Paper No. 715

MANAGEMENT OF SURFACE AND GROUNDWATER RESOURCES IN CHOLISTAN DESERT OF PAKISTAN FOR DRINKING AND FARM PRODUCTION

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By

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ABSTRACT

Cholistan desert is located between latitudes 27° 42′ and 29° North and longitudes 69° 57′ 30″ and 72° 52′ 30″ East. The main source of water in this desert is rainfall and the groundwater is mostly saline. The mean annual rainfall in the desert is low and variable, ranging between 100 to 250 mm. The rainwater is collected in the man made ponds locally called tobas. These small tobas provide water maximum three to four months. Therefore, people are used to migrate towards canal irrigated areas alongwith their livestock till next rainy season when water from small ponds is exhausted. The Pakistan Council of Research in Water Resources conducted research on rainwater harvesting system and identified the potential for water resources development from rainfall more than 350 million cubic meter annually in normal rainy years. The Pakistan Council of Research in Water Resources started mega project for rainwater harvesting and to utilize other existing water sources for supplying good quality drinking water to human and livestock population. The water resources developed in Cholistan desert by PCRWR is 8.4 million cubic meter (1700 million gallons) through rainwater harvesting, pumping good quality ground water and desalination of highly saline groundwater making contribution 1.38, 7.0 and 0.01 million cubic meter respectively. As a result now drinking water for human and livestock is available throughout the year. Migration due to water scarcity has stopped and livestock production is contributing about Rs.6.0 billion annually by 2.0 million livestock animals in the national economy. This rainwater harvesting system has demonstrated the bright future of drylands.

1. INTRODUCTION

Total area of Pakistan under deserts is 11.0 million hectares making about 14 percent of the whole country. The main deserts are Thar, Cholistan, Thal, Chagi and Kharan. The Cholistan desert is spreaded over about 26,000 sq.kms. It is located between latitudes 27° 42′ and 29° North and longitudes 69° 57′ 30″ and 72° 52′ 30″ East. The main source of water in the desert is rainfall. Rainwater is collected in the natural depressions or man made small ponds called tobas. Water of ponds lasts for maximum three to four months. The ground water is mostly saline. The groundwater from dug wells is drawn by leather buckets pulled through camel. The ground water is used when water from tobas is exhausted. Due to low rainfall the fodder production from grasses and natural vegetation is very less and can not provide fodder to the animals for the whole year. Therefore, due to shortage of water and fodder, people migrate from desert toward canal irrigated areas on the periphery of desert which have enough drinking water and fodder. Further, Cholistani people purchase fodder from the farmers of irrigated area on payment and sell them milk and dung to be used as organic manure. The desert people return in the desert after monsoon rainfalls when surplus water and natural fodder become available. This migration of people and livestock toward irrigated areas and back toward desert create many problems for human and animals in the form of death, diseases, hunger, thirst, tiredness, sickness, losses in production and damage to crops for the farmers of irrigated lands. The mean annual rainfall in the desert is low, variable and erratic. Most of the rainfall is received in the

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months of July, August and September during monsoon season. The annual rainfall varies between 100 and 250 mm. The mean annual temperature of the area is about 27.5^{o}C. The average summer temperature is 35.5^{o}C. While average winter temperature is 18.0^{o}C. The average maximum monthly temperature goes up to 46^{o}C and average minimum monthly temperature falls down to 7^{o}C. Some time maximum temperature during the year exceeds 50^{o}C and minimum temperature falls down to 1^{o}C.

The Cholistan desert is divided into two parts i.e. Greater Cholistan and Smaller Cholistan. The smaller part has small sand ridges and alluvial plains. The extent of this part is about 1.50 million hectares. While the greater part is under big sand dunes having height upto 125 meters with rolling to moderate steep topography. The area under this part is about 1.0 million hectares. The vegetation cover in Cholistan desert is poor to moderate but at some spots it is good to excellent. The major and common land use of the area is livestock grazing. Rangelands are mostly poor having less carrying capacity due to uncontrolled and over grazing of livestock. The ranges are not maintained properly under scientific system. The grazing potential of these ranges are much more than the present carrying capacity if water points are arranged at appropriate places and systematic controlled grazing is introduced. The state of other basic facilities i.e. health, education and communication in the desert is also very poor. As a result, the life of human and livestock is miserable. Adoptation of scientific management of water resources and desertification control measures in Cholistan can make the desert productive.

Cholistan Desert

Death of Animals due to Water Scarcity

2. TRADITIONAL WATER RESOURCES

The main sources of water in the Cholistan desert are rainwater and groundwater. The rainwater is collected in the tobas (ponds) and Kunds for drinking and domestic use. The ground water is obtained through dug wells and tubewells.

2.1 Tobas:

The primary source of fresh water in the Cholistan desert is rainwater, which is collected in natural depressions or man-made ponds locally called ‘Tobas’ during rainy season. These tobas are mostly not at appropriate places because the sites have not been identified based on scientific information required prior to their construction e.g. contour survey, soil physical characteristics, infiltration rate, soil porosity etc. Further, Tobas are not properly designed scientifically. As a result, stored water is wasted rapidly and can not be used for long period. These tobas supply water maximum for three to four months. Major water losses from the tobas are seepage and evaporation. Desiltation of tobas is also not done regularly, which further reduces their water storage capacity. There are about fifteen hundred small tobas in Cholistan desert. Whereas only about five hundred are working while other one thousand tobas have silted up to the level of land surface. These one thousand abandoned tobas can be seen by signs and practically no pond is there. The size and storage capacity of each toba varies depending on length, width and depth. Further the filling of these tobas with rainwater also varies due to size of catchments. The water storage capacity of these tobas ranges between 400 and 800 cubic meter (0.1 and 0.2 million gallons). Therefore total water storage capacity on the average of 500 tobas is about 0.3 million cubic meter (66 million gallon). Due to seepage and evaporation water losses from these all tobas about 50 percent water is reduced to be used for drinking. Therefore, net water storage available for drinking of human and livestock is about 0.150 million cubic meter (33 million gallons). The human and livestock population in the Cholistan desert is about 0.10 million and 2.0 million respectively. The minimum drinking water requirement for this population is about 7.0 million cubic meter (1700 million gallons) annually. These small tobas do not meet drinking water requirement, therefore, after three to four months people migrate alongwith their livestock toward irrigated areas and stay there till the next seasonal rainfalls.

Local Pond (Toba)

2.2 Kunds:

Kund is a structure mostly resembling to dug well used to store rainwater in the Cholistan for drinking of human beings in addition to ponds. Kunds are constructed by using pucca material (bricks, cement etc.) in the shape of well above the level of ground water depth to store rainwater for long period to be used for drinking by the people whenever, there is no water in the tobas. Kund is plastered with cement having concrete bed floor and roof with ventilators above the ground surface level. Kunds are capable of storing water for long period but its storage capacity is small with high cost of construction. Further, the stored water becomes smelly and provides favourable environment for mosquito breeding. The diameter of kund ranges between 8 and 10 meters while depth ranges between 3 and 5 meters. Kunds can store rainwater for longer period than tobas because seepage from the bottom and sides is stopped totally due to concrete material. While evaporation is also stopped totally by the concrete lid on the mouth. The cost of the structure is high whereas its storage capacity is less. The Kunds need to be improved for keeping water free from dung, insects and mosquites. The number of kunds in Cholistan desert are between 100 and 200.

Kund

2.3 Dugwells:

The secondary source of water for drinking in the Cholistan desert is ground water. Which is mostly saline and brackish. This water is not mostly useable for human drinking due to very poor water quality. Even then this water is used for drinking due to absence of other alternatives in the area e.g. river, canal etc. The depth to water table of the most wells varies between 20 and 50 meters. The diameter of wells ranges between two and six meters. The groundwater from these wells is drawn through big leather buckets pulled by camel tied with long rope. The well is property of the tribe which has constructed it. The water of the well is used when rainwater in the toba is exhausted. However, the rainwater collected in the tobas is preferred as compared to most wells for drinking because the toba water contains less concentration of salts. The areas where pucca bricks can not be transported easily due to absence of roads and very remote conditions, the earthen wells are plastered with locally available lime to keep the walls strong and to avoid its falling. The number of dug wells in Cholistan are about three hundred.

Dugwell

2.4 Tubewells:

During the last fifteen years some tubewells have been installed by the Cholistan Development Authority (CDA) where useable ground water is available. The depth of tubewells varies between 60 and 100 meters.

Tubewell Installed by PCRWR

3. INNOVATIVE TECHNIQUES FOR MANAGEMENT OF SURFACE WATER RESOURCES

3.1 Runoff Potential

Rainwater harvested from suitable catchments can be used to supply water for drinking of human, livestock and wildlife as well as for domestic use, afforestation and crops etc. in the Cholistan desert. About 17 percent of Cholistan desert is consisting of dense fine textured soils devoid of vegetation or having poor vegetation canopy. This area is mostly flat, impervious, saline-sodic and has a pH above 9.0. The soil profile characteristics of catchments at various locations in Cholistan have been studied by digging pit of measurement 1x1x2 meter. The soil profile characteristics indicate that the clayey soils are non-porous or very poorly porous. Therefore, they can generate good rain runoff for storage in the ponds. Non-porous feature of the catchment is best to prefer it on other areas which are porous for water percolation. Runoff depends mainly on quantity and intensity of precipitation as well as on infiltration rate of the soils. Therefore, the availability of data for these two characters is fundamental requirement for estimation of runoff.

Rainwater Harvesting Catchment in the Cholistan Desert

The water intake characteristics of clayey catchments were determined by infiltration rings at various locations in Cholistan desert. The water infiltration rate in these saline-sodic clayey catchments is slow to very slow. This indicates that catchments consisting of saline-sodic clayey soils with slow to very slow water infiltration rate are impervious or pooly drained. Therefore, these areas are considered best catchment for runoff collection. The water intake characteristics of fine textured catchments is given in Table –1.

Table 1: Water Intake Soil Characteristics

Location No.	Time after beginning infiltration (minutes)								Accumulative Water Intake (cm)	Average Intake Rate (Cm/hr)	Infiltration class
	05	15	35	65	110	170	260	380			
1	0.3	0.56	0.86	1.09	1.32	1.58	2.01	2.57	2.57	0.41	Slow
2	0.3	0.5	0.7	0.9	1.1	1.4	1.8	2.30	2.30	0.36	Slow
3	0.4	0.6	0.7	0.8	0.9	1.0	1.3	1.7	1.7	0.27	Slow
4	0.36	0.49	0.59	0.64	0.69	0.74	0.79	0.84	0.84	0.10	V. Slow
5	0.60	0.86	1.02	1.18	1.34	1.50	1.66	1.89	1.89	0.30	Slow
6	0.66	0.79	0.89	0.99	1.19	1.39	1.69	2.09	2.09	0.31	Slow

Source: PCRWR

The extent of impervious and very poorly drained catchments in Cholistan desert is about 0.442 million hectares. These scattered catchments in pieces at various locations have excellent potential for rainwater harvesting and storage. To study the potential of rain runoff for harvesting and collection in Cholistan, a model catchment of 90 hectares was selected at Dingarh. The catchment was flat and consisting of dense saline-sodic clayey, impervious to poorly drained soils. Major part of the catchment was barren and having no vegetation while some parts had vegetation canopy less than 10%. The slope of the catchment was 0.006 percent from North toward South. The rainfall and other meteorological data of the catchment was recorded regularly since 1989 to 2011 by installing Meteorological Observatory. The monthly rainfall and runoff is given in Table-2. The data indicates that average rainfall in Cholistan desert is 160 mm annually. While potential for runoff from this average rainfall is 78 mm annually. The quantity of water had to be made available from this runoff over the catchments of 0.442 million hectares is between 168 and 672 million cubic meter annually. The average annual runoff available is 350 million cubic meter.

Potential Runoff Available for Storage in the Desert

Table-2: Potential for rain runoff from effective scattered catchments in Cholistan

Year	Annual Rainfall (mm)	Potential runoff estimated by SCS curve 95 (mm)	Estimated potential runoff from catchments in Cholistan consisting of 0.442 m.h. (mm)
1989	84.2	38	168
1990	144.1	42	187
1991	173	87	385
1992	231	115	506
1993	155.9	89	392
1994	299.2	152	672
1995	213	132	582
1996	152	81	359
1997	201	74	327
1998	172	65	287
1999	20.8	3	15
2000	126.4	62	273
2001	148.6	50	223
2002	2	0	0
2003	240	106	467
2004	99	22	97
2005	133	50	220
2006	157	84	369
2007	183	70	308
2008	297	205	903
2009	186	95	418
2010	117	80	400
2011	145	82	410
Average	160.01	77.57	346.43

Source: PCRWR

4. SURFACE WATER DEVELOPMENT THROUGH RAINWATER HARVESTING TECHNOLOGY

4.1 Selection and Development of Catchments

The catchments are identified and selected after proper contour surveys carried out under scientific procedure. Impervious clayey soils exist over an estimated area more than 0.4 million hectares (1.0 million acres). These areas are mostly level without vegetation or with poor vegetation. The clayey soils in these areas are shallow to moderately deep, poorly drained, calcareous and saline-sodic. These clayey areas are naturally developed good catchments and need some alteration for producing more rain runoff through network of micro and macro ditches and to obtain prompt runoff response even with low rainfall. These clayey soils mostly start runoff after water infiltration of about 9 mm with continuous rainfall. However, if rainfalls are occurring less than one or two days intervals then runoff starts after less rainwater absorption. These clayey areas scattered in pieces at various locations in the Cholistan desert are best catchments for rainwater harvesting and storage in ponds.

A suitable catchment for rainwater harvesting and storage in pond should be selected after proper contour survey within the area having very poor to poor water intake characteristics. The preference should be given to bare areas having less vegetation cover to avoid obstacles in the way of natural runoff flow toward pond. The small hummocks, sand dunes within the catchment should be cleared or stabilized to repell the runoff instead of absorption. About 17% area of Cholistan desert is flat, dense, saline-sodic, clayey impervious and very poorly drained having pH more than 9.0. These soil characteristics are best for an effective catchment to generate maximum natural runoff. Infiltration rate in such clayey catchments should be measured to identify the best appropriate site, which is more impervious or poorly drained. If clayey impervious soils are covered with dense vegetation it should be removed to increase maximum runoff. Further lowest points in the catchment should be interlinked by a network of ditches or bunds leading towards the pond or reservoir. The other catchment development techniques e.g. sand stabilization, soil compaction and surface smoothing should also be followed. As a result of such efforts it will develop an efficient catchment, from where required quantity of runoff can be collected in the storage.

4.2 Site Selection and Construction of Reservoir

Appropriate site for reservoir in the catchment should be selected at the lowest point through contour survey to collect maximum rainwater within shortest possible time after rainfall. Rainwater standing symptoms in the catchment and history of catchment from the local people residing in the area should also be considered for selection of reservoir site within the catchment. The location of the catchment and reservoir should be identified near the settlement as much as possible to make easy supply of water to the people. The site of catchment and reservoir should be preferred at the place where traffic and livestock movement is minimum to avoid mixing of dung and dust particles in the water stored in the reservoir as well as to avoid possible accident for falling any human or animal in the reservoir in the night. The site of the reservoir should also be preferred where chances of siltation of sand to be brought by winds is minimum and evaporation can be easily reduced. The reservoir site should be near the rangeland or grazing land as much as possible to make easy approach for the livestock to minimize their travel to reduce their water drinking and fodder requirements. Infiltration rate of candidate catchments should be measured to identify the best one which can repel more runoff or having minimum seepage to harvest maximum rain runoff for storage.

The optimum size of reservoir (pond) for construction in Cholistan desert has been finally selected by Pakistan Council of Research in Water Resources after making experiments for many years with storage capacity of 15000 cubic meter for catchment of 20 to 50 hectares with average runoff of 20 to 60 mm annually. The length of reservoir on the surface is 60 meter, while length of the reservoir on the bottom (reservoir bed) is 40 meter. The width measurements of reservoir are same as length. The depth of reservoir is 6 meter with side slope of 1:2. The reservoir is connected with catchment through main channel of 16 meter, long with steps on the front side depth wise for safe entry of runoff from the catchment to avoid possible damage to the reservoir structure by water erosion. The network of ditches having silt trap in the form of small ponds in the way toward reservoir is connected with the main channel to bring runoff from the catchment and deload material before entry in the reservoir. The purpose of ditches is to collect runoff promptly during and after the rain. The main channel and steps in reservoir should be constructed with sound pucca material. The slope of reservoir sides should be 1:2 to avoid its collapse.

The seepage losses from the reservoir have been minimized economically by keeping the bed of reservoir on the dense impervious clay layer and by spreading good quality polyethylene sheets on the bed of the reservoir covered by 15 cm thick compacted layer of dense clay. The evaporation losses from the reservoirs have been reduced by reducing surface area of the reservoir by increasing its depth, establishment of wind breaks around the reservoir by growing trees in the multistory form and erecting high earth bunds around the reservoir to minimize direct contact of hot desert winds with the water in the reservoir causing evaporation.

Reservoirs Constructed by PCRWR in the Cholistan Desert

5. MANAGEMENT OF GROUNDWATER RESOURCES

The salinity level of groundwater in Cholistan desert varies from site to site. About 31 percent area of Cholistan has ground water quality with EC less than 2.5 dSm^{-1} , 23 percent area has groundwater with EC between 2.5 to 5.0 m^{1}, 11 percent area has ground water of EC from 5 to 7.5 dSm^{-1} , while 6 percent groundwater has water quality with EC ranging between 7.5 and 10.0 m^{1} and 29 percent area has EC above 10 dSm^{-1}. Relatively low salt content ground water which is available at few locations in the Cholistan desert mostly under the abandoned channel of Hakra River. This water can be utilized for drinking of human and livestock population as well as for growing of precious fruit plants through efficient irrigation methods on small scale. The useable groundwater is found in the abandoned bed of the 'Old Hakra' river which commences just East of Fortabbas and extends down stream West to South-West over a length of about 100 km (about 63 miles). The aquifer bearing this water thins out West of Moujgarh. Its maximum width is about 14 km (9 miles). The estimated total quantity of relatively fresh ground water is 9.87 billion cubic meter (8.0 million acre feet). The recharge of this water is estimated to be only 2 mm per year. The Pakistan Council of Research in Water Resources has installed twenty deep tubewells in the this area within length of 100 kilometer for making water supply for drinking to human and livestock population. The ground water pumping capacity of these tubewells annually is about 7.0 million cubic meters (1405 million gallons). These deep tubewells supply ground water when rainwater from tobas and big ponds (Reservoirs) is exhausted. These tubewells play their role as second defence for water supply when there is a drought due to non occurring of rains. Before selection of sites for the tubewells resistivity survey was carried out. The sites where tubewells have been installed were investigated for soil profile and water profile quality wise by making hole up to 100 meter through hand drilling method. The soil and water samples were collected from each 3 meter interval up to 100 meter and analyzed for sand, silt, clay percent and water quality. After the detailed study of soil and water profiles the best suitable column was selected for putting filter pipe of the tubewell while unsuitable column was closed through blind pipes. As a result best suitable quality groundwater is pumped among the available saline water zone. Tubewells installation in this abandoned bed of old Hakra river are not suggested for irrigation of crops due to this precious water to be used only for drinking of human and livestock in emergency when rainwater is not available as per demand or drought conditions caused due to no rainfalls for longer period.

Tubewell Installed by PCRWR for Providing Drinking Water
to Human and Livestock

6. DESALINATION OF HIGHLY SALINE WATER THROUGH REVERSE OSMOSIS (R.O) TECHNIQUES.

There are sites in Cholistan where rainwater harvesting and collection is impossible due to absence of catchments in the form of flat, impervious, clayey soils and ground water is not drinkable due to its high salinity. There only choice left is for desalination of highly groundwater through Reverse Osmosis Plants of small and medium size having desalination capacity between two and four thousand gallons per day for human and livestock drinking. The quantity of desalinized water can be increased by mixing appropriate quantity of saline water keeping the quality within the permissible limits of water quality standards for drinking of livestock. The Pakistan Council of Research in Water Resources has installed two R.O. Plants in the Cholistan desert at Dingarh and Thandikhui villages with desalination capacity between 10 and 20 cubic meter daily (2000 and 4000 gallons). This quantity can be doubled by mixing saline water keeping the quality within the drinking limits.

7. INTEGRATED WATER MANAGEMENT OF RESOURCES

A net work of water resources has been established by PCRWR in the Cholistan desert by developing 92 reservoirs at appropriate locations normally after 10 to 15 km each with water storage capacity of 15000 cubic meter (4.0 million gallons) making total of 1.35 million cubic meter (368 million gallons) from all reservoirs annually. Twenty deep tubewells have been installed by PCRWR with discharge annually about 7.0 million cubic meter (1405 million gallons) in the Cholistan desert where ground water is usable for drinking of human and livestock population. Two Reverse Osmosis Plants have been installed to desalinize the highly saline ground water with desalination capacity .01 million cubic meter annually for human and livestock drinking. The developed water sources have been distributed in the whole Cholistan desert considering population of human and livestock to meet the requirement of drinking water. The overall drinking water requirements annually for human and livestock population is about 7.0 million cubic meter (1681 million gallons). Whereas water sources have been developed for providing water more than 8.4 million cubic meter (1800 million gallons) annually.


Integrated Water Management of Water Resources

8. EFFICIENT AND EFFECTIVE UTILIZATION OF WATER RESOURCES

The rainwater collected in the earthen reservoirs is utilized for human, livestock and wildlife drinking as well as for domestic use as a fundamental requirement of life. The average potential for rainwater harvesting in the Cholistan is more than 350 million cubic meter annually. Total water requirement for drinking and domestic use in the Cholistan desert for 0.1 million human and 2.0 million livestock population as well as for existing wild life is about 7 million cubic meter annually. Therefore, surplus rainwater in the Cholistan desert for harvesting and storage is about 343 million cubic meter which can be utilized for growing precious vegetables and orchard plants through water economical and efficient irrigation systems (trickle and sprinkler). This amount of good quality water is enough to use more than 0.1 million hectares desert land for growing of vegetables and fruit trees. Further the water reservoirs constructed to store rain harvested water for agriculture can also be utilized as fish ponds to produce fish meat. The water of fish reservoirs will become enrich for plant nutrients due to fish feed, dung and other biological activities. The fish reservoir water can be utilized for irrigation of crops for obtaining optimum yield with minimum inputs.

9. ECONOMIC AND ENVIRONMENTAL IMPACT OF WATER RESOURCES DEVELOPMENT

The research results of rainwater harvesting and storage experiments carried out at Dingarh Field Research Station in the Cholistan desert for the last 15 years have been multiplied and distributed throughout the desert spreaded over about 26000 sq. km. Ninety two rainwater storage reservoirs each with storage capacity of 15000 cubic meter have been developed after proper scientific surveys for identification of catchments, topography, soil profiles, vegetation, hummocks, seepage, evaporation, development of catchments and design of reservoirs. Twenty deep tubewells have been installed by identifying fresh water quality zone through test holes and preparing water quality profile for selection of good strata holding good quality and more quantity of water. The discharge of these twenty tubewells annually is 7.0 million cubic meter. Two Reverse Osmosis desalination plants have been installed to desalinate highly saline ground water for drinking purpose. The desalination capacity of these two plants per year is 0.01 million cubic meter. The water resources developed through rainwater harvesting systems, pumping good quality groundwater and desalination of highly saline ground water are more than 8.4 million cubic meters. Whereas the annual water requirement for drinking of human, livestock and wildlife is 7 million cubic meter. Now drinking water in the desert is available through out the year. As a result of water source development migration of human and livestock due to shortage of water has stopped and losses of rupees 6 billion annually caused due to reduction in livestock production in the form of mortality, diseases, loss of meat and milk as well as damage to crops in canal irrigated areas have been saved for addition in the national economy. Further, micro-climate around the reservoirs has also been improved friendly to life. Now birds and other wild life can be seen frequently around the reservoirs as well as more and new vegetation species can also be identified.

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