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*A REVIEW*

# Sustainable agriculture in drylands of India : Unlocking the water constraint

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***Abstract*** **:** There are lot of key topics which are concerned with real world resources development and management problems in India. Sustainable agricultural development considering the water constraint is one of them. By 2020, India has got to increase productivity above 340 million tonnes of foodgrains in view of population growth, so the President of India appealed to agricultural scientists and technologists to work hard to double the productivity of available land in view of less area being available for cultivation, with limited water supply and diminishing number of available farmers. The drylands have to be targeted to increase productivity of foodgrains through sustainable agriculture, if India has to succeed in a second green revolution, without creating serious negative consequences to natural environment. So in present article focuses on key water constraints in Indian dryland agriculture and some solutions are suggested in brief.

***Key Words*** **:** Genotypes, Micronutrient, Tillering behavior, Direct seeding, Seed treatment

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The President of India, A. P. J. Abdul Kalam has called for a second green revolution, while inaugurating the triennial conference on Global Forum on Agricultural Research at New Delhi on 9 November 2006. This is not the first time that he has spoken about this issue. Three years ago, he had outlined the applications of technological innovations to meet future foodgrain needs demanded by the increasing population growth. By 2020, India has got to increase productivity above 340 million tonnes of foodgrains in view of population growth, so the President appealed to agricultural scientists and technologists to work hard to double the productivity of available land in view of less area being available for cultivation, with limited water supply and diminishing number of available farmers. The drylands have to be targeted to increase productivity of foodgrains through sustainable agriculture, if India has to succeed in a second green revolution, without creating serious negative consequences to natural environment.

At the 1992 Earth Summit in Rio De Janeiro, FAO defined "Sustainable Agriculture and Rural Development" as, it is a development and management of natural resource base and orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs and present and future generation. Such sustainable development (in agriculture, forestry and fisheries sector) conserves land, water land and animal genetic recourses is environmentally non-degrading, technically appropriate, economically viable and socially acceptable. Sustainability is the successful management of resources to satisfy the challenging human needs, while maintaining or enhancing the quality of environment and conserving natural resources. Effective management of agriculture extension has special relevance in Indian content where agriculture plays a key role in meeting food requirement and supporting raw materials, also is crucial for obtaining high returns from a production system on sustained basis.

Drylands, which cover about 41 per cent of Earth's land surface and are inhabited by more than 2 billion people (about

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one third of world population) are characterized by scarcity of water, show a gradient of increasing primary productivity, ranging from hyper-arid, arid, and semiarid to dry sub-humid areas. Deserts, grasslands, and woodlands are the natural expression of this gradient. In drylands potential water deficit affects both natural and managed ecosystems, which constrains the production of crops, forage, and other plants and has great impacts on livestock and humans. Four dryland subtypes are recognized *viz.,* dry subhumid, semiarid, arid, and hyper-arid; based on an increasing level of aridity or moisture deficit (UNEP). The current socioeconomic condition of dryland peoples, about 90 per cent of whom are in developing countries, lags significantly behind that of people in other areas.

Existing water shortages in drylands are projected to increase over time due to population increase, land cover change, and global climate change. The water availability in drylands is projected to decline further from the current average of 1,300 cubic meters per person per year (in 2000), which is already below the threshold of 2,000 cubic meters required for minimum human well-being and sustainable development. This increased water stress will lead to reduced productivity of croplands and availability of fresh water, resulting in further adverse impacts on human wellbeing. There is a high degree of certainty that global climate change, land use developments, and land cover changes will lead to an accelerated decline in water availability of drylands.

According to India's Fourth Five-Year Plan, areas with an annual rainfall of less than 375 mm are classified as arid (desert) and those receiving 375-1125 mm are dry land (FAO, 1993). Dryland agriculture means cultivation of crops entirely under rain-fed condition. It has a distinct place in Indian agriculture occupying 67 per cent of the cultivated areas, contributing 44 per cent of the population. The resource poor infrastructure and low investment in technology and inputs characterize it. Such dryland agriculture contributes about 45 per cent of natural food grain production. After full exploitation of drylands, it may contribute up to 75 per cent of total food grain production. Pulses and oilseeds are mainly grown in such areas. Important commercial crops *viz.,* cotton, castor, groundnut and all coarse grains *viz.,* jawar, bajara, maize are rainfed. The major part of milk, meat, wool hides, bonemeal etc. are also from this area. But if we compare irrigated areas with drylands, the average yield of irrigated land is about 2.5-3.5 t/ha, whereas the yield from dry land (rainfed land) is only about 0.7-1.5 t/ha (Sivanappan, 1997).

In the present times, most of the agriculture in India is managed on the basis of natural resources that safeguard agricultural production. Improvement of dry land farming is a key to the development of agriculture and removal of poverty in rural areas. Also in order to increase production for feeding present as well as future population, emphasis must be placed on strengthening rainfed farming through soil and water conservation, water management techniques and enhanced soil fertility.

Shah *et al.* (1998) reported that, undoubtedly, India is a land of villages with 700 million people living in over 600,000 villages, many in the enormous drylands. No developmental strategy can succeed that neglects the rural drylands that occur in 177 districts or 56 per cent of India's total geographic area, covering States such as Rajasthan, Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu. The drylands in these states have to be targetted to increase productivity of foodgrains, if India has to succeed in a second green revolution, without creating serious negative consequences to natural environment.

The UN Convention to Combat Desertification (UNCCD) has classified drylands in India as given in Table 1.

Heathcote (1983) reported that drylands are characterized not only by low annual precipitation, but also by erratic precipitation that is subject to large temporal and spatial variability. While precipitation in many semiarid lands averages between 200-500 mm/yr, which is suitable for some crops, the extreme fluctuations in precipitation from year to year make such averages of little use. He also told that precipitation alone does not define the climatic character of drylands. Aridity describes the normal conditions of drylands that are the result of factors that create low levels of moisture availability which includes not only low annual precipitation amounts, but also high evaporation demands.

Branson (1976) stated that ratios of evapotranspiration to precipitation are generally large in drylands, exceeding 95 per cent in some areas.

Vo¨ro¨smarty *et al.* (2005) reported that, total renewable water supply from drylands is estimated to constitute only around 8 per cent of the global renewable water supply (about 3.2 trillion cubic meters per year) , and only about 88 per cent of this is accessible for human use. Thus, almost one third of the people in the world depend on only 8 per cent of the global renewable water resources, which makes per capita availability in drylands just 1,300 cubic meters per year. It is substantially less than the average global availability and even lower than the 2,000 cubic meters regarded as a minimum by FAO (FAO, 1993).

Sivanappan (1997) reported from a study conducted in Punjab, India, that 54 per cent of the catchment area can be irrigated once with 5 cm depth of water so collected. Further, it was observed that the average response of one such supplementary irrigation to maize and wheat at its most critical stage increased the grain yield by 0.4 t/ha in the case of maize and 0.77 t/ha in the case of wheat. The benefit-cost ratio of tanks designed on a runoff basis for pre-sowing irrigation for wheat was double that of tanks designed for seasonal periodical runoff. In the case of maize tanks designed on a periodical runoff basis, the benefit-cost ratio varied from 1.6 to 4.56. This ratio increases with the capacity of the tank

**Table 1 : Classification of drylands in India (UNCCD, 1999)**

| Regions | Rainfall | Growing period (days) | Total land area | | Regions of India |
|---|---|---|---|---|---|
| | | | In mha | In % | |
| Arid | 0-10 cm | <90 | 39.1 | 1.96 | Hot arid (31.7mha): Western Plains inc. Thar desert, DeccanPlateau(parts) Cold Arid (7.4 mha): Western Himalyas (Leh, Kargil in J& K, some areas in Chambal and Kinanur in H.P) |
| Semi-arid | 10-40 | 90-150 | - | 37 | Aravalis, Gujarat Plains, parts of Deccan Plateau, Eastern Ghats (part), Central Highlands (part). |
| Sub-humid | 40-80 | 150-180-210 | - | 21 | Northern Plains, Central Highlands (parts), Eastern Plateau (parts), Western Himalayas (parts) |
| Humid | 80-200 | >180-210 | - | 22.4 | Bengal, Assam, Eastern Himalayas |
| Pre-humid | 200-400 | >210 | | | Northeastern hills, Eastern Coastal Plains, Western Ghats |

In FAO's repore on Water Harvesting (2001) some examples of successful water harvesting in India were discussed. It was written that, in this region, 75 per cent of the agriculture is rainfed and most parts of the country receive rainfall no more than 50 days in short but heavy showers. Rainwater harvesting is now rapidly expanding in response to an escalating water scarcity. Ranges of water harvesting techniques have been developed for both drinking water supply and irrigation, to be found in the arid plains, the semi-arid plains, the floodplains and in the hill/mountain regions. A number of 'success stories of greening of villages' have been developed in response to the severe droughts of the last three decades. In Rajasthan, Gujarat and Madhya Pradesh, communities that have undertaken water harvesting have a completely different livelihood situation compared to those without water harvesting. The projects have often been initiated by individual persons (especially famous are Anna Hazare and V Salunke) or by NGO's. A problem is that local institutions needed often are inconsistent with the predominant governmental structures and institutional set-up prevailing in the country.

To mitigate this shortage, exacerbated by the large within and between-years variability in rainfall, a variety of practices have been developed. From the least to the most technology-laden ones, these are:

– Watershed management, including conservation and rehabilitation of degraded vegetation cover for generating and capturing surface runoff for deep storage in the soil (protecting it from evaporation) (Oweis, 2000);

– Floodwater recharge and construction of dams and weirs for minimizing impact of floods and water loss;

– Irrigation, to circumvent the temporal variability in provision (often based on extraction from aquifers, with frequent over-pumping leading to salinization)-however, the transportation of water from other ecosystems that may be severely affected and the salinization of the irrigated drylands often make this option unsustainable;

– Mining of nonrenewable fossil aquifers (which are quite common in drylands), for cultivation that is otherwise impossible;

– Treatment of wastewater, mainly from urban sources, and reusing it for irrigation-a promising practice provided that concerns about adverse impacts on human health, crops, soils, and groundwater can be overcome (Karajeh *et al.*, 2000);

– Desalination of brackish water and seawater for all uses (which is safe and uses renewable sources but has a high energy demand and is relatively costly, and the accumulated brine often poses a salinization risk). These interventions are critical for relieving pressure on the water systems of drylands.

In the FAO's report (1993) it was highlighted about the importance of efficiency in irrigation schemes. It was reported that water is generally not efficiently used in irrigation schemes. It has been estimated that as much as 60 per cent of the water diverted and pumped for irrigation is wasted. It was also suggested that the promotion of good agronomic practices and efficient markets for input and output from irrigated areas can help improve the management of irrigated areas. This report also throws light on water salinization problems in drylands. Degradation problems in irrigation are often on-site and related to salinization. There are also frequent problems of displacement, groundwater depletion, water contamination, and water-borne diseases. Improper management of irrigation water can also raise the groundwater table, and problems attached to salinization may occur. It is estimated that 25 per cent of the irrigated areas in developing countries has problems related to salinization.

Brown *et al.* (1992) gave some importance of small scale irrigation projects. Less complex, small-scale irrigation schemes run either by individual farmers or by communities appear to be the most viable. This is especially the case when irrigation can be based on gravity. However, the initial investment cost is often too high for local communities to raise sufficient funds to build needed dams. One major problem, moreover, is that small-scale irrigation dams often fill rapidly with sediments. To avoid such problems it is important that soil and water conservation measures are in place in the dam watershed prior to its construction.

El-Ashry (1993) suggested the change in cropping pattern in order to use water efficiently. It was suggested that, in years when water levels in rivers become critical, however, irrigated land should be used for crops with high water use efficiency, such as pearl millet, sorghum, and wheat, instead of rice. Water use efficiency (ton grain produced per ton of water) of wheat is twice that of rice.

Cleaver (1997) reported that, large part of investment in the agricultural sector is used to develop irrigation facilities. Thirty per cent of World Bank lending to agriculture during the 1980s was used for this purpose. The performance ratings of existing and completed irrigation projects have been worse than the average agricultural project, and large-scale public-sector irrigation schemes have in general not been economically viable. Water for irrigation is also a highly subsidized sector, and water tariffs are set below the supply cost and often below the operation and maintenance costs. Consequently, cost recovery remains low, increasing the burden on the central government to provide capital to maintain existing systems.

Mehta (1998) mentioned that a village is rarely the homogenous and happy place it is often made out to be. There are poor and rich; weak and powerful. In order to gain legitimacy the implementing agency nearly always operates through traditional power-brokers. These are often men and from the higher castes. Only occasionally do the concerns of women, key water users, and those from lower castes come to the fore. Economically weaker groups such as the landless and pastoralists are also largely excluded from benefits. In many small-scale schemes, targets such as technicality and environmental regeneration seem more important than issues of equity and social justice. They opt for homogenous communities or to focus on just one articulate (powerful) group. Thus, despite often lofty intensions to secure participation and equality, such projects build on skewed power and social relations.

**Situation analysis and key constraints (Why farmer's yield in drylands is low?):**

There are several problems with such conventional analyses. The reasons related to water are first, the majority of land users in semi-arid tropical farming systems depend on rainfall for their livelihoods, and not on irrigation. Secondly, it is impossible to carry out assessments of water resources for food production on a country scale, when hydro-climates vary enormously within a country.

Rainfall has an approximate range of 200 - 1000 mm from the dry semi-arid to the dry sub-humid zone. The length of growing period ranges from 75-120 days in the semi-arid zone, and 121 – 179 days in the dry sub-humid zone, which is determined by the relation between rainfall and the potential evapotranspiration (PET). PET varies between 1500 - 2300 mm per year. Rainfall in the drylands exceeds PET only during 2 - 4.5 months (Kanemasu *et al*., 1990). On an annual basis semi-arid areas are characterised by PET > annual rainfall (P) with the ration P/PET < 0.65 in the "wettest" dry sub-humid zone (UNESCO, 1977). Daily PET levels are high, ranging from 5 - 8 mm day-1 (FAO, 1986). This gives a cumulative PET for the growing season of 600 - 900 mm, which explains the limited water surplus recharging aquifers and rivers.

Rainfall is highly erratic, and most rain falls as intensive, with very high rainfall intensity and extreme spatial and temporal rainfall variability. The result is a very high risk for annual droughts and intra-seasonal dry spells. Such short dry spells of water stress can have a serious effect on crop yields if occurring during water sensitive development stages like, e.g. during flowering. The annual (seasonal) variation of rainfall can typically range from a low of 1/3 of the long term average to a high of approximately double the average; meaning that a high rainfall year can have some 6 times higher rainfall than a dry year (Stewart, 1988). Statistically in a semi-arid region, severe crop reductions caused by a dry spell occurs 1-2 out of 5 years, and total crop failure caused by annual droughts once every 10 years. Thus the poor distribution of rainfall over time often constitutes a more common cause for crop failure than absolute water scarcity due to low cumulative annual rainfall.

Also the agro-hydrological challenge in drylands is not necessarily related to inadequate cumulative rainfall - at present basically only 1/8 - 1/3 of the rain is used in crop production on average. Instead the challenge is to manage the unreliable distribution of rainfall over time, and minimize non-productive water flow in the water balance. Research has shown often only a small fraction of rainwater reaches and remains in the root zone, long enough to be useful to the crops. It is estimated that in many farming systems, more than 70 per cent of the direct rain falling on a crop-field is lost as nonproductive evaporation or flows into sinks before it is used by plants. It is only in extreme cases that only 4 -9 per cent of rainwater is used for crop transpiration. Therefore, in rain-fed agriculture wastage of rainwater is a more common cause of low yields or complete crop failure than absolute shortage of cumulative seasonal rainfall.

**High yielding hybrid crop varieties:**

During recent years, the dryland regions of the country have increasingly come under the hybrid crop varieties. While the crop yields from the hybrid varieties was surely high, the flip side of these varieties – these varieties are water guzzlers – was very conveniently ignored. For the sake of comparison, let us take the example of rice: The high-yielding varieties of rice normally require about 5000 litres of water under drylands to produce one kg of rice. Common sense tells us that the rice varieties cultivated in the dryland regions of the country should be those that require less amount of water. What is in reality happening is just the opposite. Large proportion of the cultivable lands in drylands are now sown with hybrid rice varieties which require still more water for growing, its requirement of water touches 7000 litres for one kilo of rice grain. Strange that in Punjab, which has assured irrigation, only high-yielding rice varieties are cultivated which require relatively less water. In the rainfed parts of Andhra Pradesh and Karnataka, hybrid rice varieties, which require roughly twice the quantity of irrigation water (than Punjab), are grown abundantly. Not only rice hybrids, all kind of hybrid varieties of sorghum, maize, cotton, bajra, and vegetables that require higher doses of water, are promoted in the dryland regions.

In addition, agricultural scientists have misled the farmers by saying that the dryland regions were hungry for chemical fertilizers. Add to this the thrust on contract farming, which requires more chemical inputs and water will turn the dryland regions barren in the years to come. Water table will plummet beyond reachable limits, as a result of which the impact of deficient rainfall will become more pronounced forcing farmers to abandon agriculture and migrate. This is what normally leads to famines (Kisan niti news website).

A large part of investment in the agricultural sector is used to develop irrigation facilities. Thirty per cent of World Bank lending to agriculture during the 1980s was used for this purpose. But the performance ratings of existing and completed irrigation projects have been worse than the average agricultural projects, and large-scale public-sector irrigation schemes have in general not been economically viable (Cleaver, 1997). Water for irrigation is also a highly subsidized sector, and water tariffs are set below the supply cost and often below the operation and maintenance costs. Consequently, cost recovery remains low, increasing the burden on the central government to provide capital to maintain existing systems.

**Irrigation efficiency:**

Water is generally not efficiently used in irrigation schemes. It has been estimated that as much as 60 per cent of the water diverted and pumped for irrigation is wasted (FAO 1993). This highlights the importance of efficiency in irrigation schemes. In order to make irrigation economically viable, water should preferably be used for high-value products (Sharma *et al.,* 1996). In years when water levels in rivers become critical, however, land should be used for crops with high water use efficiency, such as pearl millet, sorghum, and wheat, instead of rice.

**Drought:**

Occurrences and the effects of drought require special attention in planning and management of natural and agricultural resources in dryland regions. A drought is a departure from the average or normal conditions in which shortage of water adversely impact ecosystem functioning and the resident populations of people. It is known that drought will likely occur in the future, but it is not possible to reliably predict when they will occur, their severity, or how long they will last. Because of these uncertainties and the severity of the impacts, there are many considerations about drought that must be taken into account in planning and management of water resources in dry lands. Drought is generally characterized by shortages of water, food for people, and forage for livestock that can lead to unplanned and often unwise use of available agricultural and natural resources. Serious degradation of land and resources can result if contingency planning is not undertaken to meet these shortages.

**Water resources:**

Much of the water that is available to people living in drylands regions is found in large rivers that originate in areas of higher elevation. These rivers include the Indus, the Ganga, Krishna etc. Groundwater resources can also be available to help support development. However, the relatively limited recharge of groundwater resources is dependent largely on the amount, intensity, and duration of the rainfall, and soil properties, the latter including infiltrations capacities and water-holding characteristics of the soil, which also influence the amount of surface runoff. Much of the rainfall is lost by evapotranspiration, and, as a result, groundwater is recharged only locally by seepage through the soil profile. Surface runoff events, soil moisture storage, and groundwater recharge in dryland regions are generally more variable and less reliable than in more humid regions. Groundwater is frequently used at rates that exceed recharge.

Problems of salinity are more widespread and acute in the drylands than other regions. Although most soil bodies contain some soluble salts, it is only when the accumulations of salts attain a level that is harmful to plant survival and growth that a saline condition has developed. In effect, therefore, plants "define" the salinity of soil in terms of their relative tolerances. Mineralization of groundwater resources is also a common problem. The causes of mineralization include the evaporation from water surfaces and shallow groundwater, fossil brines from ancient lagoons and lakes, and airborne salts deposited by precipitation and in the form of dry fallout.

**Solutions:**

*Irrigation practices:*

The general approach of flood irrigation often leads to high losses of water to evaporation from the soil and water surface, leading to low productivity of water. Water productivity can be improved by introducing precision irrigation. This involves the application of the required quantity of water, when it is required and in the root zone where it is required. Technologies for achieving the necessary high levels of control are already available. The examples are micro-drip techniques for high frequency, low volume, partial-areas application of water and nutrients to crop fields. Precision irrigation overcomes the problems of unproductive depletion of water from the soil. By applying the water directly to the root zone, transpiration by plants is increased due to improved contact between water and roots while soil evaporation and deep percolation are reduced. This increases the productivity of water. Furthermore, improved control of the timing of application of water makes it easy to implement supplementary irrigation strategically to overcome seasonal dry spells. The number of supplemental or protective irrigations depends on the frequency and severity of dry spells as well as the amount of water available. The method of application of irrigation depends upon the landscape, the crop grown and investment capacity.

*Small-scale irrigation schemes:*

Less complex, small-scale irrigation schemes run either by individual farmers or by communities appears to be the most viable. This is especially the case when irrigation can be based on gravity. However, the initial investment cost is often too high for local communities to raise sufficient funds to build needed dams. One major problem, moreover, is that small-scale irrigation dams often fill rapidly with sediments. To avoid such problems it is important that soil and water conservation measures are in place in the dam watershed prior to its construction. Characteristics of successful small scale irrigation projects found the following characteristics (Brown and Nooter, 1992):

– The technology is simple and low cost.

– The institutional arrangements are private or individual.

– When institutional arrangements larger than individual ownership are needed, the most effective arrangements were found to be (in decreasing order of success): extended family groups, private voluntary groups, water users associations, and cooperatives.

– Supporting infrastructure is important in order to have access to inputs and markets.

– There is a high cash return to farmers at the time they need it.

– The farmer is an active and committed participant in project design and implementation.

**Water harvesting:**

This is the process of collecting, concentrating and improving the productive use of rainwater and reducing unproductive depletion. It is believed that water harvesting techniques originated from Iraq over 5000 years ago in the fertile crescent, where agriculture once started some 8000 BC. This often involves collecting rainwater from a catchment area and channeling the runoff and using it to increase the water available in a relatively smaller growing area. In micro-catchment systems, water is collected from land adjacent to the growing area, while with macro-catchment systems large flows are diverted and used directly or stored for supplementary irrigation. The aim of water harvesting is to mitigate the effects of temporal shortages (but not insufficient cumulative amount) of rain, so-called dry spells; to cover both household needs (for drinking, cooking, sanitation, etc.) as well as for productive use (supplemental or protective irrigation) (Fig. 1 and 2).

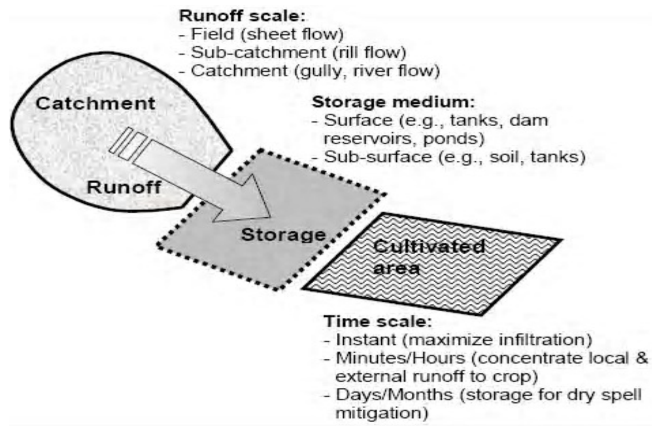


**Fig. 1: Principle of water harvesting for plant production (FAO, 2001)**

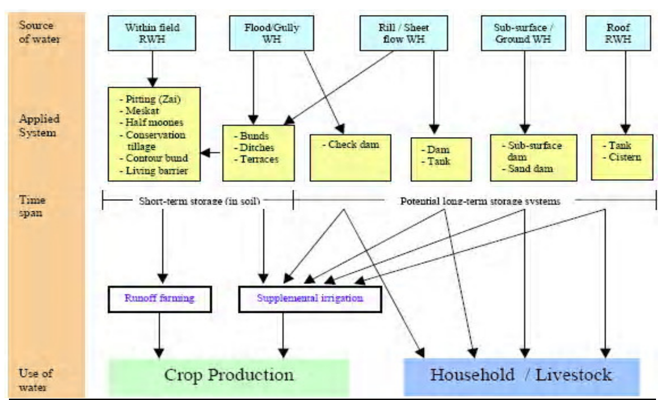


**Fig. 2: Classification of water harvesting systems on criteria of source of water and duration of storage (Fox, 2001)**

**Water collection systems:**

– *Within field RWH* refers to rain collected on the place it falls. Through various formations such as pits, the water will stagnate, infiltrate and thus made available to the plant root zone.

– *Flood/Gully WH* involves the collecting of storm surface floods from gullies. The harvested surface water can be stored in a reservoir (for longer term storage) or be diverted directly to a field for direct infiltration by arresting the flow of water with the help of bunds, ditches and terraces (for shorter term storage).

– *Rill/Sheet flow WH* is the collection of runoff of a gentler form than gully flooding. Here the slope does not exceed 1 per cent, along a length shorter than 50-150 meters and that the surface runoff is mainly harvested in form of sheet and rill flow. Beyond 150 meters water will generally start to flow in minor gullies and eventually gullies.

– *Sub-surface/Ground WH*. Extraction of sub-surface water flow, from either soil water trapped in shallow sand layers or from the water table. Storing water under ground is attractive as it reduces evaporation losses and often contributes to high quality water thanks to filtration through especially sand. Sand dams and sub-surface dams, where water is trapped behind small dam-walls in sandy riverbeds, is a very efficient and cheap form of WH.

– *Roof WH* involves collection of rainwater through a gutter or drain pipe from the roof. The system requires a tank to be built, which if correctly constructed can give water through piping straight into the house and thereby limit various forms of contamination. Roof RWH is primarily used for household use since the quantity obtained is seldom enough to cover agricultural needs greater than small-scale gardening. A combined area surface from several houses or school buildings, garage buildings, hospitals etc. can though produce considerable amounts of rainwater runoff, enough to be used for irrigation (Zhu and Li, 2000).

**Runoff enhancing methods:**

These include: land alterations, soil compaction, soil deflocculents and additives, spraying asphalt membranes, liners, cement lining, natural clay layers and pottery clay liners (burned) (Sivanappan, 1997). The percentage of runoff, combined with total rainfall and the aim of the water use will decide the size of the needed catchment area. In agriculture, the crop will be the water user, and normally the catchment requirement is described as the ratio of the runoff producing catchment to the cultivated area (C:CA ratio). A rule of thumb is a C: CA ratio of at least 3:1 (Anschutz *et al*., 1997). However, depending on the hydro-climate, runoff coefficients, and crop water requirements, catchment to cultivated area ratios will vary from 1:1 to 10:1. Depending on utilization, the runoff coefficient will vary greatly and the catchment area in relation to its intended use needs to be designed accordingly so as to correspond to the objective. The risk of contamination has to be observed depending on the intended use of the harvested water.

**Storage:**

Whether for household or agriculture, water that is harvested for a longer time of duration, and tapped only when required, involves a storage component. Various forms that exist include:

– *Micro-dams, earth dams, farm ponds*. Runoff water is stored in open structures, which can consist of small concrete dams, earth dams or simply ponds.

– *Sub-surface dams, sand dams or check dams.* Water is stored under ground - in an artificially raised water table or local sub-surface reservoir (e.g. water stored in sand on top of a sealing layer of clay).

– *Tanks* of various forms (plastic, cement, clay, soil etc.). These can be either under or above ground depending on space, technology, investment capacity and forms of extracting the water.

**Storage losses:**

Seepage and evaporation losses are the main forms of losses from storage reservoirs. Evaporation losses can be reduced through the minimization of open water surfaces and the covering of the surfaces. Sub-surface dams are one solution to prevent water surfaces to be fully exposed to atmospheric demands for water. Seepage losses can be considerable, especially in soils that are permeable. Prevention is done by reducing the wetted surface area, self sealing through siltation or applying various types of lining. Because of the high costs it is often cheaper to include the losses in the water needs calculations and construct storage capacities that include the losses as well (Critchley and Siegert, 1991).

**Choice of water harvesting technology:**

The choice of technique will depend on biophysical fit, socio-economic environment and capacity to maintain the system. All systems require various degrees of maintenance, mostly of erosive damage caused by rainfall and runoff. Also the time the structures lay idle through the dry seasons can give rise to needs of maintenance. This must be included in the operation procedures of the technique. The choice of technique will also be affected by the type of crop production (Table 2).

The factors determining which system to use depend on several factors:

– *Potential source of water:* WH is particularly suited for semi-arid regions (300-700 mm average annual rainfall) (Anschutz *et al*., 1997) but is also used in more arid regions such as some parts of Rajasthan. In more arid regions the implementation costs are higher due to the need of larger catchment structures.

– *Storage capacity* (in time): In agriculture if the purpose is supplemental irrigation, then irrigation requirements and scheduling need to be assessed in relation to (i) the depth of water required, (ii) most likely timing of yield affecting crop water stress (iii) the possible depth of water that can be harvested

**Table 2 : Runoff farming techniques suited for various production needs (Critchley and Siegert, 1991)**

| For rangeland and fodder | For trees | For crop |
|---|---|---|
| - Planting pits | - Contour bunds | - Contour stone bunds |
| - Contour bunds | -Closed micro catchments | - Earth bunds with stone spillways (“Meskat”) |
| - Semi-circular bunds | - Semi-circular bunds | - Contour earth and/or vegetation bunds |
| - Contour stone bunds | - Infiltration pits | - Living barriers |
| | | - Planting pits (Zai) |
| | | - Semi-circular bunds |

– *Purpose of use*: single or multi purpose use (*i.e.* a combination of objectives such as irrigation, household water, livestock etc.)

– *Volume of water required*: It can be obtained by analyzing rainfall data to assess probabilities of dry spell or stress occurrence and the actual requirements of water for the various intended uses (e.g. daily crop water requirements).

– Investment capacity of the owner of the system (individual farmers, farmer groups, communities etc.).

– *Physical site conditions*: Land availability including catchment availability and the runoff coefficient of the catchment surface are decisive factors in calculating runoff potentials. It is not recommended to conduct WH from slopes exceeding 5 per cent due to uneven distribution of runoff, soil erosion and the high costs of the structures required.

– *The characteristics of the catchment area*: It should preferably permit as much runoff as possible. The more compact (rocky), sealed and barren as possible, the better.

– *The application area*: It is also important to realize that an investment in water harvesting may well result in a shift in crop production system. Therefore, in many cases the estimated costs and benefits from a certain water harvesting system should be based on a different crop production system than the original system practiced prior to any WH introduction. For example, water harvesting structures with storage components are rarely seen as economically viable by farmers, if used only for staple food crops. Instead, the construction of, e.g., a farm pond, will most probably result in a shift in production system, toward high value crops such as tomatoes, garlic, onions, fruits, etc.

**Incentives and policies needed:**

Soil erosion, conservation of moisture and soil nutrients are still problems in drylands of India, especially among small farmers. While the threat of land degradation is generally recognized, soil and water conservation is often denied the priority it deserves. The fact is that many rainfed farmers have to struggle for their daily subsistence. Few may have the resources, and state governments are providing incentives by way of subsidies covering as much as 30 per cent of the cost of works. The benefits of investment have been difficult to quantify in economic terms, though there are many direct and indirect benefits. Gestation periods are long, and returns to farmers are slow. Financing agencies are generally hesitant to support large-scale soil and water conservation works in developing countries. It is, therefore, necessary to have proper incentives at the farm level, and sound technical, institutional and legal frameworks are essential to achieve good land use. In addition, land users among the general public should be well informed of the need for means of improving soil productivity.

**Social constraints:**

None of the development activities described above could have been undertaken without the active support of the people in the area. There are non-government organizations or voluntary organizations in many places, and their services can be utilized profitably. The people should be educated through various means to understand the seriousness of the problems and the remedial measures. Pilot projects and demonstration plots can be introduced to illustrate the need for and advantages of these technologies for sustaining their livelihood. There are many constraints upon achieving these goals in the developing countries like India. These can be classified as socio-cultural and economic constraints, and institutional cum political constraints (Fig. 3). Sociocultural and economic constraints include the following (Sivanappan, 1997).

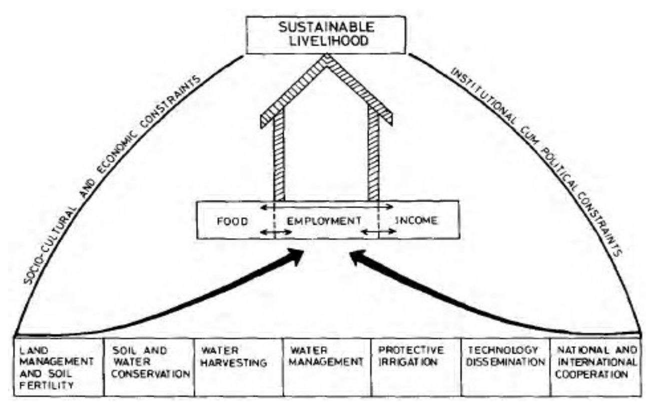


**Fig. 3 : Prospects for sustainable human livelihood in dry lands**

– Caste, community
– Religious institutions
– Illiteracy
– Poor economic status of the majority of the farmers
– Farm size and fragmentation
– Land ownership patterns and tenancy

The institutional cum political constraints are:

– Policy instruments
– Credit instruments (banks)
– Marketing institutions (regulated market)
– Research institutions
– Appropriate technology for rainfed farming
– Extension agencies for popularizing such technology
– Role of NGOs and voluntary organizations
– Policy and decision-making level (government/donor agencies)

There may be numerous obstructions and constraints upon the dissemination and implementation of technologies and practices which have been proved successful. The factors promoting the spread of successful technology should be identified and acted upon for the future development of soil and moisture conservation and related activities.

**Summary and conclusion:**

The drylands have to be targeted to increase productivity of foodgrains through sustainable agriculture, if India has to succeed in a second green revolution, without creating serious negative consequences to natural environment. Sustainable agriculture will certainly play the major role in this revolution. But there are some constraints for lower yield from Indian drylands related to water. These are,

– Rainfall is highly erratic. The result is a very high risk for annual droughts and intra-seasonal dry spells. Such short dry spells of water stress can have a serious effect on crop yields if occurring during water sensitive development stages.

– Much of the rainfall is lost by evapotranspiration, so groundwater is recharged only locally by seepage through the soil profile. Surface runoff events, soil moisture storage, and groundwater recharge in dryland regions are generally more variable and less reliable. Groundwater is frequently used at rates that exceed recharge.

– The high yielding hybrid crop varieties recommended in dryland region require high amount of water to achieve the expected yield. But due to rainfed agricultural practices being adopted frequent failure in rains causes frequent crop failures.

– A large part of investment in the agricultural sector is used to develop irrigation facilities. But the performance ratings of existing and completed irrigation projects have been worse than the average agricultural projects.

– Drought, which is frequent in drylands is generally characterized by shortages of water, food for people, and forage for livestock that can lead to unplanned and often unwise use of available agricultural and natural resources. Serious degradation of land and other resources is result of this.

– Problems of salinity are more widespread and acute in the drylands than other regions. Mineralization of groundwater resources is also a common problem.

– Other than above, there are institutional, socio-cultural and economic constraints which very well affect the water management practices in drylands.

The solutions for above problems can be as follows:

– Less complex, small-scale irrigation schemes run either by individual farmers or by communities need to be designed and constructed. These schemes should be linked to precision irrigation practices (instead of traditional flooding practices.).

– Various water harvesting practices listed above must be adopted in order to mitigate the effects of temporal shortages of rain, so-called dry spells; to cover both household needs (for drinking, cooking, sanitation, etc.) as well as for productive use (supplemental or protective irrigation).

– Soil and water conservation practices must be given sufficient importance in sustainable development of drylands in India. The non-government organizations or voluntary organizations of local people must come forward for dryland developments.

– None of the development activities described above should undertake without the active support of the people in the area. The people should be educated through various means to understand the seriousness of the problems and the remedial measures. Pilot projects and demonstration plots can be introduced to illustrate the need for and advantages of these technologies for sustaining their livelihood.

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