. Rajendra Singh (water man of India), an eminent environmental activist from Rajasthan has been conferred the prestigious Stockholm Water Prize of the year 2015 for his innovative water restoration efforts to empower communities in Indian villages. His strenuous effort to harvest every drop of rainwater has brought the River Arvari in dry and drought-prone Rajasthan back to life. According to historical records, the river Arvari was once capable for providing groundwater recharge to wells in the area. But nobody can remember seeing it flow except during the short monsoon period. The river—in its 45 km journey to its confluence in the reservoir of a dam on the River Sainthal—flows through about 70 villages. Its source lies in the degraded hills near the village of Bhaonta-Koylala. In 1986, working with a local NGO, the Tarun Bharat Sangh (TBS), the villagers of Bhaonta-Koylala built rain-water harvesting structures called Johads to trap the rainwater and recharge the groundwater. Since then, many more water harvesting structures have been built in the Arvani catchment. These small dams have helped to recharge the river and since 1995 it has been perennial. For these efforts, Mr. Singh was awarded the Stockholm Water Prize of the year 2015. Born in 1959, Rajasthan-based Singh for several decades have dedicated himself to defeating drought and empowering communities. We need to take Mr. Singh's lessons and actions to heart if we are to achieve sustainable water use in our lifetime (The Hindu, March 22, 2015).

Sukhomajri Model at Chandigarh is another successful story of community participation in water conservation. Sukhomajri is the first village in India to have income tax levied on earnings from the ecological regeneration of its degraded watershed. The combination of public, private and community investments and the participatory efforts of the villagers have resulted in a rate of return of 19% according to one cost-benefit analysis. In 1979, when the nation was facing a severe drought, the villagers near the city of Chandigarh built small tanks to capture rainwater. They agreed to protect their watershed to ensure the tanks did not get silted up. The villagers made an agreement with forest department so that they would have the right to use forestland and its grass as major incentive (benefit from the biomass produced) in return for protecting the watershed. The watershed management activities of the villagers have resulted in a threefold increase in crop production. The amount of grass and tree fodder available to cattle in the protected forest has increased considerably and as a result more milk is being produced. In short, the water management activities with people's participation led to increase the prosperity and economy of Sukhomajri (Agarwal and Narain, 1999).

Another instance for community participation in water conservation management was cited from Ralegan Siddhi village of Maharashtra, a drought-prone area till 1975. The annual rainfall of this village is between 450 mm and 650 mm. Villagers could never confidently rely on a regular harvest. In 1975, the village was poverty stricken and there was less than half a hectare of irrigated land per family. The strenuous effort of Krishna Bhaurao Hazare, a retired driver from the Indian army, transformed the drought affected Agro-ecosystem of Ralegan Siddhi village. He constructed many storage ponds, reservoirs and gully plugs at appropriate sites, which steadily enhanced the percolation of water thereby increasing the level of groundwater table. Simultaneously, 300,000- 400,000 tree saplings were planted in and around the village utilizing social forestry schemes of the Govt. Because of the increased availability of irrigation water, fallow land was brought under cultivation. The total area under production increased from 630 to 950 hectares and average yields of millets, sorghum and onion increased substantially (Agarwal and Narain, 1999 a). The Ralegan Siddhi model of water conservation is an excellent example that gives more emphasis to participatory democracy than representative democracy. The village created an impressive system of decision making and some 14 committees ensured that people participated in all decisions. A participative democratic institution, Grama-Sabha, was established to take community decisions and to ensure the involvement of each household in the development process (Mahapatra, 1997).

The Rajiv Gandhi Watershed Development Mission in Madhya Pradesh is an excellent paradigm for government interventions promoting public participation in environmental management. This programme is integrated / participatory in its approach. It was initiated by the chief minister Digvijay Singh who was inspired by Krishna Bhaurao Hazare's work in Ralegan Siddhi. Today trees are flourishing in this district that 15 years ago looked like a moonscape and wells are literally overflowing with water in a place that was described as chronically drought-prone (Agarwal and Mahapatra, 1999). The programme created several tiers of institutions: policy coordination at state level; implementation and coordination at the district and macro-watershed level, and work at village level to ensure that all villagers are involved in the effort. Some 1748 women's self help groups have been created in 374 villages in Jhabua and together they have 25,506 participants. The novelty of this programme is that local communities exercise the power over decision making, control over resources and management of programme funds. Nearly 80% of the programme's funds are put in a bank account, managed by Watershed Development Committees made up of village people. The Watershed Development Committee brings together the important interest groups in the village in a way similar to the Gram- Sabha. In short, the village level institutions are built along the lines of Gandhian concept of Gram-Sabha and it empowers the adults of the village to take decisions.

However, it should be noted that, higher order of democracy and transparency in decision making is a must for ensuring the co-operation and discipline within the group members.

A few studies were reported to assess the mode of functioning of watershed development programmes. Nirmala (2003) studied the impact of watershed development program on socio-economic dimensions in Ranga Reddy district of Andhra Pradesh and reported the farmer perception and based on constraints analysis stated that technologies were beneficial in the form of increased income (58.33%), increased moisture (51.66%) and increased productivity (48.33%) along with increased employment generation. Reduced soil erosion and integrated ground water recharge are the other benefits of technology as perceived by the farmers.

The study by Chackacherry (1996) focuses on the problems of beneficiary participation in irrigation water management. The study has identified major issues involved in the management system of irrigation water in Kerala. Though irrigated area has increased, productivity levels remain low and have not risen to any significant extent. He has rightly indicated the existing paradox of officials in controlling the irrigation systems. The study recommends a stoppage of new projects till the existing projects are made efficient keeping off vested interests in decision making process of irrigation water management. Kareemulla *et al.* (2009)' studied the impact of National Rural Employment Guarantee Scheme (NREGS) on rural livelihoods and soil and water conservation (SWC) works. NREGS is under implementation level at different rural districts of India and its major objective is to ensure rural livelihood through productive works. Rajasthan, Andhra Pradesh and Madhya Pradesh are the three states leading in scheme implementation. The NREGS earnings are being used mainly for food, education and health security.

Enrichment and proper management of the local natural resources is an essential and effective strategy to be adopted for poverty alleviation. The case studies discussed in this section clearly show that eco-restoration of highly degraded lands will increase local rural economies and alleviate poverty in a sustainable and cost-effective way. 'Helping people to help themselves' is the motto behind the success of participatory approach in natural resource management. The key to eco-restoration lies in good management and use of the local rainwater. This must be supported by community decision-making systems and institutions. There must also be legal and financial structures to enable and promote the community activities. It should be noted that the laws dealing with natural resources like land, water and forest will have to be amended to give citizens the rights to improve, develop and protect their natural resources without waiting for government approval. It should be noted that in the present system, various agencies/ functionaries of the government is controlling the finances upon which the village development depends. Most often, only a small proportion of the fund allocated for the proposed project reaches the community and it is often spent on projects over which the village has less priority and control.

3. Traditional rain water harvesting structures

Many states of India are blessed with different types of natural water resources. People used to utilize these resources for their daily water requirements viz., domestic and agricultural activities. Besides, the practice of water harvesting in appropriate structures and reusing the stored water for domestic or irrigation purpose was prevalent in India since ancient times. However, the technology and engineering of water harvesting structures differs depending on whether they provide water for drinking, domestic or irrigation purposes. Each state of India has its own water harvesting structures reflecting geographical peculiarities and cultural uniqueness of the community. Many water harvesting structures and water delivery systems specific to different regions and cultures were reported from different states of India. The residents of different states in India have developed their own indigenous water harvesting techniques to meet their water requirements. In the publication of centre for Science and Environment (1997) titled "Dying wisdom: Rise, Fall and Potential of India's traditional water harvesting systems" there is a detailed description of India's traditional water harvesting systems with particular reference to segmented approach to irrigation and drinking water locally demanded and locally supplied, solving water crises region by region and about reviving a millennial tradition. The evidences of multi-millennial mission, as found in ancient text, inscriptions, local folk and mores, and archaeological remains were discussed in the first chapter on Traditional water harvesting. The subsequent chapters deal with different types of water harvesting systems, the rise and fall of water harvesting and also about the revival of local water harvesting systems prevailed in India.

Usually, rain water has been considered clean and safe to drink. Today people are cautious about pesticides, bacterial or mineral contamination and other impurities in their runoff water. It is to be noted that, various filtering technologies have been employed in the past to purify water by using sands, gravel, rocks and charcoal from burned coconut shells to wash out different pollutants. Local people have developed their own indigenous techniques to harvest the rain water directly or from rooftops and to drain and store it in tanks built in their courtyards. They have their own efficient systems to collect and divert rain water from open community lands and store in specially designed artificial wells or ditches. They also designed and constructed water harvesting structures to capture water from monsoon runoff, swollen streams as well as flooded rivers.

The water harvesting / management strategies prevalent in different states of India are: *Baudis, Nawns, Khads, Kuhls* and *Khatris, Chhrudus, wells and Nalas* (Himachal Pradesh): *Naula* (Uttaranchal); *Dongs* (Assam);

Johad (Rajasthan); *Virdas* (Gujarat); *Kattas/Bandhs/Mundas, Surangams, Korambus, Ponds* and *Wells* (Kerala and Karnataka); *Eris* and *Ooranis* (Tamil Nadu*)*; *Zabo/ Ruza* system and *Cheo-ozihi* (Nagaland); *Bamboo* drip irrigation (Meghalaya) and *Apatani* (Arunachal Pradesh). (Agarwal and Narain, 1997). In a study conducted at Vanjuvankal watershed of Andhra Pradesh, Naidu (2001) reported the advantage of water harvesting structures and percolation ponds in enhancing the level of ground water in watershed area by 2 to 3 meters. A brief description of selected water harvesting structure is presented below.

3.1. Baudi

Baudi, a deep stoned circular/ square structure which gently narrows down towards the bottom pit in the centre, is dug where water percolates naturally from the earth surface**.** While constructing *Baudi*, the masons place stones in a particular sequence to have continuous percolation of water from the ground. At about every 20cm interval from top to bottom ladders by stones are constructed in a way that one could get down to collect water, whenever the water level become low due to seasonal variations. This structure is provided with an outlet and is covered with roof to protect the water. Its water is used only for drinking purposes. Mostly, the *Baudi* js constructed at an approachable distance from residential area. Some communities of Himachal Pradesh have a customary practice of placing the stone carved structures, locally called *moore*, on the sides of *Baudi* in the memory of their ancestors. The villagers offer prayers and give bath to their ancestors–*moore*. A special breed of small fish, called *donka*, is grown in such structures to restrict the growth of insects and fungi (Sharma and Kanwar, 2009).

3.2. Khatris

These are rectangular deep structures (10 x 12 feet in size and six feet deep) made on the hill slopes in hard rock mountain, where the rain water is collected through seepage from rocks. Specially trained masons were employed to construct *Khatris*. Usually the water storage capacity of a *Khatri* varies between 30,000- 50,000 L. This structure is built at the foot hills by digging a horizontal tunnel of 3-4 m length, followed by a vertical basin at the inner end. The tunnel is provided with steps going down the basin. There may have different Khatris on a particular hill, but all at the same level. These types of traditional water harvesting structures are found in Kangra, Mandi and Hamirpur districts of Himachal Pradesh. Two types of khatris are generally constructed: one for animals and washing purposes in which rain water is collected from the roof through pipes, and the other one is constructed for human consumption, where the rainwater is collected by seepage through rocks (Sharma and Kanwar, 2009). Khatris are owned either by individuals or government. The government khatris are maintained by the panchayat.

3.3. Kuhls

Kuhls are traditional irrigation system (water channels found in precipitous mountain areas) in the lower belts (Kangra, Mandi, Hamirpur) of Himachal Pradesh and Jammu Kashmir. Kuhls carry water from glaciers to villages in the Spiti valley of Himachal Pradesh. *Kuhl* system is prevalent since British colonial rule in India. These surface channels divert water from natural streams called *Khuds* and run at a higher elevation than the stream, to irrigate more upstream land than the *khud* itself. A community *kuhl s*erves 6 to 30 farmers, irrigating an area of 20 ha. This system has a temporary headwall (constructed usually with river boulders) across a *khud* (ravine) for storage and diversion of the flow of water from field to field and surplus water drains back to the *Khud.* By modern standards, building *kuhls* is simple, with boulders and labour forming the major input. The *kuhl* was provided with *moghas* (*kuchcha/* outlets) to draw out water and irrigate nearby terraced fields. Besides irrigation purpose, these structures are also used to run the flour mills, *gharaat*. Homemade wooden wheels are used as turbines to run the mills. When the terrain is muddy, the *kuhl* is lined with rocks to keep it from becoming clogged. The construction, operation, maintenance and distribution of water were managed by Kohlis with the support of the community members. They belong to a particular caste of Himachal Pradesh, whose traditional occupation is management of *Kuhl* system (Sharma and Kanwar, 2009). Actually these people play the role of trained local engineers. At the beginning of the irrigation season, the *kohli* (the water tender) would organize the farmers to construct the headwall, repair the *kuhl* and make the system operational. Any person refusing to participate in construction and repair activities without valid reason would be denied water for that season. Since denial of water was a religious punishment, it ensured community participation and solidarity.

3.4. Naula

It is a surface-water harvesting method typical to the hill areas of Uttaranchal. These are small wells or ponds in which water is collected by making a stone wall across a stream.

3.5. Dongs, Garh and Dara

Dongs are pond like structures constructed by the *Bodo* tribes of Assam to harvest rain water for irrigation. These structures are individually owned with no community involvement. In some places, the *Garh* is built to channelise river water to the Agricultural field. In *garh*, both sides have big and long embankments and the middle side is left open to flow water. In the paddy field, the whole area is divided into small square areas, creating small square embankment called *Dara*, where rain water is stored for cultivation.

3.6. Johad

Rajasthan has a long and unbroken tradition of water conservation. The builders of the famous Chittoor and Ranthambore forts had the vision of exploiting the natural catchments in the forts created by the undulating hill tops. The strenuous efforts of local NGO, the Tarun Bharat Sangh (TBS) have led to the revival of the age old water harvesting structures called Johads to trap the rainwater and recharge the groundwater. Now it meets the water requirements of more than 700 villagers in the state without any hassles. Essentially, Johads are simple stone and mud barriers built across the contour of slope to arrest rain water. A Johad prevents rainwater from running off, allowing it to percolate into the ground, recharging water aquifers. The engineering knowledge to make Johad is entirely indigenous. Dr. Rajendra Singh (Water man of India) played a catalyzing role in fulfilling the needs of the people of Rajasthan by initiating the construction of 8600 *johads* (water harvesting structures) in 1058 villages that spread over an area of 6500 sq.km. Out of these, 3500 *johads* were built by Tarun Bharat Sangh (TBS) with community participation and as an after effect of these the community gets motivated to build the remaining 5100 structures (The Hindu, 2015).

Following the efforts of the NGO, Professional Assistance for Development Action (PRADAN), Ratkhurd village in the Alwar district of Rajasthan has been transformed into a green paradise. A series of bunds put up along the hill slops were found to arrest the rain water runoff. Each bund has spillway which passes on the excess water to the rest in the line. Once checked the run-off percolates underground and increases the moisture content of the soil and recharge aquifers effectively. This makes the availability of water for irrigation round the year (Borthakur, 2009).

3.7. Virdas.

Virdas are shallow wells, dug in low depressions called *jheels* (tanks). They are found all over the Banni grasslands in Gujarat. They are systems built by the nomadic *Maldharis*, who used to roam these grasslands. Now settled, they persist in using *virdas*. These structures harvest rainwater. The topography of the area is undulating, with depressions on the ground. By studying the flow of water during the monsoon, the *Maldharis* identify these depressions and make suitable *virdas* in these places. Essentially, these structures use a technology that helps the *Maldharis* to separate potable freshwater from non-potable salt water. After rainwater infiltrates the soil, it gets stored at a level above the salty groundwater because of the difference in their density. A structure is built to reach down (about 1 m) to this upper layer of accumulated rainwater. Between these two layers of sweet and saline water, there exists a zone of brackish water. As freshwater is removed, the brackish water moves upwards, and accumulates towards the bottom of the *virda*. This system can be used with appropriate modifications to solve the fresh water availability in the coastal areas with salinity intrusion.

3.8. Kattas (Bandhs / Mundas)

Kattas (*mundas* / *bandhas*) are small temporary check dams which being constructed in some parts of Kasargod district since many years. These structures were built to capture and conserve river water for improving river percolation and ground water recharge. The water thus conserved was used for irrigation during summer months. *Kattas* were constructed by farmers on a community basis using their traditional wisdom soon after the withdrawal of the monsoon (Samuel, 2003). These structures were the main irrigation sources in the ancient tribal kingdom of the Gonds (now in Orissa and Madhya Pradesh). Most of these kattas were built by the village headmen known as Gountias, who in turn, received the land from the Gond kings. The Land was classified into four types based on its topography: (i) *aat*, (highland); (ii) *mal* (sloped land); (iii) *berna* (medium land); (iv) *bahal* (low land). This classification often helps to construct suitable water harvesting structures. A *katta* is a strong earthen embankment constructed north to south, or east to west. This structure is slightly curved at either end and is built across a drainage line to hold up an irregularly-shaped sheet of water. It is so constructed to leverage on the natural drainage line (Borthakur, 2009). The undulations of the country usually determine its shape of which the dam forms the base. It commands a valley, the bottom of which is the *bahal* land and the sides are the *mal* terrace. As a rule, there is a cut high up on the slope near one end of the embankment from where water is led either by a small channel or tal, or from field to field along terraces, going lower down to the fields. In years of normal rainfall, irrigation was not needed because of moisture from percolation, and in that case, the surplus flow was passed into a nullah. In years of scanty rainfall, the centre of the tank was sometimes cut so that the lowest land could be irrigated. *Munda* is a small embankment built across any kind of drainage channel, a river let or a stream. *Bondha* is four sided tank excavated below a *Katta* from which it receives water by percolation.

3.9. Surangam

Kasaragod district in the northern Malabar region of Kerala is an area whose people cannot depend directly on surface water. The terrain is such that there is high discharge in rivers in the monsoon and low discharge in the dry months. People here depend, therefore on groundwater, and on a special water harvesting structure called *surangam*. The word *surangam* is derived from a Kannada word for tunnel. It is also known as *thurangam*, *thorapu*, *mala*, etc, in different parts of Kasaragod. It is a horizontal well, mostly excavated in hard laterite rock formations. The excavation continues until a good amount of water is struck. Water seeps out of the hard rock and flows out of the tunnel. This water is usually collected in an open pit constructed outside the *surangam*. A *surangam* is about 0.45-0.70 metres wide and about 1.8-2.0 m high. The length varies from 3-300 m. Usually several subsidiary *surangams* are excavated inside the main one. If the *surangam* is very long, a number of vertical air shafts are provided to ensure atmospheric pressure inside. The distance between successive air shafts varies between 50-60 m. The approximate dimensions of the air shafts are 2 m by 2 m, and the depth varies from place to place. *Surangams* are similar to qanats which once existed in Mesopotamia and Babylon around 700 BC. The initial cost of digging a *surangam* is the only expenditure needed, as it hardly requires any maintenance. Traditionally, a *surangam* was excavated at a very slow pace and was completed over generations.

3.10. Zabo

The *zabo* (the word means 'impounding run-off') system is practiced in Nagaland in north-eastern India. It is also known as the *ruza* system and it combines water conservation with forestry, agriculture and animal care. Villages such as Kikruma, where *zabos* are found even today, are located on a high ridge. Though drinking water is a major problem, the area receives high rainfall. The rain falls on a patch of protected forest on the hilltop; as the water runs off along the slope, it passes through various terraces. The water is collected in pond-like structures in the middle terraces; below are cattle yards, and towards the foot of the hill are paddy fields, where the run-off ultimately meanders.

3.11. Cheo-ozihi

It is a type of channel irrigation system practiced in Nagaland. The water of the river, Mezii that flows along the Angami village of Kwigema is brought down by a long channel. From this channel, many branch channels are taken off, and water is often diverted to the terraces through bamboo pipes. One of the channels is named *Cheo-oziihi* (*oziihi* means water and *Cheo* was the person responsible for the laying of this 8-10 km-long channel with its numerous branches). This channel irrigates a large number of terraces in Kwigwema, and some terraces in the neighboring village.

3.12. Tanks (Eris)

Every part of India has unique water harvesting and conservation systems. In South India, two types of artificial tanks were employed for harvesting and conserving water: the large man-made earthen reservoirs (*Eris*) and the temple tanks (temple ponds). Approximately one-third of the irrigated area of Tamil Nadu is watered by tanks (*eris*). *Eris* play several important roles in maintaining ecological harmony as flood-control systems, preventing soil erosion and wastage of runoff during periods of heavy rainfall, and recharging the groundwater in the surrounding areas. Besides, it provides a micro-climate in the surrounding areas. Historical data from Chengalpattu district, indicates that in the 18th century, about 4-5 per cent of the gross produce of each village was allocated to maintain *eris* and other irrigation structures. Assignments of revenue-free lands, called *manyams*, were made to support village functionaries who undertook to maintain and manage *eris*. These allocations ensured upkeep of storage tanks through regular cleaning of inlets and irrigation channels.

The Temple tanks associated with sacred groves are important ecological traditions of South India. These ponds have played a significant role in the protection and preservation of the environment (Amirthalingam and Muthukrishnan, 2004). The temple tanks are considered to be sacred, due to the reverence shown by the devotees. The temple tanks serve multiple purposes viz., for religious purposes, ritual baths, annual float festival, and also for water harvesting.

The study conducted by Ambujam *et al*. (2003) focuses on water management systems prevailed in south India, namely tanks. As described in this paper, India had a vibrant tradition of not just isolated techniques, but a complete integrated structure that was evolved independent of the modern systems..

3.13. Ooranis

The tanks, in south Travancore, though numerous, were in most cases Oornis containing just enough water to cultivate the few acres of land dependent on them. The irregular topography of the region and the absence of large open spaces facilitated the construction of only small tanks unlike large ones seen in the flat districts of the then Madras Presidency, now Tamil Nadu.

3.14. Bamboo drip Irrigation

Meghalaya has an ingenious system of tapping of stream and spring water by using bamboo pipes to irrigate plantations. About 18-20 litres of water entering the bamboo pipe system per minute gets transported over several hundred metres and finally gets reduced to 20-80 drops per minute at the site of the plant. This 200-year-old system is used by the tribal farmers of Khasi and Jaintia hills to drip-irrigate their black pepper cultivation. Bamboo pipes are used to divert perennial springs on the hilltops to the lower reaches by gravity. The channel sections, made of bamboo, divert and convey water to the plot site where it is distributed without leakage into branches, again made and laid out with different forms of bamboo pipes. Manipulating the intake pipe positions also controls the flow of water into the lateral pipes. Reduced channel sections and diversion units are used at the last stage of water application. The last channel section enables the water to be dropped near the roots of the plant. Bamboos of varying diameters are used for laying the channels. About a third of the outer casing in length and internodes of bamboo pieces have to be removed while fabricating the system. Later, the bamboo channel is smoothened by using a dao, a type of local axe, a round chisel fitted with a long handle. Other components are small pipes and channels of varying sizes used for diversion and distribution of water from the main channel. About four to five stages of distribution are involved from the point of the water diversion to the application point. This is a wet rice cultivation cum fish farming system practiced in elevated regions of about 1600 m and gentle sloping valleys, having an average annual rainfall about 1700 mm and also rich water resources like springs and streams. This system harvests both ground and surface water for irrigation. It is practiced by Apatani tribes of ziro in the lower Subansiri district of Arunachal Pradesh.

In Apatani system, valleys are terraced into plots separated by 0.6 meters high earthen dams supported by bamboo frames. All plots have inlet and outlet on opposite sides. The inlet of low lying plot functions as an outlet of the high lying plot. Deeper channels connect the inlet point to outlet point. The terraced plot can be flooded or drained off with water by opening and blocking the inlets and outlets as and when required. The stream water is tapped by constructing a wall of 2-4 m high and 1 m thick near forested hill slopes. This is conveyed to agricultural fields through a channel network.

3.15. Korambus

Korambu is a temporary dam stretching across the mouth of channels, made of brushwood, mud and grass. It is constructed by horizontally fixing a strong wooden beam touching either banks of the canal. A series of vertical wooden beams of appropriate height is erected with their lower ends resting firmly on the ground and the other ends tied to the horizontal beam. *Korambu* is constructed to raise the water level in the canal and to divert the water into field channels. It is so built that excess water flows over it and only the required amount of water flows into the diversion channels. The height of the *Korambu* is so adjusted that the fields lying on the upstream are not submerged. Water is allowed to flow from one field to another until the entire field is irrigated. They are built twice a year especially before the onset of the monsoon season in order to supply water during winter and summer season. In Kasargod and Thrissur districts of Kerala, *Korambu* is known as *chira*.

3.16. Jackwells

The difference in the physiography, topography, rock types and rainfall meant that the tribes in the different islands followed different methods of harvesting rain and groundwater. For instance, the southern part of the Great Nicobar Island near Shastri Nagar has a relatively rugged topography in comparison to the northern part of the islands. The shompen tribals here made full use of the topography to harvest water. In lower parts of the undulating terrain, bunds were made using logs of hard bullet wood, and water would collect in the pits so formed. They make extensive use of split bamboos in their water harvesting systems. A full length of bamboo is cut longitudinally and placed along a gentle slope with the lower end leading into a shallow pit. These serve as conduits for rainwater which is collected drop by drop in pits called Jackwells. Often, these split bamboos are placed under trees to harvest the throughfalls (of rain) through the leaves. A series of increasingly bigger jackwells is built, connected by split bamboos so that overflows from one lead to the other, ultimately leading to the biggest jackwell, with an approximate diameter of 6 m and depth of 7 m so that overflows from one lead to the other.

4. Studies on water harvesting

Water harvesting irrespective of the technology used essentially means harvesting and storing water in days of abundance, for use in lean days. Various water harvesting techniques have been practiced in different countries, especially in arid and semi-arid regions of the world. In water harvesting, the runoff instead of being left to cause erosion, is harvested and utilized for productive purposes. It is practiced as an efficient method of water conservation to promote significant water saving in residences. Critchley *et al*. (1991) stressed the importance of harvesting the runoff from the roofs and ground surfaces as well as from intermittent or ephemeral watercourses to mitigate water scarcity and promote agricultural productivity. Julius, Prabhavathy and Ravikumar (2013) presented an elaborate review of rain water harvesting with special emphasis on methods, design of rain water harvesting systems and its impacts based on studies done in different parts of the world. Mati *et al*. (2006) defined rain water harvesting (RWH) as the deliberate collection of rainwater from a surface known as catchment and its storage in physical structures or within the soil profile. Kahinda *et al*. (2008) defined RWH as the collection, storage and use of rainwater for small-scale productive purposes. According to Kim *et al*. (2005), rainwater harvesting may be one of the best methods available to recover the natural hydrologic cycle and enabling urban development to become sustainable as it has the potential to assist in alleviating pressures on current water supplies. Samuel and Mathew (2008) reported a case study on rejuvenation of water bodies of Kasargod district of Kerala state by adopting Rain water harvesting and Ground water recharging practices. As described in this study, the rain water harvesting can be implemented at any land anywhere as a viable alternative to conventional water supply or on-farm irrigation projects. As suggested in this study, rejuvenation of the traditional water harvesting structures and implementation of water management schemes with people’s participation are suitable options to mitigate the ill effects of drought and soil erosion.

United Nations Environment Programme conducted a study to determine if RWH technologies can be mapped at continental and country scales (Mati *et al*. 2006). The project utilized a number of GIS data sets including rainfall, land use, land slope, and population density to identify four major commonly adaptable RWH technologies: roof top RWH, surface runoff collection from open surfaces into pans/ponds, flood flow storages and sand/sub-surface dams and *in-situ* RWH.

Israel has taken a number of countermeasures during the past several years to strengthen its efforts to address the desertification processes. Most of these activities were part of planning viz., environmental and development strategies or policies for the sustainable use of natural resources. The Israel has made substantial contributions to reduce erosion, increase agricultural productivity in the semi-arid dry lands and also to promote afforestation efforts throughout the country (Schary, 2008). The country's long experience in managing limited water resources along with the development of novel water technologies have made Israel a leader in all aspects of the water sector. Their expertise and diverse solutions are now being exported to countries worldwide for the benefit of growing populations with scarce water and food resources. Israel's afforestation / land reclamation efforts in degraded dry lands provide examples for countries with arid lands, how to recreate forests and parks that provide multiple environmental benefits, combat desertification and preserve open space.

Appan (2000), Handia *et al*. (2003) and Li and Gong (2002) evaluated the water harvesting systems performed in Singapore, Zambia and China. Fayez *et al.* (2009) evaluated the potential for potable water savings by using rain water in residential sectors of the twelve Jordanian governorates and provided suggestions and recommendations regarding the improvement of both quality and quantity of harvested rain water. Similar investigations were reported from Brazil (Ghisi *et al*., 2009), Florianopolis (Marinoski *et al*., 2004), Germany (Herrmann and Schmida, 2008), Australia (Coombes *et al*., 2011) and Northern Taiwan (Cheng and liao, 2009). A study by Ngigia *et al*. (2005) in the Laikipia district, Kenya showed that improved farm ponds provide one of the feasible options of reducing the impacts of water deficit that affect agricultural productivity in semi-arid environments in Sub-Saharan Africa. The field evaluation revealed that on-farm RWH systems are common in the study area with sizes ranging from 30 to 100 m^3 and catchment areas varying from 0.3 to 2 ha. The hydrological evaluation of the farm ponds revealed that one of the challenges was how to reduce the seepage and evaporation water losses. He reported significant water losses through seepage and evaporation, which accounted on average for 30–50% of the stored runoff. The high losses are one of the factors that affect the adoption and up-scaling of on-farm water storage systems. If seepage loss is reduced with lining material and if RWH is combined with drip irrigation, on-farm storage systems will be economically viable and farmers are able to recover the full investment costs within 4 years.

Rain water harvesting is an eco-friendly approach to address water scarcity in many water deficit regions of India. Water harvesting in India has boomed during the past two decades in two markedly different ways from the traditional techniques. They can now use recent advances in soil, geosciences and hydro-sciences, plus modern techniques and technologies in survey and investigation, earth moving and construction. While the traditional techniques represented the best engineering feats of the times, in terms of water technology used for water harnessing, distribution and the volume of water handled, modern water harvesting systems are at best miniature versions of the large water resource systems that use advances in civil engineering and hydrology (Agarwal and Narain, 1997). The water harvesting initiatives according to Dineshkumar *et al*. (2006) are derived from certain basic principles and assumptions based on the amount of monsoon flow which remains un captured, local water harvesting systems and water needs, economic /social/ environmental values of water, incremental structures with low water storage and diversion capacities (Dineshkumar *et al*., 2006).

In India, Rain fed agriculture contributes 40 per cent to the country's food grain production with 60 per cent area vulnerable for weather vagaries. These areas largely account for migration towards urban / industrial areas, leading to neglect of the already degraded natural resources (Government of India, 2007). However, many states in India viz., Gujarat, Rajasthan, Maharashtra, Tamil Nadu, Karnataka, Andhra Pradesh, Madhya Pradesh, Orissa and Chhattisgarh have taken up rain water harvesting and ground water recharge on a large scale to mitigate water crisis. A major part of these regions is covered by six water scarce river basin systems viz., Sabarmati, rivers of Kachchh and Saurashtra, Pennar, Cauvery, east flowing rivers between Mahanadi and Godavari, east flowing rivers between Pennar and Kanyakumari, which have less than 1000 $m^3$of renewable water per annum (Gupta, 2000).

Gitte and Pendke (2002) conducted a study on the water conservation practices, water table fluctuations and ground water recharge in watershed areas of Maharashtra. As revealed in this investigation, the water conservation measures were found to be effective for raising the water table of the observation wells, located in the middle and lower reach of the watershed. Venkatesh and Jose (2007) identified homogeneous rainfall regimes in parts of Western Ghats region of Karnataka. The study revealed three distinct zones of rainfall regimes in the study area viz., Coastal zone, Transition zone and Hilly (*Malanad*) zone. It is observed that, the maximum rainfall occurs on the windward side ahead of the geographical peak. Further, mean monthly rainfall distribution over the zones has been depicted to enable agricultural planning in the study area.

Julius *et al*. (2013), described the roof top rainwater harvesting in Chennai Airport Terminal buildings using GIS. The surface runoff was estimated using SCS method and design of rainwater harvesting structures were described. Thematic maps were digitized in map Info GIS software and roof drainage delineation was done in GIS environment. Based on the topography and lithology of airport, the artificial recharge structures like recharge shaft, recharge well and recharge pit were designed and located. Venkateswara Rao (1996) in his article has reviewed the importance of artificial recharge of rainfall water for Hyderabad city water supply. Rainfall water from the roof tops of the buildings was recharged through specially designed pits in order to augment the ground water resource in the city and as stated in this study, it meets almost 80% of domestic water requirements. Runoff from the public places like roads, parks and play grounds is recharged through naturally existing tank within the city by not allowing municipal sewage and industrial effluents in these tanks. As suggested in his report, wherever natural tanks are not existing, community recharge pits are to be constructed at hydro-geologically suitable locations. Jebamalar and Ravikumar (2011) investigated the implementation of rain water harvesting structures and its hydrologic responses in terms of quality and quantity of water in two hydrologically different localities of Chennai city in Tamil Nadu state, India. Deepak *et al*. (2004) have reviewed the impact of RWH on ground water quality at Indore and Dewas, India using the data from tube wells. The roof top rain water was put through sand filter leading to a reduction in the concentration of pollutants in ground water. Venkateswara Rao (1996) has reviewed the importance of artificial recharge of rain fall of Hyderabad water supply. In another investigation, Sharma and Jain (1997) studied the ground water recharge through roof top rain water harvesting in the urban habitation at Nagpur city. In a similar study, Vijaya Kumar (2005) evaluated the ground water potential as per the norms of Ground water estimation committee. A simulation model has been developed by Srivastava (2001) to design a system for determining catchment/ command area ratio, size of the tank etc. He studied the impact of roof top rain water harvesting techniques in relation to the quality and quantity of Ground water. The roof top rainwater was used to put into the ground using sand filter as pretreatment system. This led to a reduction in the concentration of pollutants in ground water which indicated the effectiveness of increased recharge of aquifer by roof top rain water. He observed the presence of fecal *coliform* in harvested tube well water than normal tube well water which indicates the lack of cleanliness of roof top and inefficiency of filter for bacterial removal. The author concludes that quality mounting of rainwater harvesting as an essential prerequisite for ground water recharge.

Precipitation is the principal source for replenishing soil moisture, which occurs through the infiltration process and subsequent recharge to the groundwater through deeper percolation. The amount of infiltrated moisture that eventually reaches the water table is accounted as the natural groundwater recharge. In a study, Julius *et al*. (2013), made an attempt to correlate the rainfall amount and subsequent rise in water level yielded. An exponential relation indicating daily rainfall exceeding 40 mm/day resulted in significant rise in water level.

Summary

This review paper is an attempt to document and discuss the prospects of various water management strategies and water harvesting structures with special reference to sustainable development. It is expected that various water management programmes described in this article with special reference to indigenous water harvesting structures and studies on rain water harvesting/ ground water recharging will be helpful to propose model strategies for integrated water management and sustainable rural development. It is also suggested that modernization of the traditional water harvesting structures in line with scientific and technological advancements may solve many water related issues of the present generation without compromising the stability of the ecosystem.

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References

Agarwal, A and S. Narain (1999). *Making water management everybody's business: water harvesting and rural development in India*. The Gatekeepers Series No. SA87. International Institute for Environment and Development. 3 Endsleigh Street, London.

Agarwal, A. and S. Narain (1999 a). *Community and household water management, the key to environmental regeneration and poverty alleviation*. Centre for Science and Environment, New Delhi.

Agarwal, A. and R. Mahapatra (1999). Madya Pradesh: regaining paradise. *In*: Agarwal, A, S. Narain & S. Sen (eds) 1999. *State of India's environment – 1999: Citizens' fifth report*. Centre for Science and Development, New Delhi.

Agarwal, A. and S. Narain (1997). *Dying Wisdom: Rise and Fall of Traditional Water Harvesting Systems*. Centre for Science and Environment. New Delhi.

Amirthalingam, M. and N. Muthukrishnan (2004). *Temple Tanks of Chennai*. P. R. Environmental Education Centre, Chennai.

Appan, A. (2000). A dual-mode system for harnessing rode system for harnessing roof water for non potable uses. *Urban Water* 1(4):317–21.

Borthakur, S. (2009). Traditional rain water harvesting techniques and its applicability. *Indian journal of Traditional knowledge* 8(4): 525-530.

Chackacherry, G. (1996). *Irrigation Water Management with Farmer Participation in Kerala, Problems and Prospects*. Department of Irrigation. Thiruvananthapuram.

Cheng C.L. and M.C. Liao (2009). Regional rainfall level zoning for rainwater harvesting systems in northern Taiwan. *Resources, Conservation and Recycling* 53(8):421-428.

Chopra, K., G. Kadekodi and M.N. Murthy (1990). *Participatory development: people and common property resources*. Sage Publications, New Delhi.

Coombes P. J., J. R. Argus and G. Kuczera (1999). Figtree place: a case study in water sensitive urban development. *Urban Water* 1:335-343.

Critchley, W., K. Siegert and C. Chapman (1991). *A Manual for the Design and Construction of Water Harvesting Schemes for Plant Production.* Food and Agriculture Organization of the United Nations, Rome.

Das, M. R. (1994). Technology and Environment. *Journal of Environmental Resources.* 2 (1-4):7-13.

Dhan Foundation (2006). Traditional Rainwater Harvesting System- Our Field Experiences *in* National Seminar on *Rainwater Harvesting and Water Management.* Nagpur.

Dineshkumar, M., Ghosh, Shantanu, Patel, Ankit., O.P. Singh and R. Ravindranth (2006). Rainwater harvesting in India: some critical issues for basin planning and research, *Land use and Water Resources Research*. 6: 1.

Fayez, A. Abdulla and A.W. Al-Shareef (2009). Roof rain water harvesting system for house hold water supply in Jordan. *Desalination* 243: 195-207.

Ghisi, E., A. Montibeller and R. Schmidt (2009). Potential for potable water savings by using rainwater: An analysis over 62 cities in southern Brazil *Building Environment* 41: 204–210.

Gitte, A.U. & M.S. Pendke (2002). Effect of water conservation practices on hydrological behavior, water table fluctuation and ground water recharge in a watershed. *Journal of Maharashtra Agricultural Universities* 27(3): 290-292.

Goel, R.S and V. B. Patel (2006). Measures for Water Conservation and improvement in Water quality, *In. National Seminar on Rainwater Harvesting and Water Management*, 11-12 Nov. 2006, Nagpur.

GoI (Government of India) (2007). *Poverty Estimates for 2004-05*. Press Information Bureau, New Delhi.

Gokhale, Y., R. Velankar, M.D.S. Chandran and M. Gadgil (2004). Sacred Woods, Grasslands and Water bodies as Self-organised Systems of Conservation, *Conserving the Sacred for Biodiversity Mangement* 365-396.

Gupta, R. K. (2000). Regional water transfer and human rights: some reflections on Sardar Sarovar Project. *ASIAN journal* 7: 112-127.

Handia, L, J.M. Tembo and C. Mwiindwa (2003). Potential of rainwater harvesting in urban Zambia. *Physics and Chemistry of the Earth* 28(20–27)

Herrmann, T. and U. Schmida (2000). Rainwater utilisation in Germany: efficiency, dimensioning, hydraulic and environmental aspects. *Urban Water* 1(4): 307–316.

Jebamalar, A. and G. Ravikumar (2011). A comparative analysis of hydrologic response to rain water harvesting- A case study. *Indian Journal of Science and Technology* 4(1): 34-39.

Julius, J. R., Prabhavathy, R. Angeline and G. Ravikumar (2013). Rainwater Harvesting (RWH)- A Review. *International journal of Innovative research and Development* 2 (5): 925-937.

Kahinda, J.M., E.S.B. Lillie, A.E. Taigbenu, M. Taute and R. J. Boroto (2008). Developing suitability maps for rainwater harvesting in South Africa. *Physics and Chemistry of the Earth* 33: 788-799.

Kareemulla, K, K. Srinivas Reddy, C. A. Rama Rao, Shalander Kumar and B. Venkateswarl (2009). Soil and Water Conservation Works through National Rural Employment Guarantee Scheme (NREGS) in Andhra Pradesh — An Analysis of Livelihood Impact. *Agricultural Economics Research Review* 22 : 443-450.

Kim, R.H., S. Lee, Y.M. Kim, J.H. Lee, S. K. Kim and S. G Kim (2005). Pollutants in rainwater runoff in Korea: Their impacts on rainwater utilization. *Environmental Technology* 26:11-420.

Li, X. and J. D. Gong (2002). Compacted microcatchments with local earth materials for rainwater harvesting in the semiarid region of China. *Journal of Hydrology* 57(1–4):134– 44.

Mahapatra, R. (1997). *Field report on Adarsh Gaon Yojana.* Centre for Science and Environment, New Delhi.

Marinoski D.L, E, Ghisi and L.A. Go´mez (2004). Rainwater harvesting and rainwater tank sizing: a case study in a multi-storey residential building located in Floriano´polis, Southern Brazil. CLACS04 - I *Confere^ncia*

Latino-Americana de Construc-a˜o Sustenta´vel e ENTAC04-10Encontro Nacional de Tecnologia do Ambiente Construı´do, Sa˜o Paulo-SP, CD Rom.

Mati, B., T.D. Bock, M. Malesu, E. Khaka, A. Oduor, M. Nyabenge and V. Oduor (2006). *Mapping the Potential of Rainwater Harvesting Technologies in Africa: A GIS overview on development domains for the continent and ten selected countries.* World Agroforestry Centre (ICRAF), Netherlands Ministry of Foreign Affairs.: Nairobi, Kenya. 116 p.

Mondal, N. C. and V. S. Singh (2004). A new approach to delineate the ground water recharge zone in hard eock terrain. *J.Geol.Soc. India.* 87(5): 658-662.

Naidu, A. (2001). Evaluation of land and water resources and socioeconomic impact assessment of Vanjuvankal watershed in Ananthpur district of andhra Pradesh, India. *Environment and People* 8(1): 3-7.

Narain, P., M.A. Khan and G. Singh (2005). *Potential for water conservation and harvesting against rought in Rajasthan, India.* Working Paper 104 (Drought Series: Paper 7). International Water Management Institute (IWMI), Colombo, Sri Lanka

Ngigia, S.N, H.H.G. Savenije, J.N. Thome, J. Rockstrom and F.W.T.P.D. Vries (2005). Agrohydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. *Agricultural Water Management* 73: 21-41.

Nirmala, B. (2003). Impact of Watershed Development Programme on Socio-economic Dimensions of Beneficiaries in Rangareddy District of Andhra Pradesh. Unpublished. *M. Sc. (Agri)*, *Thesis*, University of Agriculture Science, Dharwad.

Samuel, M. P. and A.C. Mathew (2008). Rejuvenation of Water Bodies by Adopting Rainwater harvesting and Ground water Recharging Practices in Catchment Area- A case Study. *In* Sengupta, M. and R. Dalwani (ed), *Proceedings of Taal 2007: The 12th World Lake Conference* 766-776.

Schary, Yitzchat (2008). 'The Path Toward Sustainable Development in Israel'. Ministry of Environmental Protection, State of Israel.

Sharma S.K and S.K. Jain (1997). Ground water recharge through roof top rain water harvesting in urban habitation. *Int. Conf. management of drinking waterres*. P.60.

Sharma, N. and P. Kanwar (2009). Indigenous water conservation systems- A rich tradition of rural himachal Pradesh. *Indian Journal of Traditional Knowledge* 8(4):510-513.

Sreevastava, R.C. (2001). Methodology for design of water harvesting system for high rain fall area. *Agri. Water management.* 47:37-53.

The Hindu (2015). 'Water Man' Rajrendra Singh wins Stockholm water prize. March 22, 2015.

Venkatesh, B. and M.K. Jose (2007). Identification of homogeneous rainfall regimes in parts of Western Ghats region of Karnataka. *J. Earth. Syst. Sci.* 116 (4):321-329.

Venkateswara Rao, B. (1996). Artificial recharge of rainfall water for city water supply-A case study of Hyderabad. *Hydrology J.* 19(4): 35-48.

Venkateswarlu, J. (2001). *Technical Manuel on Watershed Management-1: resource conservation.* National Institute of Agricultural Extension Management. Hyderabad. 43-82.