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PEOPLE-CENTRED APPROACHES TO WATER AND ENVIRONMENTAL SANITATION

Design and performance indicators for water harvesting irrigation tanks in India

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Small reservoirs (known as tanks) for rainwater harvesting and supplementary irrigation are necessary for improving the productivity of rainfed agriculture in India.There are hundreds of thousands of such tanks in the country and many more being created. However these tank systems are not categorized for planning purposes. Review of these tank systems is necessary to understand the relationships amongst its component parts. In this paper these tank systems are reviewed with the objective of studying catchment-storage-command area (CSC) relationship. These systems are classified based on their physical setting and functioning. The CSC relationships for these systems show wide variation from region to region and also in the same region. In the literature there is lack of uniformity in describing these systems. Hence a classification system and ten indicators are proposed for describing these systems. It is suggested that when reporting such studies, the system should be discussed under one of the classes and the proposed indicators must be given along with other details.

Introduction

Water is an important social and economic resource for any nation and is a key to improved health, nutrition and quality of life. The "right to water" must be protected for equitable as well as sustainable development for protecting the human rights of people. There is also an emerging international consensus on this. Sustainable and equitable use of water resources is possible only through an integrated approach to soil, forest and livestock and community based management. Watershed development and management programmes initiated in India on Governmental and Non-Government levels are based on these integrated and community based approaches and revolve around uplifting the rural people by making water available to them on sustainable basis. In these programmes it is important to take account of existing users of water downstream, to ensure that the development is not at the expense of other people.

Water harvesting tanks are constructed in these watersheds during the process of development for recharging groundwater and storing the runoff water for its subsequent use as supplementary irrigation to the crops. It is estimated that there are 350,000 tanks in the country (Kumar 2002). Tank systems ranging from a simple tank of a few hundred cubic metres capacity and serving a single farm or few orchard trees in hilly regions to large complex tank systems with few thousand cubic metres of storage capacity irrigating hundreds of hectares of farm are found in different parts of the country.

Normally tanks are surrounded by agricultural lands and situated near one or more villages. Some domestic and most agricultural needs of such villages are met by these tanks (Mayya and Prasad 1989). These structures are of different types and assigned different names from region to region like bandharas, percolation tanks, farm ponds, earthen embankments, masonry weirs etc. Tank normally means a storage created by constructing an embankment in the stream where as pond or on-farm-reservoir (OFR) means storage created by excavating soil below ground level. In this paper all these reservoirs are grouped and discussed under a common umbrella term of water harvesting irrigation (WHI) tank system. The term refers to the capture, diversion, storage and subsequent use of surface runoff generated in the watershed (Scott and Silva-Ochoa 2001). In order to have meaningful comparisons between different systems and to develop guidelines for other schemes, this paper proposes a classification system and ten indicators for WHI tank systems in India.

Relation between catchment, storage capacity and command area

These WHI tank systems have three major components-catchment, dam and reservoir (or more popularly called tank) and command area. Catchment serves the purpose of collecting water through runoff for irrigation of crops in command area. This water is stored in the tank. Hence there exists a relationship between these components for a given location. The knowledge of this relationship will help in the better design of WHI tank systems and comparing the performance of different systems. Evidence from literature also confirm this fact. Guerra et al (1990) in Philippines found that minimum catchment area required to support a reservoir of given capacity was nearly 5 times higher for a grassed catchment than for a catchment under paddy rice. As

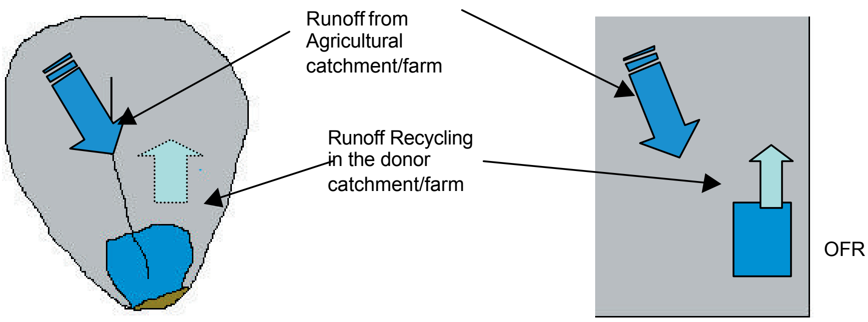

Figure 1. WHI tank system with same catchment and command area upstream of the tank.

mentioned by Das (1990), in South Australia, catchment to storage ratio of less than 6:1 is considered as uneconomical. In Arizona, USA, 10 variable catchment and storage size relations have been examined for providing water to cattle and households. He further indicated the need of development of appropriate catchment-storage relationships for different site conditions with different objective functions for Indian conditions. Thus though catchment-storage-command components are related with each other, their relationships vary as both supply (catchment) and demand (command) related relationships vary with agroclimatic regions. India has been classified into 9 water harvesting regions depending upon the geography, climate, soils and vegetation. Water harvesting practices in these regions differ and separate norms should be developed for these regions. Developing such relationships for very diverse conditions in a vast country like India is not an easy task. According to Sharda and Shrimali (1984), in the design of such water harvesting systems, the greatest problem is faced in determining the ratio of catchment size to storage capacity. This is normally based upon local experience which depends upon climate, topographical, soil and land use characteristics. Srivastava (2002) observed that in most cases in Orissa there is no linkage between catchment area, size of the tank and area claimed to be irrigated.

Due to the significance and complexities of this relationship, an attempt is made in this paper to review and discuss these relationships for studies carried out at different places in the existing experimental watersheds in India.

Proposed classification of WHI tank systems

It is proposed to classify the WHI tanks systems in India into following groups for studying the catchment area-storage-command area relationship. This classification is based on the physical setting and functioning of the system. Tank

1. Runoff recycling based WHI tank systems (Tanks with same catchment and command area upstream of the tank) (WHI-1)
2. Gravity flow based WHI tank systems (Tanks with upstream catchment and downstream command area) (WHI-2)
3. Runoff recycling & gravity flow based WHI tank systems (combination of above two systems) (WHI-3)

Suitability of a particular system depends upon the topographic constraints and the objectives. If small arable catchment area is to be provided with supplementary irrigation then runoff recycling based irrigation system tank can be constructed. If there are distinct upstream catchment and downstream command areas then gravity irrigation based tank system can be constructed. If the geology and topography permit, water can be allowed to recharge into groundwater. Cascaded tanks (tanks in series) are constructed when a long ephemeral stream passes through a watershed with good agricultural land surrounding it and requiring supplementary irrigation for crop production, thus comprising both runoff recycling and gravity flow based systems

Runoff recycling based WHI tank systems (Tanks with same catchment and command area upstream of the tank)

These WHIT systems are used when a small agricultural catchment area is to be brought under irrigation. Part of the donor catchment receives water through irrigation by lifting the water from the tank constructed at the end of the catchment. When these tanks are excavated on individual farm these are known as on farm reservoirs (OFR). Fig.1 shows the runoff recycling based WHI tank systems.

Case studies

Table 1 lists the catchment-storage capacity relations for tanks in ravines of Chambal region, farm ponds from Bangalore, Karnal and Gujarat. In the ravine areas of Chambal the catchment area storage capacity ratio (CSR) is very high (10:1 to 20:1), therefore dugout type ponds are constructed to store enough runoff to irrigate some fraction of donor catchment and a part of catchment is then treated to generate more runoff.

From the table it is observed that CSR is about 7 for Chambal, 12 to 40 for Bangalore region, around 30 for Karnal, and 27 for Gujarat. But very high CSR are also found in Chambal (50.98) and Rajkot (100). The supporting data on the irrigation potential, and losses are not given and hence it is difficult to draw any conclusion on the catchment-storage capacity relation for these regions.

Table 1. Catchment storage capacity ratio of some ponds

Name of farm pond	Region	Catchment area, ha	Storage capacity, ha-m	CSR	Reference
Diara	Chambal ravines	28.3	4.0	7.07	Samra et al (2002)
Rawantha	Chambal ravines	375.0	48.0	7.81	----------,,-------
Mandhana	Chambal ravines	673.0	13.2	50.98	----------,,-------
FP-1	Banglore	0.4	0.01	40	----------,,-------
FP-2	Banglore	0.6	0.05	12	----------,,-------
FP-3	Banglore	6.0	0.31	19.35	----------,,-------
Pond-1	Karnal	30	1.44	28.83	Gupta and Narayana (1974)
Pond-2	Karnal	6	0.22	27.27	----------,,-------
Pond-3	Karnal	26	0.80	32.5	----------,,-------
Pond -1	Rajkot, Gujrat	4.5	0.045	100	Ghghada et al (1997)
Pond-2	Gujrat	19	0.70	27.14	----------,,-------

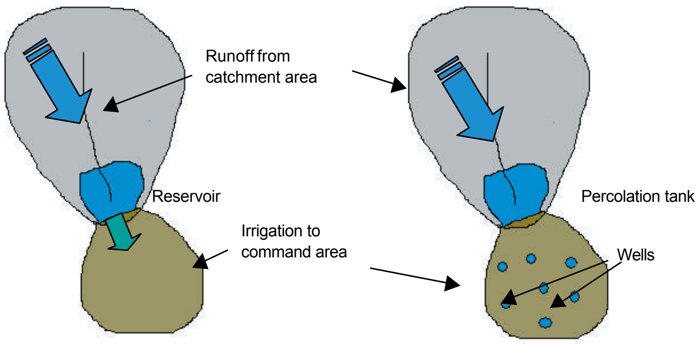

Figure 2. WHI tank system with distinct upstream catchment and downstream command areas

Table 2:Catchment-storage-command relationships of water harvesting ponds/tanks (Samra et al, 2002)

Name of Tank/Pond	Location	Catchment area, ha	Storage Capacity, ha-m	Command area, ha	Catchment -Storage Ratio (CSR)	Storage Command Ration (SCR)	Catchment Command Ratio (CCR)
Ramasagar	M.P.	2897	587	315	4.94	1.863	9.20
Badoni	M.P.	129	42.50	16	8.06	2.656	8.06
Agora	M.P.	805	358.65	137	2.24	2.618	5.88
Bhadera	M.P.	362	109.19	84	3.32	1.3	4.3
Unao	M.P.	241	78.55	55	3.07	1.428	4.38
Rawatpura	M.P.	684	98.88	62	6.92	1.595	11.03
Raja ka Tal	M.P.	161	55.74	27	2.89	2.064	5.96
Parasari	M.P.	80	25.67	18	3.11	1.426	4.44
Lallana	M.P.	80	17	12	4.71	1.417	6.67
Gyarah, Naya	M.P.	364	51.35	53	7.09	0.969	6.86
Pipra	M.P.	212	7.57	63	28.01	0.12	3.36
Silori	M.P.	64	23.32	49	2.74	0.476	1.30
Jignia	M.P.	233	21.51	77	10.83	0.279	3.02
Average (excluding Ramasagar)		**284.58**	**74.16**	**54.42**	**6.92**	**1.36**	**5.44**
Sukhomajri II	Haryana	9.1	5.5	20	1.65	0.275	0.45
Nada	Haryana	58.7	19.68	31.5	3.16	0.625	1.86
Bunga I	Haryana	155.0	59.6	243	2.60	0.245	0.64
Average		**74.26**	**28.26**	**98.16**	**2.47**	**0.382**	**0.98**
Relmajra	Punjab	59.0	13.7	25	4.31	0.548	2.36

Research studies by Juyal and Katiyar (1991) have shown that in Doon valley 0.20 ha-m capacity farm pond can be constructed for every 1 ha of catchment area (giving CSR of 5). In another study in Doon valley, Sastry and Singh (1993) worked out the relationship between the catchment area-pond size to 1.0 ha-mcapacity for every 6 to 9 ha of catchment area for lined and unlined ponds respectively. Sometimes the size is reported in terms of land occupied by the OFR as some percentage of catchment area. For example Ambast and Sen (1998) recommended 20% watershed area to be brought under OFR to harvest the excess rainfall in the Sundarbans delta in the eastern India. Panigrahi et al (2001) recommended a LDPE lined OFR of 2 m depth with 1:1 side slope occupying 9% ricelands to satisfy 144 mm of supplementary irrigation demand of rice during reproductive stage. Panigrahi and Panda (2003) found an OFR of 2 m depth requiring 12% of the 800 m2 farm area with volume of 61 m3 as optimum for supplementary irrigation to rice crop.

Gravity flow based WHI tank systems (Tanks with upstream catchment and downstream command area)

These are comparatively larger systems and have distinct upstream catchment and downstream command areas as shown in Fig 2. Tank connects the catchment and command area. Irrigation to the command area is by gravity flow irrigation system through small channels. When the tank is percolation tank, water is utilised through wells which are in the command area of the percolation tank.

Case studies

Table 2 gives the data on 17 water harvesting irrigation tanks From the table it is seen that average catchment-storage ratio is 6.92 for tanks in MP where as it is only 2.47 in Haryana. In MP, 1.36 ha-m storage is required to irrigate 1 ha command area whereas it is only 0.382 ha-m in Haryana. Catchment-command area ratio (CCR) is also high (5.73) in MP as compared to Haryana (0.98). From the data in the table, the catchment-storage and catchment-command relationships for M.P. are obtained as follows.

$Y = 0.21\ X + 12.43$ ($R2 = 0.88$, $N = 12$)
$Z = 0.1\ X + 25.27$ ($R2 = 0.93$, $N = 12$)
Where
X = Catchment area, ha
Y = Storage capacity, ha-m
Z = Command area, ha
N = No. of data points

Table 3 lists the catchment-storage capacity relations for some tanks in the Shiwaliks and N.E. hills. From the table it is seen that the catchment-storage capacity ratio is 3.86 for Shiwaliks region whereas it is 12.79 in N.E. -hill region. In Shiwaliks the average annual rainfall is 1100 mm where as it is 2800 mm in NE Hills. In Shiwaliks geography consists of steep slopes with sparse vegetation whereas in NE Hills it is natural forests. Supporting data is needed to compare the differences in catchment-storage ratio. From the available data in Shiwaliks it is found that the storage capacity is related to the catchment area by the following equation.

$Y = 0.31\ X - 1.44$ ($R2 = 0.94$, $N=19$)
Where
X = Catchment area, ha
Y = Storage capacity, ha-m
N = No. of data points

Srivastava (1996) found a catchment command ratio of 5.0 or more and a tank storage capacity of 1326 m3/ha command area for rice based cropping system for the U.P. midhills of India and CCR of 3.0 and tank size of 1750 m3 /ha command area for eastern India (Srivastava 2001). In southern hilly region studies have shown that for storage capacity of 1 ha-m in the embankment type pond under different covers, the contributing area varies from 8 to 20 ha. In black soil region 7:1 and 10:1 ratio of catchment to storage capacity has been recommended for medium black soils and deep black soils respectively (Samra et al, 2002).

In the case of percolation tanks in hilly tracts the catchment may be as small as 250 ha while in comparatively flat country it can be anything up to 1250 ha. In basaltic formations a percolation tank normally influences about 1.5 to 2.0 km2 area and recharges about 0.15 x 106 m3 of runoff during the normal rainfall years. In Maharashtra, hundreds of percolation tanks of less than 15 ha-m capacity have been constructed in valleys occupying and submerging paddy fields. The utilization through recharge is estimated as 40% while 60% water evaporates into atmosphere. Wells are dug out in the command area to tap the groundwater for raising cash crops like sugarcane and onion. (Samra et al 2002)

Combination of runoff recycling and gravity flow based WHI tank systems

Ephemeral streams offer a good opportunity of storing water by constructing a series of check or stop dams. Check dams are small water harvesting structures constructed across small streams or nalas to collect and impound the surface runoff from catchments of streams during monsoon rains. They have been found quite effective in storing the water in the nala to a good length upstream of the structure. Farmers use the stored water by using 5-10 hp pumps all along the nala. These structures have been found useful in augmenting groundwater. Surrounding wells in the vicinity of the structures are reported to have increased yield of water. Table 4 below lists such check dams constructed on streams in Datia district of Madhya Pradesh. The check dams show an average CCR of around 60 by only constructing low head structures (1.75 to 3.0 m). (Samra et al 2002).

From table 2 and 4 it is seen that the catchment-command ratio (CCR) for gravity based irrigation system tanks in Datia district is 5.73 whereas it is 60.88 when the tanks are in series. Again the supporting data are not available to compare such vast differences in the CCR for the two systems at the

Table 3. : Catchment area-storage capacity relationships (CSR) in Shiwaliks (Samra et al, 2002)

Name of pond/tank	Location	Catchment area, ha	Storage capacity, ha-m	CSR
Sukhomajri I	Haryana	4.3	0.8	5.37
Nada II	Haryana	22.0	6.0	3.67
Nada III	Haryana	11.7	6.1	1.92
Dulopur I	Haryana	72.0	25.9	2.78
Prempura	Haryana	34.0	7.5	4.53
Paniwala I	Haryana	48.0	6.6	7.27
Moginand	Haryana	28.0	7.2	3.89
Chowki II	Haryana	60.0	9.7	6.18
Ambwal III	Haryana	88.0	28.6	3.08
Parch II	Punjab	8.1	2.8	2.89
Chottibari Nangal	Punjab	10.8	3.8	2.8
Fatepur II	Punjab	20.0	5.6	3.57
Majrikahot	Punjab	27.4	11.6	2.36
Hirdapur	Punjab	54.7	15.3	3.58
Nada	Punjab	125.0	35.0	3.57
Karoran III	Punjab	63.0	14.7	4.28
Bardar	Punjab	190.0	62.3	3.05
Majothu	H.P.	7.0	2.5	2.8
Basolan	H.P.	42.0	7.4	5.68
Average		**48.21**	**13.65**	**3.86**
Structure –I **	NE Hill region	6.9	0.35	19.7
Structure – II	NE Hill region	11.1	1.43	7.76
Structure – III	NE Hill region	3.21	0.22	14.59
Structure – IV	NE Hill region	15.0	1.83	8.20
Structure – V	NE Hill region	17.8	1.3	13.69
All 5 structures from Juyal and Katiyar(1991) **Average		**10.80**	**1.03**	**12.79**

same location. Average catchment-storage ratio of 4 tanks at Hyderabad was 28.44. (Table 4)

Discussion

Study of the catchment-storage and command area relationships of different tanks in the different water harvesting regions of the country show wide variations between these relationships. Variations among different tank systems are also observed at the same location. Graph of catchment area versus CSR is plotted for three types of WHI systems and shown in Fig.4. From this figure also no trend is found between these parameters for all the three systems. Some

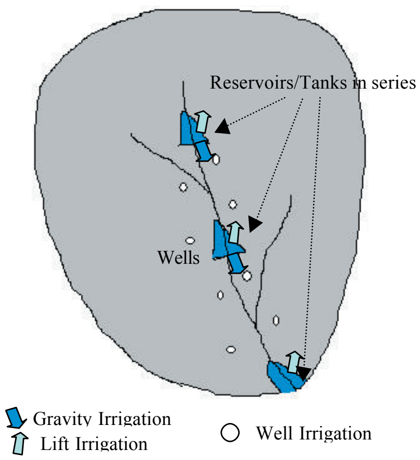

Figure 3. Combination WHI tank system

Table 4. Water harvesting structures in Datia district (Samra et al, 2002)

Name	Catchment area, ha	Command area, ha	CCR
Chandawa	2828	42.00	67.33
Kamrar	1925	21.49	89.57
Katili	1250	28.20	44.32
Ganeshkhera	994	24.02	44.38
Badoni	1446	30.15	47.96
Kalipura	1536	33.59	45.72
Khaikhera	2048	27.81	73.64
Bohradoda	1800	27.73	64.91
Khiriya ghogoo	1906	27.20	70.07
Average	**1748**	**29.13**	**60.88**

Table 5. CSR for some ponds at Hyderabad (Samra et al, 2002).

Name	Location	Catchment	Capacity,	CSR
RW1	Hyderabad	18.55	0.29	63.96
RW2A	Hyderabad	35.27	1.2	29.39
RW3A	Hyderabad	5.05	0.39	12.95
RW3B	Hyderabad	3.8	0.51	7.45
Average		**15.67**	**0.60**	**28.44**

findings from the review are as below.

1. The catchment-storage capacity ratios are found to be higher i.e. about 30 for Hyderabad region and 60 for MP region for cascaded tank systems, followed by 10 to 20 for runoff recycling tank system and around 10 for gravity based irrigation tank systems. More data is needed to draw meaningful conclusions on these relationships for different tank systems.
2. The type of WHI tank system is not mentioned clearly at

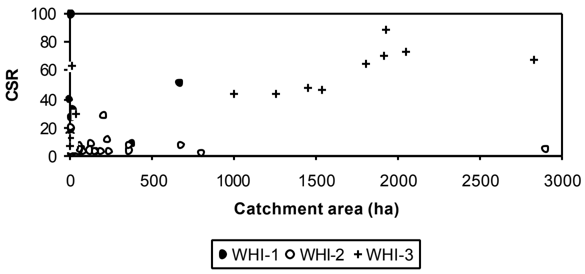

Figure 4. Catchment-storage relationship for different WHIs

many places. It is necessary to discuss the system under one of the three groups mentioned in this paper.

3. Though considerable work has been done to develop water harvesting technology in different regions of the country, there is absence of vital information about the important parameters of these systems in the literature.
4. Most of the studies have been carried out in the rice based cropping system. Such studies are needed for other crops systems also.

Authors reviewed the work by Singh(1991), Juyal and Katiyar (1991), Pandey and Hiran(1992), Singh (1995), Sahu (1996), Chittaranjan et al (1997), Ghaghada et al (1997), Khandelwal et al (2002), and from the review of literature it is observed that there is lack of uniformity in reporting of the parameters of such systems. It was difficult to compare different systems due to missing or inconsistent data in different studies. Sur et al (1999), Srivastava et al (2003) and Panigrahi and Panda (2003) have given good description of the WHI tank systems with detail performance parameters. Such reporting is necessary in all the studies describing the WHI tank systems. Review of WHI systems at the national level done by Samra et al (2002) is an important step in this direction. Authors strongly feel that following points should invariably be mentioned while reporting the studies on the WHI tank systems.

1. System should be classified in one of the above classes of WHI tank systems.
2. Following ten performance indicators of the system should be given
   i. Catchment area
   ii. Tank storage capacity
   iii. Command area (This should be irrigable command area)
   iv. Water yield (of catchment)/storage capacity ratio
   v. Irrigation potential (i.e. water utilised for irrigation)
   vi. Uncontrolled release from the tank (i.e. outflow in excess of the capacity of the tank)
   vii. Seepage and evaporation losses from the tank
   viii. Groundwater recharge
   ix. Storage period, days
   x. No of fillings of reservoir and number of seasons for which water is utilised for irrigation (i.e. monsson and or post monsoon)

Conclusion

From the study of literature on the water harvesting irrigation tank systems in India, it is concluded that there is wide variation in the catchment-storage-command area relationships of these tanks and also in the literature on these systems. In the absence of complete information it is difficult to draw any conclusions about these relationships. In order to understand these relationships and draw meaningful guidelines for other schemes, it is necessary that the reporting should be uniform and it should include some basic indicators of the system. Authors have proposed a classification system and listed ten performance indicators for these tank systems. It is recommended that this classification and performance indicators of the system should be indicated while reporting the studies on WHI tank systems.

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