Climate Change Mitigation in India's Drylands

Case Study of Sadguru's Ecofriendly Check Dams

By

Prof. Dr. G. Agoramoorthy

Distinguished Research Professor at Tajen University, Taiwan &

Tata-Sadguru Visiting Chair at Sadguru Foundation, Gujarat, India

June 2014

“The world is now warmer than it has been at any point in the last two millennia, and, if current trends continue, by the end of the century it will likely be hotter than at any point in the last two million years” — Elizabeth Kolbert

Introduction

Water has emerged as one of the most important commodities of the 21st century. Nevertheless, water is a shared responsibility of consumers, communities, governments and corporations (UN 2006). The global demand for freshwater over the next 25 years is expected to exceed by 40% with serious ecological, economic and social consequences (Hoekstra 2013). To make matters worse, desertification has become a serious environmental threat with major implications for sustainable development (D’Odorico, *et al.* 2013). The further degradation of the fragile drylands will impact the environment gravely and experts have warned that 50 million people worldwide will be displaced as a result of intense desertification within the next decade (Haag 2007). The drylands cover 41% of the Earth’s total surface area; they also sustain 38% of the world’s human population (Millennium Ecosystems Assessment 2005). Therefore the United Nations has adopted the Convention to Combat Desertification in 1992 so that sustainable development projects can be promoted to decelerate environmental deterioration. Nevertheless, drylands around the world are expanding rapidly due to the steady increase in the temperature as a result of the looming climate change scenarios (Feng and Fu 2013).

India harbors a population of 1.2 billion inhabitants and 69% of the landmass falls under the category of drylands accounting to about 564 million acres out of the total 810 million acres of land area (National Report to UNCCD 2011). Besides, India has the second largest arable land in the world following the United States. But the country's agriculture is dominated by small farms where 60% of landholders own 17% of farmlands with an average holding of 2.5 acres. In contrast, 7% of medium-to-large landholders (>10 acres) own 40% of farmlands (European Commission 2007; Agoramoorthy 2012a). Moreover the small landholders are subsistence farmers with low investment potential hence they cannot sustain farming without financial backing. The collapse of Doha 2006 WTO Development Round negotiations for instance has showed the alarming trend (Pritchard 2009).

Climate change impact models have predicted that India will face extreme weather conditions that include consecutive droughts, severe monsoons, serious floods and rapid rise in sea level (Schellnhuber *et al.*, 2006; Mujumdar 2013; Shinde & Modak 2013). Therefore sustainable development is crucial to minimize climate change impacts. Sustainability refers to meeting future demands without compromising the integrity of Earth's natural environment including the delicate ecosystems (Daly & Cobb 1989). The large-scale land use patterns for example across India has contributed to drastic decline in the surface and ground water resources (Giordano & Villholth 2007; Agoramoorthy 2012b; Chinnasamy *et al.* 2013). Besides, irrigation water is the major driver of agricultural productivity since majority of the workforce (68%) across India relies on farming despite its contribution to gross domestic product has diminished from 38% in 1975 to 17% in 2012 (Agoramoorthy, 2012a). Irrigation has been known to increase outputs even in drylands stabilizing food security with affordable cost (Hanjra & Gichuki 2008; Hanjra *et al.* 2009; Agoramoorthy & Hsu 2013). As a matter of fact, just 19% of irrigated land in 270 Mha areas has been reported to supply nearly 40% of the global food productivity enhancing substantial socioeconomic benefits (Molden *et al.* 2010). In spite of that water scarcity can also reduce agriculture production hence influence food insecurity locally and globally (Agoramoorthy, 2008; Falkenmark & Molden 2008).

But the fundamental problem lies in the agriculture sector since it's the single largest user of surface and groundwater resources in the world. The water withdrawals for irrigation lead to 70% of the total anthropogenic use of renewable water resources nearly 2630 Gm^3/year out of 3815 Gm^3/year (Fischer *et al.* 2007). Sadly, only half of the water withdrawals reach the crops while the rest wasted in leakage associated to poorly maintained canals and evaporation (Agoramoorthy 2012a). Irrigation water is therefore critical to eliminate not only global food insecurity but also mitigate the looming climate change crisis. Water scarcity is already critical in many parts of the world and the water footprints have gained momentum in recent years (Hoekstra 2013). Politicians and policy-makers from around the world are having tough time tacking the water needs of the burgeoning human population since the future wars can be over the scarcity of water resources (Chellaney 2013).

Rivers are considered sacred in India for centuries. The *Puranas* (Hindu holy text) for example portray that a person can gain salvation by bathing in the Ganges and the same goal can be achieved merely by catching the sight of Narmada. But the survival of many rivers across India is at stake now due to aggressive developmental activities (Agoramoorthy 2012a). By building large dams, humans have drastically changed the amount and timing of river flows. Prior to 1900, only 40 reservoirs had been built with storage volume greater than 25 billion gallons (Molden 2007). Currently there are 50,000 dams over 15m high that occur worldwide and half of them are located surprisingly in China. In total, these dams hold over 6,000 cubic km of water. An additional 1,600 large dams are under construction in several countries with an annual expense of over USD 50 billion. The existing dams generate 19% of the world's total electricity where one-third of the countries heavily rely on hydropower electricity. Half of these mega dams were built primarily for irrigation to meet the growing food demand and about 30 to 40% of the 271 million ha irrigated areas worldwide rely on dams. There are about 227 large rivers worldwide and 60% of them are fragmented by dams, diversions, and canals leading to ecological degradation (Postel & Richter 2003). The dam displaced human population goes up to 80 million worldwide and the 20th century alone has spent over USD 2 trillion on dams. The water usage has been tripled worldwide since the 1950s, and for decades, policy makers and politicians have met this rising demand by building bigger dams. The battle over big dams is at the center of conflicts involving water scarcity, environmental disaster, biodiversity loss, and the survival of indigenous people (Kumar 2006). India’s Sardar Sarovar became the most contentious dam because of its displacement of people and negative ecological impact. India by the way is one among the most prolific dam builders in the world with 4300 big dams; it ranks third globally in completed big dams, closely following China and USA (Ray 2010).

India’s leading rural development stalwart, Harnath Jagawat states that the country cannot entirely depend on big dams and canal irrigation because it harbors enormous areas of drylands beyond the reach of all mega dams (Jagawat 2005). Therefore he reiterates that rainwater harvesting through small dams (also known as check dams) is absolutely necessary if India needs to combat local climate change scenario involving surface and ground water. Besides, not all rural areas can access canal irrigation from major dams therefore the minor check dams are extremely necessary. This report presents data on how the ecofriendly check dams can transform infertile drylands to productive agricultural lands, restore rivers during dry season, enhance forest growth along rivers, recharge ground water, and ultimately mitigate climate change in local perspectives.

Study area

The present study was carried out in three districts of western India namely Dahod (Gujarat State) as well as Jhalawar and Banswara (Rajasthan State) where most of the check dams were constructed during 2001-2006 (Government of India 2011). The Dahod district (area 3,642 km²) harbors a population of 1,636,433 with 72% belong to the tribal (also known as *adivasi*, meaning 'aboriginal people') communities. The average maximum temperature goes up to 46ºC while the minimum goes down to 8ºC with a mean annual temperature of 26ºC. The district receives 860 mm of annual average rainfall. The Jhalawar district (area 6928 km²) is not only the poorest but also the least developed districts in Rajasthan state. It supports a population of 1,180,342 (Government of India 2011) and 86% live in rural areas. The district harbors 1585 villages and only 40% of the total area has access to irrigation water. The region receives an average annual rainfall of 95 to 1000 mm. The Banswara District has an area of 5,037 km² (1.47% of Rajasthan State) and it is one of the least developed districts in Rajasthan State.

Data collection and analysis

Surveys were done using topographic maps and satellite imageries to assess the water harvesting potential in selected field sites before finalizing the dam construction sites. The Sadguru Foundation, which is a non-government organization (NGO) based in Dahod (Gujarat, India) has been involved in water resource management since 1974 to enhance the livelihoods of dryland farmers (Jagawat 2005). Using the field maps and satellite imageries, patterns of forest types and drainage network of rivers were identified. Field survey methods, instruments for the design, preparation of drawings and check dam estimates follow the standard civil engineering methods (Bondelid *et al.* 1982, Lindsely 1992). Data on variables such as need for check dams, environmental sustainability, community benefits, farmers' migration pattern, education, family structure, and employment opportunities were collected. The water storage in check dams was calculated according to methods described by Bondelid *et al*. (1982) and Design of Small Dams (1987). Satellite photographs showing before and after construction of check dams in rivers between 1990 and 2007 were obtained from the National Remote Sensing Agency. Check dams located in Gujarat, Rajasthan and Madhya Pradesh were visited to record data their impact on community and environment following the methods adopted after McNeely and Scherr (2001).

Data on rivers, dam measurement, storage of water in dams, water recharging in village wells, local people employment for dam construction, and impact on local ecology and people were pooled from the archives of Sadguru Foundation. Discussions and interviews of 300 villagers were conducted while visiting several villages where check dams and lift irrigation corporatives were operated by the community to record details on ecological and livelihood benefits (McNeely & Scherr 2001). Groundwater levels in village wells were monitored by using graduated steel tape (Lapham *et al.* 1997).

A total of 356 check dams were constructed between January 1990 and December 2012. All statistical analyses were conducted using Statistical Analysis System software (SAS Institute 2000). All mean values are presented as ± 1 standard deviation. A linear regression analysis was used to estimate the cost (USD) according to the length of check dams. Various general linear models were used to test the effects of variables such as the total length, crest and height of dams, water storage capacity, irrigated area, command area and cost of check dams. A general linear regression analysis was used to estimates the cost while analysis of variance (ANOVA) was used to test factors that influenced the capacity of check dams. The India rupee was converted to USD according to yearly exchange rate offered by the government of India.

Sadguru’s ecofriendly check dam model

The check dams are made of small barriers using stones, steel, cement and concrete; they can be built across the direction of water flow on rivers or streams to store rainwater (Agoramoorthy 2012b). They retain excess flow during monsoon rains in small catchment areas behind the dam. The major benefit is the replenishment of nearby groundwater reserves and wells. The water entrapped by the dam (surface /subsurface) is primarily intended for irrigation after the monsoon and later during the dry season, but can also be used for livestock and other domestic purposes.

The Grand Anicut (‘*Kallanai*’ in Tamil language) is considered to be India’s oldest check dam, which is still operational. It was built by the Chola King (Karikalan) in the Cauvery river of Tamil Nadu in south India during the 2nd century AD. During the British occupation of India (1757-1947), two military engineers had pioneered India’s large-scale irrigation. They were namely Proby Cautley, who built the Ganges Canal, and Arthur Cotton, who rebuilt the Grand Anicut on the Cauvery—both systems redistributed water over hundreds of miles of canals to boost agriculture productivity. When the British East India Company took control of the Cauvery delta in 1799, it was unable to check the rising river bed due to silt backed up against the dam. They struggled for 25 years and finally, using indigenous technology, Arthur Cotton was able to solve the problem by renovating the Grand Anicut. He later wrote “it was from them (Indians) we learnt how to secure a foundation in loose sand of unmeasured depth. The Madras river irrigations executed by our engineers have been from the first the greatest financial success of any engineering works in the world, solely because we learnt from them" (Cotton 1874). To honor the ancient king Karikalan and engineer Arthur Cotton, local people have erected statues near the Grand Anicut that can be seen even today.

The basic rule of check dam involves a few steps. The dam site must possess minimal degraded catchments with maximum rock formation and with less sediment load in the river. The cross section of river should be such that the length of the barrier as small as possible and open out upstream. The bed-gradient of main drainage channel need to be straight and capable of storing maximum water, and the created reservoir must not submerge nearby farms and property. The downstream geological condition must catalyze water recharging in aquifers, recycle of water in nearby wells and enhance local geology (Agoramoorthy 2008, 2012b). The smaller dams as part of the river valley system can hold sufficient water during the dry season and building of those check dams should start at the source of the river or rivulet and proceed downward forming a series. They form a cascade of smaller reservoirs but large enough to equally distribute water among the villages that traditionally never see water during the dry season. The trapped water would trickle down to the ground leading to increase in groundwater reserve that can be recycled through wells.

Cost, conservation and community benefits

By strictly following the basic design of the Grant Anicut model, the Sadguru foundation constructed a total of 356 such check dams between 1990 and 2012 across the tribal drylands of western India covering states of Gujarat, Rajasthan and Madhya Pradesh (Table I). These areas are classified as drought prone semi-arid and inhabited predominantly by indigenous tribal population, who are often poor and struggle for survival in the harsh landscape (Jagawat 2005; Phansalkar & Verma 2005).

Table 1 Summary of water-centered development work implemented by Sadguru foundation in the drylands of Gujarat, Rajasthan and Madhya Pradesh states till March 2014

Poverty reduction activity	*Physical achievements*	*Area benefitted (acres)*	*No. of beneficiaries*	
			Households	*Persons*
Community lift Irrigation	391	51,550	26,691	160,146
Check dams	371	55,076	23,940	143,640
Village well recharging	18,449	36,156	18,454	110,766
Drinking Water system	98	-	3,679	24,409
Watershed development	96,476	96,476	30,387	182,322
Social forestry-No. of saplings planted	65,942,843	69,106	126,241	757,446
Joint forest management (acres)	13,390	13,390	4,339	26,034
Horticulture plants	30,793	17,156	30,793	184,758
Vegetable cultivation	3,986	1,742.50	3,986	23,916
Floriculture plots	6,633	621.71	5,533	33,198
Green house	02	01	02	12
Net house	186	78,70	186	1,116
Bio gas system	2,828	-	2,828	16,968
Total		268,672.91	317,193	1,905,535

This massive effort benefited 317,193 households or 1,905,535 people. The farming communities lived below the poverty line prior to the intervention, but afterwards enjoy an economically enhanced life (Table I). A total of USD 17.22

million was used to construct 365 dams from 1990 till 2012 with 55237 acres irrigated area increment. From 1990 till 2012, an average 15.5 dams per year was finished with the maximum occurred on 2000 (n=30) and the minimum on 1990 (n=6). The total water storage capacity was 2011.75 mcft. The average cost for building the check dams per year was USD 55,890 or Rs 2794500 ± 48540 (USD 12480 or Rs 624000-18973 or Rs 948650; n=23). The area irrigated after the construction of check dams was highest in 2006 (Fig. 1).

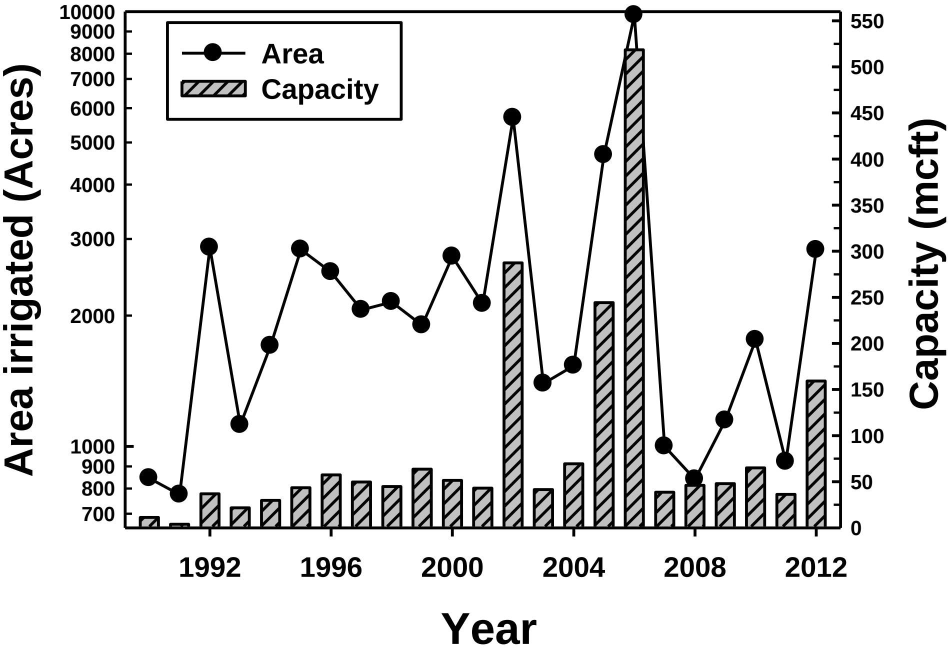


Figure 1. Expansion of irrigated area (log scale) and water storage capacity of 356 check dams constructed from 1990 till 2012 in Gujarat, Rajasthan and Madhya Pradesh states, India.

The highest amount of irrigated area increase was 9813 acres in 2006 from 18 check dams completed with a total water storage capacity of 518.5 mcft, followed by 5696 acres (2002) from check 22 dams completed with a total water storage capacity of 287.5 mcft (Fig. 1). The number of people benefited was highest in 2006 with

23,904 and it was mainly due to the largest and expensive check dam Baneshwardham (Dungerpur, Rajasthan state) benefitting 18,000 people (Fig. 2).

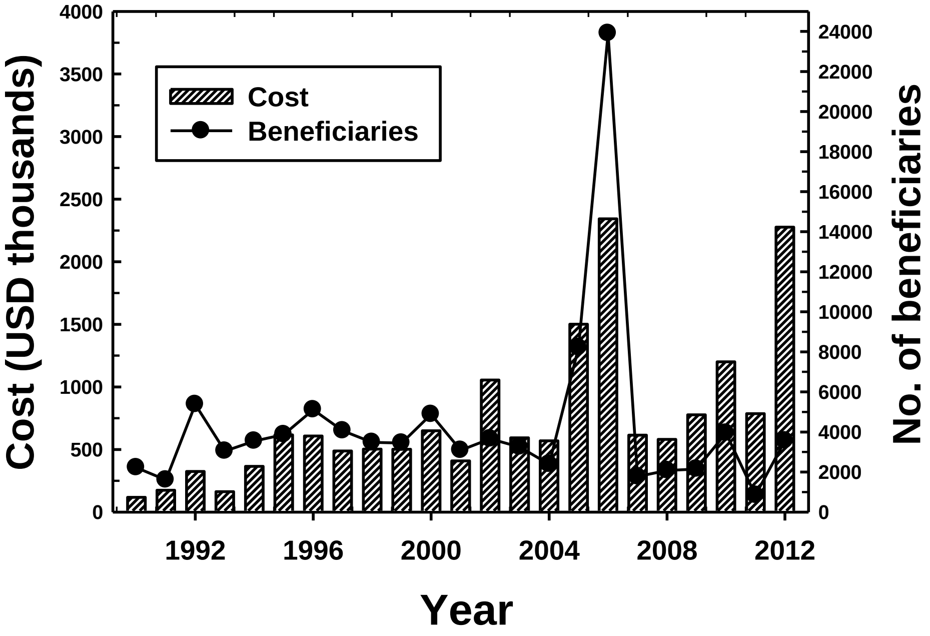


Figure 2. The cost to complete construction of check dams and number of people benefited each year from 356 dams built between 1990 and 2012 in India.

The average height of the constructed check dams was 2.79 ± 0.83 m (range 0.75-7.25 m) and the average length of check dam was 62.31 ± 44.10 m (range 12-367 m). The average capacity of check dams to hold water was 5.65 ± 22.12 mcft (range 0.1-350 mcft). The average number of beneficiaries included 46.57 ± 162.34 households (range 2-3000 households). These families used to grow one rain fed crop each year and frequent droughts often force them out of their villages to search for jobs in nearby towns. Ever since check dams were constructed, local people migrating to nearby towns and cities for labor work stopped. During the time of check dam construction, local villagers were employed and the employment averaged 2152.68 ±1577.79 for males and 2215.79 ± 2350.87 for females. This showed no gender bias since both men and women had to work for a living in the arid landscape. The average irrigation area expansion after the construction of check dams was 155.16 ± 406.14 acres (range 3-7000 acres).

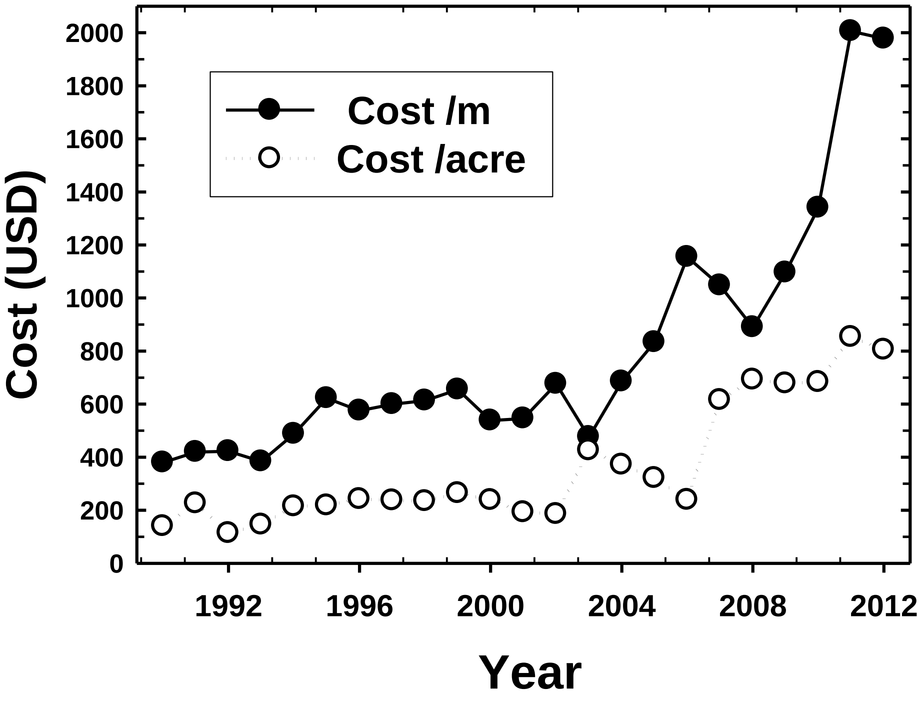


Figure 3. The construction cost of check dams (USD per meter or per acre) between 1990 and 2012 in India.

The length, height, water storage capacity, irrigated area and command area had significant effects on the cost of check dam construction ($F_{5,\,323}$=92.3, R^2=0.59, p<0.001). Among them, the length of check dam was the major factor influencing the cost of construction ($F_{1,\,323}$=46.7, p<0.001). The longer the length of the check dam was costlier for construction due to materials, machineries and manpower usage. The total length of all constructed check dams was the longest in 2006 (2029.88 m) followed by 2005, 2002 and 2000. The capacity of total water stored after completion of check dams was highest during 2006 (518.5 mcft) followed by 2002 (287.5 mcft) and 2005 (244.35 mcft, Fig. 1). The enormous amount of water stored would not have been done without the check dams. Without the check dams, the water would have gone straight to the sea, dispersed in surface area and evaporated to due harsh weather conditions.

In 2006, the total cost of constructing check dams was highest accumulated to USD 2.34 million, which is about 1.6-2.2 times that of 2005 (USD 1.50 million) and 2002 (USD 1.06 million). The height, command area, irrigated area and cost of check dams had significant effects on the capacity of check dams ($F_{4, 324}$=349.58, $p < 0.001$, R^2 =0.81). However, the check dam cost per meter was lowest during 1990 (379.4 USD/m) and 1993 (383.7 USD/m, Fig. 3). However, the cost of benefited irrigation area per acre was lowest in 1992 (113.3 USD/acre) and 1990 (139.8 USD/acre) and highest in 2011 (852.7 USD/acre) and 2013 (804.5 USD/acre).

It was not easy for the rural NGO to embark on the construction of check dams. The check dam proposals went through 2-tier government clearance— initial technical clearance from irrigation department and final clearance from finance department scrutinized by development authorities. At the beginning, engineers from NGO had difficulty to get clearance since government officials were skeptical and feared that structures would not withstand flooding. Nonetheless, all check dams constructed by Sadguru foundation are still operational as of March 2014 and managed by the community through peoples' cooperatives since the communities depend on water to sustain livelihoods. India's government-built big dams are properly planned and maintained. However, many of the check dams constructed by various government agencies through private contractors were often not functional due to lack of monitoring, community support and flawed site selection. A total of 60 such small check dam structures were seen within one week fieldtrip in Gujarat and Rajasthan States during January 2013. The exact number and the amount spent for the construction of such failed check dams by government agencies throughout India is not clearly known since the data are not shown in public records.

In order to make check dams operational, village institutions (peoples' cooperative) run by community were created to manage the structures. The construction of check dams is demand-driven and done only on justification from the community to boost agriculture productivity and to protect ecology. Villagers who would benefit from check dams were involved from the beginning and ultimate management was transferred to the user groups with 100% charges paid by them for services obtained. The implementation of participatory and demand-driven approach ensures that people obtain the level of services they desire and they also can afford to pay for services. Furthermore, full cost recovery of operation, maintenance and replacement costs would ensure the financial viability and future sustainability of water harvesting structures. Unfortunately, government agencies while building check dams do not follow this people-oriented approach therefore often leading to failure.

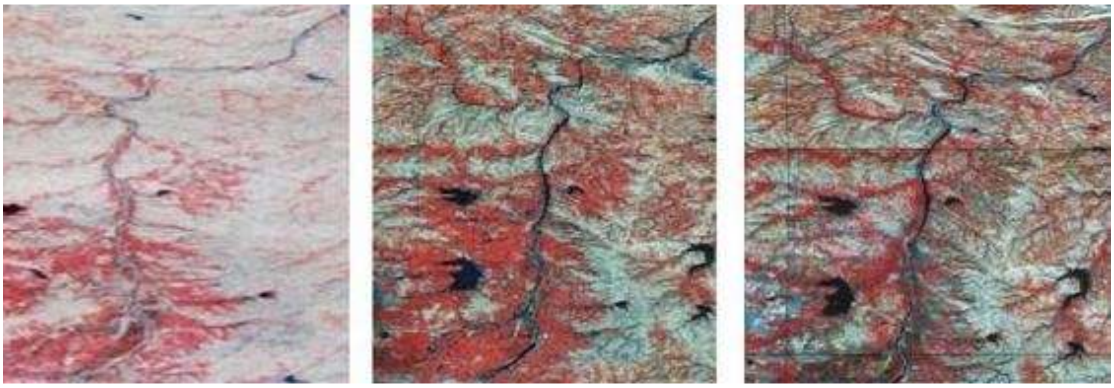
Eco-benefits of dams mitigating climate change

After building the check dams in rivers, water conservation was possible in the drylands especially during the dry season when the entire landscape is dehydrated therefore the conserved water promoted local climate change mitigation measures. This eventually increased agricultural productivity ultimately leading to eradication of poverty and restoration of natural resources in terms of ground water recharging, growth of forest vegetation, and supporting numerous flora and fauna. Due to higher capacity of stored rain water in check dams, benefited irrigation area also showed similar upward growth (Figure 1). The check dams did not have negative effect to natural environment indicating their role as an environment-friendly minor irrigation development structure that deserves strong support from the government and corporate sectors.

Figure 4. A view of the dry Chambal river near Sindhla village in Rajasthan State (India) in January 2002 before the construction of check dam (above). In November 2003, the new check dam's back water could be seen for miles (below) indicating the great potential of small dams.

The check dams also revived ground water resources, especially wells in villages that people often use for domestic purposes (drinking, cooking, etc). In Rozam village of Gujarat State for instance, 10 check dams have increased ground water level from 0.55 m to 9.5 m in 60 nearby open wells. The average water table went up by 2.94 m in the open wells and the well water yield also increased from 0.88 lps to 1.98 lps after the completion of check dams. Over all, the ground water recharge increased the surface water availability by 9.44 mcft from July to December each year and 17.20 mcft of ground water recharge, which is available round the year since 2006.

The higher volume of stored rain water in check dams indeed benefited irrigation while showing similar upward growth with no negative impact on local environment (Figure 4). For example, the River Machhan, which is a small local river that runs across the drylands of Dahod district of Gujarat State, has been shown in the satellite imagery before and after the construction of check dams with and without water during the dry season (Figure 5). The satellite photos clearly indicate more water storage and thick vegetation cover induced by the stored water (red/blue shades) after the construction of check dams in rivers (Figure 5). The satellite photos provide an example of positive evidence on the significant role of small dams in effectively storing water and reviving rivers during the dry season and it also promotes the growth of forest cover along the river banks and beyond ultimately mitigating negative impact of climate change locally (Fig. 5). The expanded forest growth in turn supports large number of faun and flora.



January 1990 January 1999 January 2007

Figure 5. Satellite imageries of rivers Machhan in the semi-arid region of western India showing more reddish tone in January 1999 and January 2007 compare to January 1990 indicating vegetation cover; and deep long line of bluish-black tone in the river indicating the storage of water after the check dams were constructed across the river.

Water is depleting fast in semi-arid regions of western India. But the check dams have improved natural resources, especially recharging ground water, growth of forest vegetation along rivers and storing water in rivers during the dry season. The dams made all neighboring villages water surplus, and those villages were once water deficit. Local villagers who have never seen their rivers full of water in dry season, celebrated near check dams in many villages (Figure 4). Interviews of villagers reflected that all farmers were aware of the increase in ground water recharge, its positive impact on agriculture, drinking water and natural resources. In addition to people, numerous live stocks were able to utilize the water in check dams during the hot summer months when water was not available. Thus, water harvesting measures, especially check dams is a rational approach for sustaining natural ecosystem in semi-arid regions while mitigating local climate change impacts. Check dams are known to reduce high levels of fluoride (beyond 1.5 ppm) in ground water reducing health hazards (Bhagavan and Raghu 2005) since fluoride poisoning is common in the drylands region of western India. Besides, check dams constructed near forest areas provide water during the dry season to large number of wildlife, especially large mammals such as elephants, gaur, tiger, leopard, deer, etc.

Discussion

India harbors about 14 large, 44 medium, and 55 minor rivers and the river basins constitute about 90% of the total drainage area. All major river basins are inter-state and 77.7% of India’s land area falls within these basins with a potential to ignite irrigation conflicts. Rivers carry 395 cubic miles of water annually and the Ganges alone carries 30% of it benefiting 400 million farmers. But the future survival of rivers is at stake due to developmental activities. Big dams built upriver in the southwestern state of Karnataka State virtually stopped the flow, especially the tributaries of Cauvery river, at the tail end the Bay of Bengal coast in Tamil Nadu State**.** Proponents of big dams believe that they deliver water to the water-scarce regions, generate power, and provide drinking water to millions. However, anti-dam activists argue that dams displace millions; they have devastating effects on floodplains, woodlands, fisheries, and forests that local communities subsist to secure livelihoods. In fact, India had spent over USD 25 billion on various irrigation projects from 1990 to 2004, but irrigation area declined from 43 million acres to 35 million acres. Although the canal irrigation supported by big dams increased during 1991–1992 at 44 million acres, it had declined reached the lowest level of 35 million acres during 2000–2001. Similarly, the World Commission on Dams (2002) reported that many irrigation infrastructures connected to big dams have not been maintained. Also, the Planning Commission of India (2002) has admitted that the water use efficiency of the big dam canal irrigation system as low (30–40%, against an ideal value of 60%) due to wastage, silting and poor maintenance. Beside, big dams account for 38% of India's irrigated area, but the estimates of agricultural production attributing to dams vary from 10% and 50%. This situation show that relying on big dams can no longer boost irrigation water in rural areas and therefore the check dam option provides better opportunities to promote sustainable agriculture to mitigate climate change.

India's big dams are properly designed, built and maintained by the government. But, numerous minor irrigation structures such as check dams and lift irrigation systems constructed by government agencies through private contractors have failed in recent years due to lack of monitoring, community involvement, and flawed construction (Choudhry & Jagawat, 2002). Nonetheless, the check dams built by a local NGO are maintained well with the involvement of farming communities. For example, the chief minister of Rajasthan State, a stanch supporter of small dams, inaugurated a large check dam at Baneshwardham (length 367 m) that cost of US$1.18 million in 2007. The dam, with its storage of 350 million cubic feet has a capacity to irrigate 7,000 acres benefiting 18,000 people. It is India's largest check dam located on the Mahi River and constructed by Sadguru foundation with the financial support of the government. There is another government-built big dam, the Mahi-Bajaj Sagar upstream from this check dam and it was built with a cost USD 300 million. This big dam irrigates 154,000 acres and it's 22 times more than the irrigation area of the Baneshwardham check dam. If 22 more check dams are to be built in a series, it would cost a total of USD 24.2 million, with the potential to irrigate the same area of the Mahi-Bajaj Sagar dam. The consequence of this dam is that if check dams are built in large numbers starting from upstream and going downstream as well, they will have similar potential as do big dams to expand irrigation. But it will cost less with less impact. Moreover, the benefits of big dams are usually restricted to areas around, while check dams can be built across many small, medium and large rivers covering vast rural agriculture areas. This would benefit large numbers of farmers who farm in remote areas along river beds.

Ground water, which is crucial for agriculture, has been severally depleted across India. The cultivable land remains static at 120 million hectares relying mainly on monsoon water. India’s green revolution has gone brown due to the creation of agrarian crisis, environmental disasters, stagnating yields and water scarcity (Atkins & Bowler 2001). Besides, a farmer commits suicide every 30 minutes since they can no longer compete with cheap cotton imported from USA where the farmers are provided with government subsidies (NCRB 2007). The continuing farmers’ deaths can be linked to shortcomings of the globalization agenda and the negligence of poverty at local levels.

The major downside of India’s sustainable agriculture strategy is the historic neglect of catchment areas in remote drylands that have been inhabited and farmed by tribal communities for centuries. A large area (1,500 km long and 500 km wide) stretching across central India (from Dungarpur in the west to Dumka in the east) provides better prospects for future sustainable agriculture development (Jagawat 2005). India’s tribal communities predominantly inhabit the drylands. They are the poorest since they have less access to public services in health, education and commerce. Most of India’s 70 million tribals are illiterate with shorter life expectancy. They constantly face challenges and foremost among the challenges are the marginal environmental conditions for agriculture often influenced by low/erratic rainfall and unreliable water supply (Phansalkar & Verma 2005). Drylands of these areas have got to be focused if India needs to succeed in agriculture sustainability, without creating negative consequences to environment (UNISDR 2013). Besides, India is one among the 25 hotspots of highly endangered eco-regions of the world so sustainable development using small dams is crucial to decelerate future climate change impacts. Also, the World Bank has already warned that India is on the brink of a severe water shortage crisis (Briscoe 2005). India's agriculture sector that largely depends on irrigation water is more vulnerable for serious climate change impacts and simulations have predicted that India may experience warmer and wetter weather due to climate change when the summer monsoon becomes more severe (Shukla *et al.* 2005). Climate change will certainly alter water cycles and consequently impact the quantity and quality of water resources not only locally but also globally (Gleick 1989).

Conclusion

Climate change has become an important economic and political concern since it will directly and indirectly impact the livelihoods of over 700 million people who inhabit rural areas across India. Therefore all ongoing sustainable developmental activities done by the government, NGO and corporate sectors across India must integrate strategies to mitigate global warming. For example, the integrated approach to water resources management has the potential to protect the integrity and function of river basins and aquifers. This is vital since rivers are crucial for human survival. It’s crucial for the government to build more check dams across rivers to supplement big dams in partnership with NGOs and business corporations. Thus the role of check dams highlighted here is simple, eco-friendly, and cost-effective. If it is adopted across the vast drylands of India and elsewhere, it has the potential to increase agricultural output, guarantee food security, enhance ground water resources, and above all mitigate climate change.

Acknowledgment: The author is grateful to Harnath Jagawat and Sharmishta Jagawat for their warm hospitality and kind support. The contributions of Sunita Chaudhary for sharing her experience on check dams are appreciated. The financial support of Sir Dorabji Tata Trust (Mumbai) to carry out research at Sadguru Foundation through Tata Visiting Chair status awarded to G Agoramoorthy is acknowledged with thankfulness.

References

Agoramoorthy, G. (2008). Can India meets the increasing food demand by 2020? *Futures* 40, 503-506.

Agoramoorthy, G. (2012a). *Dryland agriculture: Case studies from India*. Lambert Academic Publishing, Berlin.

Agoramoorthy, G. (2012b). India’s dam dilemma: An eco-friendly remedy. *Environ. Sci. Tech.,* 46, 591-592.

Agoramoorthy, G., and Hsu, M.J. (2013). Partnership for poverty reduction in Gujarat, India: A case study of Sadguru foundation’s water resource development work. *Asia Pacific J Social Work Develop.,* 23, 59-70.

Atkins, P., and Bowler, I. (2001). *Food in society. Economy, culture and geography.* Arnold, London.

Bhagavan, S.V., and Raghu, V. (2005). Utility of check dams in dilution of fluoride concentration in ground water and the resultant analysis of blood serum and urine of villagers, Anantapur District, Andhra Pradesh, India. *Environ. Geochem. Health* 27, 97-108.

Briscoe, J. (2005). *India's water economy: Bracing for a turbulent future*. World Bank press, Washington, DC.

Chellaney, B. (2013). *Water, peace and war: Confronting the global water crisis.* Rowman and Littlefield publishes Inc., Maryland.

Chinnasamy, P., Hubbart, J.A., and Agoramoorthy, G. (2013). Using remote sensing data to improve groundwater supply estimations in Gujarat, India. *Earth Interactions* 17, 1-17.

Choudhry, K., and Jagawat, H. (2002). *A study of government installed lift irrigation schemes in district Jhabua, Madhya Pradesh*. Sadguru Foundation report, Dahod.

Cotton, A. (1874). *Lectures on irrigation works in India*. School of Military Engineering, Chatham, UK.

Daly, H., and Cobb, J. (1989). *For the common good: Redirecting the economy toward community, the environment, and a sustainable future*. Beacon Press, Boston.

Design of Small Dams (1987). *A water resources technical publication*. US Government Printing Press: Denver, Colorado.

D'Odorico, P., Bhattachan, A., Davis, K.F., Ravi, S., and Runyan, C.W. (2013). Global desertification: Drivers and feedbacks. *Advan. Water Resour.,* 51, 326-344.

Falkenmark, M., and Molden, D. (2008). Wake up to realities of river basin closure. *Water Resour. Develop.,* 24, 201–215.

Feng, S., and Fu, Q. (2013). Expansion of global drylands under a warming climate. *Atmosph. Chem. Phys.,* 13, 10081–10094.

Fischer, G., Tubiello, FN., van Velthuizen, H., and Wiberg, D.A. (2007). Climate change impacts on irrigation water requirements: Effects of mitigation, 1990–2080. *Technol. Forecast. Soc. Change.* 74, 1083-1107.

Giordano, M., and Villholth, K.G. (2007). *The Agricultural groundwater revolution: Opportunities and threats to development*. CAB International, Oxford.

Gleick, P.H. (1989). Climate change, hydrology, and water resources. *Reviews Geophysics* 27, 329–344.

Government of India (2011). *Census of India 2011.* Government press, Delhi.

Haag, A.L. (2007). Is this what the world’s coming to? *Nat. Rep. Clim. Chan.*, 75-75 doi:10.1038/climate.2007.56.

Hanjra, M.A., and Gichuki, F. (2008). Investments in agricultural water management for poverty reduction in Africa: case studies of Limpopo, Nile, and Volta river basins. *Nat. Resour., Forum* 32, 185–202.

Hanjra, M.A., Ferede, T., and Gutta, D.G. (2009). Pathways to breaking the poverty trap in Ethiopia: investments in agricultural water, education, and markets. *Agri. Water Manag.*, 96, 2–11.

Hoekstra, A.Y. (2013). *The water footprint of modern consumer society*. Routledge, New York.

Jagawat, J.H. (2005). *Transforming the dry lands. The Sadguru story of western India.* Delhi, India Research Press.

Kumar, H.D. (2006). *Water woes: Conserving and managing our future lifeline*. Daya publishing house, Delhi.

Lapham, W.W., Wilde, F.D., and Koterba, M.T. (1997). *Guidelines and standard procedures for studies of ground-water quality: Selection and installation of* *wells, and supporting documentation.* US Geological Survey Water-Resources Investigations Report 96-4233, Washington, DC.

Lindsely, R.K. (1992*). Water resources engineering*. McGraw Hill, New York.

McNeely, J.A., and Scherr, S.J. (2001). *Common ground, common future. How ecoagriculture can help feed the world and save wild biodiversity?* IUCN press, Gland.

Millennium Ecosystem Assessment (20050. *Ecosystem and human wellbeing: Desertification synthesis*. World Resources Institute, Washington, DC.

Mujumdar, P.P. (2013). Implications of climate change for sustainable water resources management in India. *Phys. Chem. Earth* 33, 354-358.

Molden, D. (2007). *Water for food, water for life*. Earthscan, London.

National Report to UNCCD (2011). *Elucidation of the 4th national report submitted to UNCCD Secretariat 2010*. Ministry of Environment and Forests, Government press, Delhi.

NCRB (2007). *Accidental death and suicide in India*. National Crime Records Bureau, Ministry of Home Affairs, Government press, Delhi.

Schellnhuber, H.J., Cramer, W., Nakicenovic, N., Wigley, T., and Yohe, G. (2006). *Avoiding dangerous climate change*. Cambridge University Press, Cambridge.

Phansalkar, S.J, and Verma, S. (2005). *Mainstreaming the margins*. Angus and Grapher, Delhi.

Planning Commission of India (2002). *Irrigation, flood control and command area*. Planning Commission report, Government press, New Delhi.

Postel, S., and Richter, B. (2003). Rivers for life: *Managing water for people and nature*. Island press, London.

Pritchard, W. (2009). The long hangover from the second food regime: a world-historical interpretation of the collapse of the WTO Doha Round. *Agri. Human Values* 26, 297-307.

Ray, B. (2010). *Water: Looming crisis in India.* Lexington Books, Lanham, MD.

SAS Institute (2000). *SAS/ETS software: changes and enhancements*. SAS Institute, Cary, IN.

Shinde, S.S., and Modak, P. (2013). Vulnerability of Indian agriculture to climate change and globalization. *Climate Vulnerability* 2, 139-152.

Shukla, P.R., Sharma, S.K., Ravindranath, N.H., Garg, A., and Bhattacharya, S. (2003). *Climate change and India: Vulnerability assessment and adaptation.* Universities press, Delhi.

UN (2006). *Water a shared responsibility: The UN World Water Development Report 2*. Berghahn books, New York.

UNISDR (2013). *Global assessment report on disaster risk reduction 2013*. United Nations press, New York.

World Commission on Dams (2000*). Dams and development: A new framework for decision making.* Earthscan, London.

World Commission on Dams (2002). *India: Large dams-India's experience.* Earthscan, London.