WATERTABLE RESPONSE TO RAINFALL IN SELECTED CANAL COMMANDS OF THE INDUS BASIN

By

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ABSTRACT: Water is the most valuable natural resource essential for human life and bio-diversity. Rainfall being the only source of fresh water in the hydrologic cycle, mankind throughout the ages has been exposed to the mercy of rainfall and river flows. He was forced to settle along streams and adopt his life and habits according to the environment. The variations of rainfall affect the land and water conditions. The excess of it results in floods causing damage to life and property but the positive impact is increased fresh water recharge to groundwater. In waterlogged areas the increased groundwater recharge further builds up the watertable, increasing the undesirable extent of waterlogging, affecting human life and environment. The shortage of rainfall leads to droughts resulting in failure of agriculture, and. shortage of food and fiber. The rainfall in Pakistan is noticeably variable in magnitude, time of occurrence and its aerial distribution. The axis of maximum rainfall is located along the foothills of the Himalayan Range and it decreases in a westerly direction across the Indus Plains. Heavy monsoon rainfall occurs mostly during the monsoon season (June through September) and covers vast areas simultaneously in several river catchments. Ground watertable in the Indus Basin canal commands exhibits an annual cycle of rise and fall depending upon groundwater recharge and its recycling. It is at its lowest point in the period prior to the monsoon (April/June). Recharged through monsoon rains and irrigation of Kharif (summer), it rises to its highest in October, when it is closest to the land surface before declining again. High watertable conditions i.e. depth to watertable within five feet depth is considered as waterlogged area. Water logged area is at its peak after monsoon. It declines gradually due to natural drainage and evapo-transpiration. Watertable in the Indus Basin canal commands is monitored twice a year during pre-monsoon (April/June) and post-monsoon (October/November). In this paper, annual rainfall data of selected stations within the canal commands for the last 25 years (1981-2005) and corresponding water logged area in the canal commands have been analyzed to depict the response of ground water table to rainfall recharge and drought. Average values of yearly total rainfall and waterlogged area were considered as base for calculating deviation due to excessive or low rain fall. The watertable behavior was different in the canal commands depending upon the climatic and hydrogeologic conditions of the area. The rise of waterlogged area in selected canal commands ranged from 88 to 2018 acres per mm of excessive rainfall. On the other hand, the decrease of waterlogged area was observed ranging from 139 to 4688 acres per mm of decrease in rainfall over the average. The watertable response was significant in canal commands of LCC-Jhang Branch, LJC and Rohri Canal. The decline rate was more than rise except in CBDC and LCC-Jhang Branch. This indicates poor drainablity of these areas. Over all the decline rate of water table during droughts was observed 50 % more than the increase due to rainfall recharge.

1. INTRODUCTION

Water is the basis of life on the Earth and rainfall is the main source of fresh water in hydrologic cycle. History of mankind reveals that he settled along the natural streams of fresh water on the mercy of rainfall and adopted his life and habits according to the environment. The variations of rainfall not only affect the mankind but also land and water conditions. The Indus Basin in Pakistan falls in the arid and semi-arid climatic region depending upon the amount of rainfall it receives. The irrigated agriculture in the Indus Plains has been developed by harnessing the surface and groundwater resources of the country. Pakistan agriculture depends almost exclusively on the stream flows, which its rivers from the upper catchments and the groundwater recharge. The excess of rainfall results in floods causing damage to life and property but with a

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positive impact of increased fresh groundwater recharge. In waterlogged areas the increased groundwater recharge further builds the watertable, increasing the undesirable extent of waterlogging, affecting human life and environment. The shortage of rainfall leads to drought resulting in failure of agriculture / shortage of food and fiber. Irrigation in the Indus Plains has a long history, stretching back to the Indus civilization of over four thousand years. In the beginning only narrow strips of land along the river banks were irrigated through inundation canals. With time, these canals were extended to the lands between the rivers (doabs) and several large areas were brought under cultivation. The gross area, within the canal commands covering Indus Plains, is 16.89 Mha (41.231 Ma) of which 14.14 Mha (14.94 Ma) is cultivable commanded area. Perennial canal supply is now available to nearly 8.81 Mha (21.77 Ma). (WAPDA 2005) The irrigated areas are shown in Figure 1.

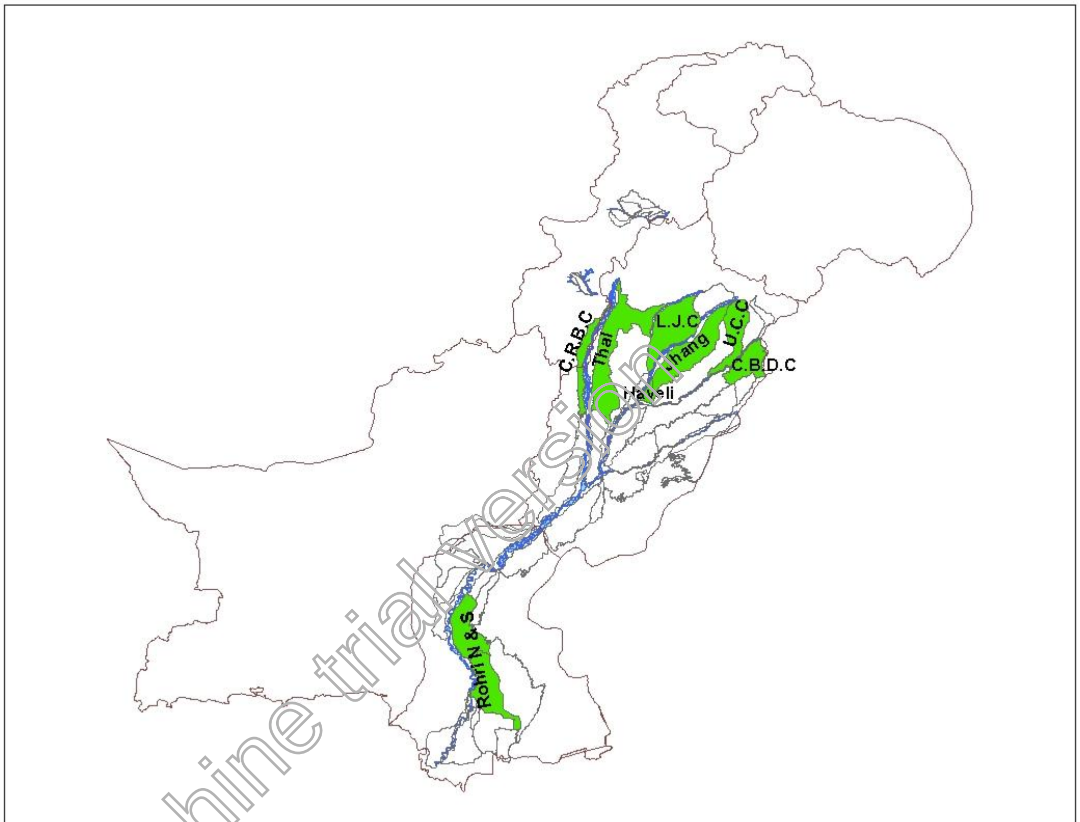

Figure-1 Map showing Irrigated Areas and Location of the Selected Canal Commands.

The catchments area of the Indus River and its tributaries are spread in Pakistan as well as bordering countries. Total catchments area of the Indus Basin River system is 374,700 sq. miles of which about 56% i.e. 204,300 sq. miles lies in Pakistan. Rivers flows in the Indus Basin are derived from rainfall, snow and glacier melts. The precipitation which feeds the system is supplied by at least two different air masses during the successive seasons. One with tropical origin i.e. the South-West summer monsoon, which is mainly responsible for the precipitation in the form of rain, while the other, North-Eastern and Northern winds of a more complex polar origin, mainly supply precipitation in the form of snow.

The Indus Basin is formed by alluvial deposits carried out by the Indus River and its tributaries and is underlain by an unconfined aquifer. In the Punjab about 79% of the area and in Sindh about 28% of the area is underlain by fresh ground water, which is mostly used for supplemental irrigation by pumping through tubewells. In NWFP most of irrigated area is underlain by fresh water whereas in Balochistan, irrigated area is underlain by saline water. The watertable is declining in most of the fresh groundwater areas due to pumpage by tubewells. At the same time it is increasing in some saline groundwater areas due to recharge from rain and surface irrigation. (WAPDA 2005)

1.1 Rainfall

The climate of Pakistan is classified as arid to semi arid. The rainfall in Pakistan is noticeably variable in magnitude, time of occurrence and its aerial distribution. The axis of maximum rainfall is located along the foothills of the Himalayan Mountains and it decreases in a westerly direction across the Indus Plains. The relative contribution of rainfall in most of the canal commands is low as compared with two other sources of irrigation i.e. canals and groundwater. More than 60% of the heavy monsoon rainfall occurs due to south-west monsoon currents in vast areas and is experienced simultaneously in several river catchments. The south-west monsoon reaches Pakistan towards the beginning of July and establishes itself by the middle of the month; then it remains steady, and starts retreating towards the end of August, occasionally it continues even in September when some of the highest floods of the Indus Basin have been recorded. Rainfall distribution pattern in Pakistan is shown in Figure-2. According to the collected data, monthly maximum rainfall of 917.6 mm occurred at Sialkot during August 1976, whereas there have been almost no rainfall frequently in lower parts of the country i.e. Sindh and Balochistan and often in Punjab and NWFP also. The sub-mountainous tracts in the North and North-East of the Indus Basin receive on the average 601-1100 mm (25-45 inches) of rainfall annually. There is a gradual decreasing trend of rainfall from North to South. The Southern Indus Plains receive average rainfall of about 127 mm (5 inches), going down in some cases to 51 mm (2 inches) per year. (WAPDA 2005). From the middle of September to the middle of November is the transitory period which may be called the post-monsoon season. In the winter a reverse process occurs. The land surface cools faster than the sea surface. This reverses winds so that they are seaward. The north-eastern winter monsoon takes place from December to early March.

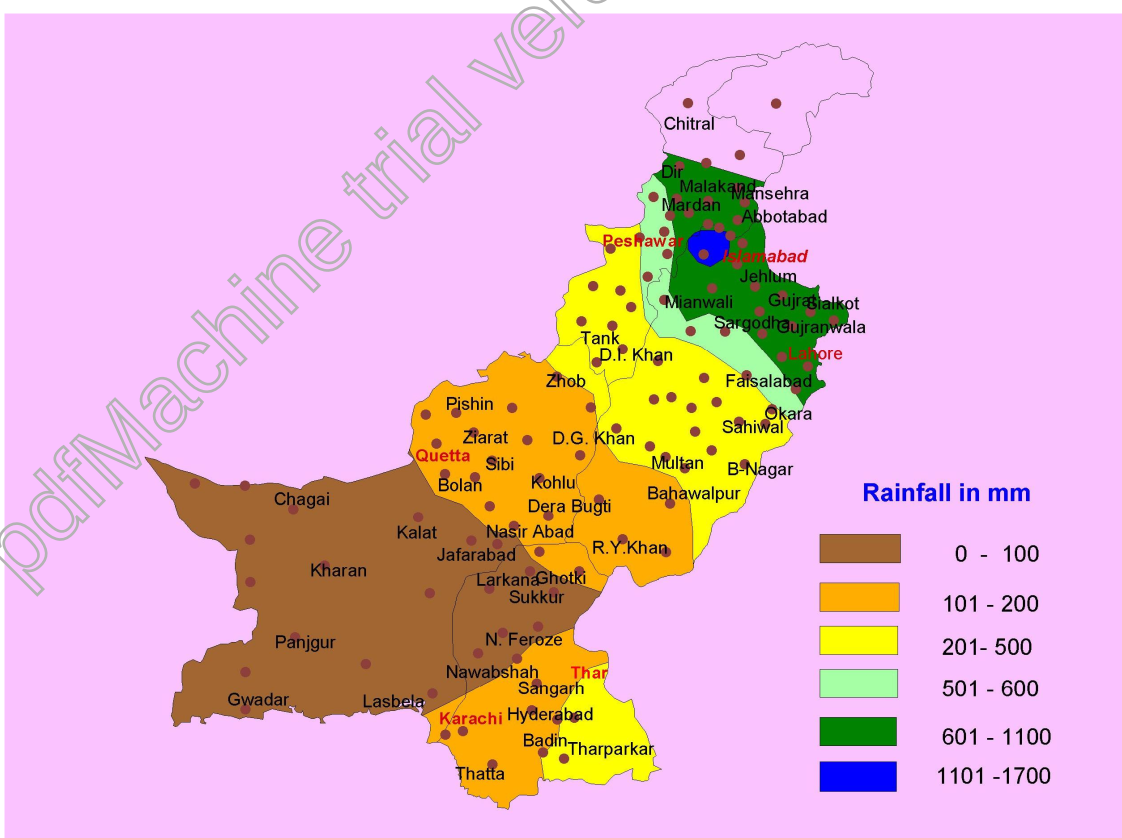

Figure-2 Rainfall Distribution Pattern of Pakistan

1.2 Ground Watertable

The advent of weir controlled canal irrigation system in the Indus Basin disturbed the natural equilibrium of groundwater. The construction of railway and road network not only the natural surface streams were further checked but also disturbed the groundwater flow lines. Prior to introduction of weir controlled irrigation the watertable in the Indus Plain was deeper than 27 m (90 ft.). The watertable started rising due to groundwater recharge through seepage from canals and entrapped rainfall runoff. In British India, waterlogging was reported in the Sirhind Canal area in 1870 and in 1880 in Bari Doab Canal area now in Pakistan. Irrigation engineers, conscious of the approaching problem, established a groundwater monitoring programme to record the groundwater levels periodically. A selection of open wells was made along arbitrarily chosen lines across the doabs of the Punjab. Fourteen lines of open wells, called provincial well lines, were selected. These lines passed through Bari Doab, Rechna Doab, Chaj Doab and Thal Doab. Some provincial lines were later extended to Bahawalpur area. The numbers of well sites along provincial lines being insufficient were further added with completion of a canal projects, called the circle well lines. Some observations of groundwater levels are available since 1882, but systematic data were collected after 1886. In Sindh, 3600 observation pipes were installed in the entire command of Sukkur Barrage and recording of observations was started in 1932. Observations of watertable levels in the canal command areas were the permanent responsibility of the Provincial Irrigation Departments (WAPDA 2005). Flat topography, lack of sufficient natural drainage, seepage from canals and deep percolation from fields, originating from rainfall or surface irrigation are amongst the major contributing factors to waterlogging. Unusual groundwater recharge from rainstorms, seepage from canals and deep percolation from surface irrigation aggravates the situation by fluctuating watertable and mobilizing salts dissolved in the groundwater aquifer causing salinity.

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1.3 Objectives

The objective of this paper is to analyze and assess the effect of extra ordinary rainfalls and droughts on watertable fluctuations in selected canal commands of the Indus Basin.

2. MATERIAL AND METHODS

2.1 Monitoring of Rainfall

The Indus Basin is fortunate to have regular hydromet data collection at key locations since 1920's. A vast network of precipitation gauging stations is scattered all over the country and is maintained by a number of agencies in Pakistan. Water and Power Development Authority (WAPDA) has established additional network since early 1960's to cover the upper river catchments using improved equipment and methodology. WAPDA is maintaining 99 stations out of which most are A-class observatories equipped with thermographs, hygrometers, anemographs and evaporation pans and 81 recording (weighing type) rain gauges. The data are observed, recorded and processed in accordance with WMO practices and published on annual basis (WAPDA 1982). Meteorological Department of Pakistan is maintaining different rainfall stations. There are 60 rainfall stations for which the Meteorological Department collects daily rainfall data. Available data for a few stations starts from 1931, whereas for rest of the locations the data is available from 1961 onwards.

For the present study the monthly rainfall data since 1981 to 2005 for the selected stations within canal commands was collected. The average annual rainfall of the period was taken to establish the deviation in different years. The excess or decrease over the average value was considered causing rise or fall of watertable i.e. increase or decrease in waterlogged area.

2.2 Ground Watertable Monitoring

Ground watertable in the Indus Basin canal commands exhibits an annual cycle of rise and fall. It is at its lowest point during the period prior to the monsoon (April/June). After recharge from monsoon/summer rains combined with irrigation, it rises to its highest point in October, when it is closest to the land surface before declining again. SCARPS Monitoring Organization (SMO), WAPDA has been monitoring the watertable twice a year for the periods pre-monsoon and post-monsoon. The data is reported in the form of area under different categories of depth to watertable. The area with depth to watertable within five feet is considered as waterlogged. The watertable position in pre monsoon is critical and is used as an index of waterlogged area for any project planning. For the present exercise the post-monsoon waterlogged area since 1981 to 2005 for the selected canal commands was collected. The average waterlogged area of the period was taken to establish the deviation in different years. The increase or decrease over the average value was considered as caused by the rainfall deviation from the average.

2.3 Selected Canal Commands and Rainfall Stations

The selected canal commands of the Indus Basin are shown in map given in Figure-1. After review of the available data of waterlogged area and rainfall data of the rainfall stations within the canal commands seven canal commands and rainfall stations in the vicinity were selected for analysis of water table response to rainfall during the period from 1981 to 2005. The location of the selected canal commands is highlighted in Figure-1. The average waterlogged area and average annual rainfall of the canal commands during 1981 to 2005 are as in Table-1.

Table-1 Selected Canal Commands and Respective Rainfall Stations in the Indus Basin

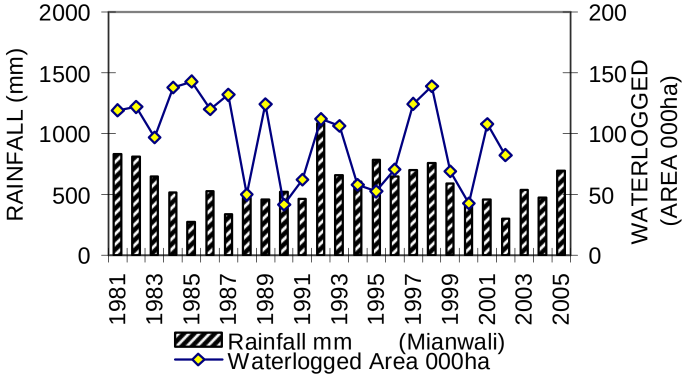
Sr. No.	Canal Command	Surveyed Area (000 ha)	Average Waterlogged Area (000 ha)	Rainfall Station	Average Rainfall (mm)
1.	Thal Canal	1075	98.3	Mianwali	584
2.	Lower Jhelum Canal (LJC)	704	122.7	Sargodha	466
3.	Upper Chenab Canal (UCC)	470	29.00	Sialkot	1030
4.	Lower Chenab Canal (LCC) Jhang Br.	860	35.55	Faisalabad	361
5.	Haveli Canal	77	8.96	Shorkot Cantt:	293
6.	Central Bari Doab Canal (CBDC)	333	22.91	Lahore	708
7.	Rohri Canal	1195	221.31	Nawab Shah	127

3. RESULTS AND DISCUSSION

The waterlogged area of canal commands and the annual rainfall data of the respective stations were tabulated and analyzed after computing averages of the 25-years. The rainfall and watertable behavior in the canal commands during 1981 to 2005 is discussed in the following paragraphs. The drainage and reclamation projects executed and operated in these canal commands are also considered.

3.1 Thal Canal

Thal canal off taking from Jinnah Barrage passes through moisture deficit area, where canal supplies support agricultural crops. The commanded area is enclosed by the rivers Indus, Jhelum and Chenab. Chashma-Jhelum and Taunsa-Panjnad Link Canals cross the area. Greater Thal Canal which is under construction will run parallel to it. The natural drainage is poor mainly due to ridges of sand dunes and low gradient. However, a few drainage systems exist in the north-east; Khushab, Dhak and Bolah drains. Various SCARPS completed in area are Hadali Unit, Khushab Unit and Anti-waterlogging schemes along C.J. Link. A total 1767 tubewells, 68 km of surface drains and 24252 ha (60,000 acres) tile drains were installed. Monitoring studies carried out indicate that the problem of waterlogging has not been solved fully. The temporal waterlogged area and rainfall are given in Figure-3(a). The total surveyed area of the canal command was 1075000 ha out of which the average waterlogged area remained 98300 ha



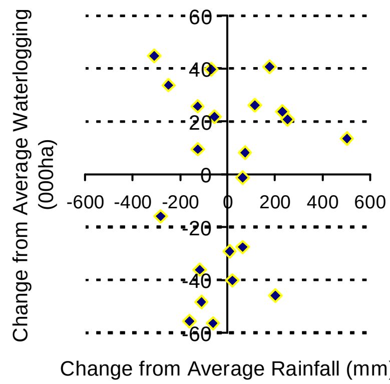


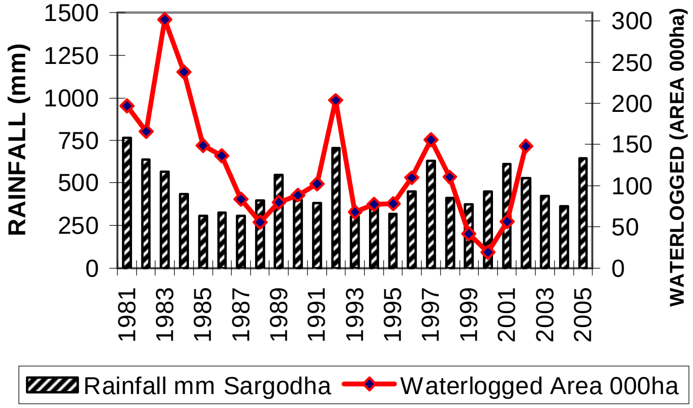
Figure-3(a) Rainfall and Waterlogged Area during 1981 to 2005

Figure-3 (b) Watertable Response to Rainfall during 1981 to 2005

The average rainfall of Mianwali was 584 mm. The watertable response to change in rainfall is presented in Figure-3(b). The data shows that inefficiency of the drainage facilities was also reason for waterlogging. There were six events of rise of watertable due to rainfall and same numbers of years of decline of watertable due to drought when there was less than average rainfall. On the basis of the average values, rate of rise of waterlogged area per mm of excessive rainfall was observed as 247 acres, whereas the decreased in waterlogged area was 718 acres per mm of decreased rainfall.

3.2 Lower Jhelum Canal

Lower Jhelum Canal (LJC) serves areas of Sargodha and Mandi Bahauddin districts. The quality of groundwater is marginal to hazardous. The canal command has an intensive surface drainage network constructed since commissioning of the canal. Three schemes, SCARP-II (FGW), SCARP-II (Saline), SCARP-II (Shahpur) were implemented during 1961-1985. Under these projects a total number of 3369 tubewells were installed and 78 km long surface drains were constructed. Out of which 918 tubewells were installed in saline zone along drains for disposal of saline effluent. Presently the fresh groundwater tubewells have been phased out and are handed over to the beneficiaries where as the saline zone tubewells are being run by the I&P Department. This is the area where the watertable fluctuates more widely and Mona Reclamation Experimental Project (MREP) was established for prediction of SCARP oriented problems and their remedies. The temporal waterlogged area and rainfall are given in Figure-4(a). The total surveyed area of the canal command was 704000 ha out of which the average waterlogged area remained 122700 ha The average rainfall of Sargodha was 466 mm. The watertable response to change in rainfall is presented in Figure-4(b). The data shows that inefficiency of the drainage facilities was also reason for waterlogging. There were six events of rise of watertable due to excessive rainfall and thirteen years of decline of watertable due to drought when there was less than average rainfall. On the basis of the average values, rate of rise of waterlogged area per mm of excessive rainfall was observed as 1049 acres, whereas the decline rate of waterlogged area was more than 1666 acres per mm of decreased rainfall.



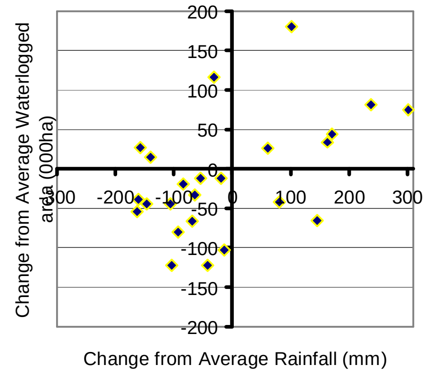
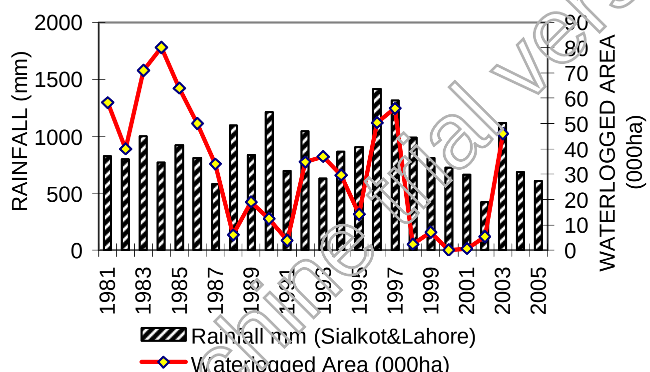


Figure-4(a) Rainfall and Waterlogged Area during 1981 to 2005

Figure-4(b) Watertable Response to Rainfall during 1981 to 2005

3.3 Upper Chenab Canal

The Upper Chenab Canal (UCC) irrigates area of Sheikhupura, and Gujranwala, districts. Soils are predominantly loam clay. The area and its surroundings receive maximum of rainfall in the Indus Basin. The existing natural drains like Aik, Deg, Nallahs, over time were inadequate to meet the required level of drainage. In the past intensive network of surface drains was provided under SCARP-IV, Muridke Mangtanwala Scheme and Upper Rechna (Remaining) Deg Unit. The temporal waterlogged area and rainfall are given in Figure-5(a). The total surveyed area of the canal command was 470000 ha out of which the average waterlogged area remained 29010 ha



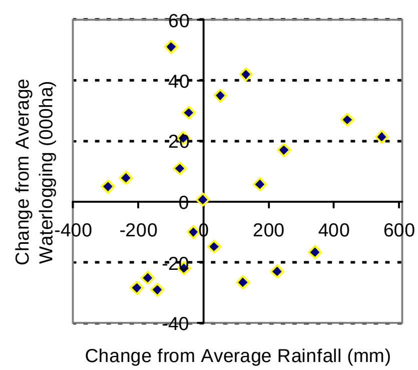


Figure-5(a) Rainfall and Waterlogged Area during 1981 to 2005

Figure-5(b) Watertable Response to Rainfall during 1981 to 2005

The average rainfall of Sialkot & Lahore was 708 mm. The watertable response to change in rainfall is presented in Figure-5(b). The data shows that inefficiency of the drainage tubewells was also one of the reasons of waterlogging. There were six events of rise of watertable due to excessive rainfall and six years of decline of watertable due to drought when there was less than average rainfall. On the basis of the average values, rate of rise of waterlogged area per mm of excessive rainfall was observed as 230 acres, whereas the decline rate of waterlogged area was little more, 324 acres per mm of decreased rainfall.

3.4 Lower Chenab Canal (Jhang Branch)

Jhang Branch of Lower Chenab Canal (LCC) falls in central part of Rechna Doab Q.B. Link canal transacts the Command area. Toba Tek Singh and Faisalabad are the main districts receiving irrigation water from these canals. To deal with the problem of waterloggong and salinity a number of salinity control and reclamation projects were implemented and a network of surface drains was provided. In the past following SCARP schemes have been implemented;

i) SCARP-I in districts of Sheikhpura, Gujranwala, Faisalabad and Jhang.

ii) Lower Rechna Remaining (Drainage-IV) in Faisalabad District.

iii) Gojra Khewra Phase-I in Toba Tek Singh District.

iv) SCARP-V, Paharing Drain (outside SCARP-I).

Under these projects surface drains were constructed and tubewells and tile drains were installed. The fresh groundwater tubewells have been phased out and are handed over to the farmers. The temporal waterlogged area and rainfall are shown in Figure-6(a). The total surveyed area of the canal command was 860,000 ha out of which the average waterlogged area remained 35,550 ha. The average rainfall of Faisalabad was 361 mm. The watertable response to change in rainfall is presented in Figure-6(b). The data shows that inefficiency of the drainage measures was also one of reasons of waterlogging. There were five events of rise of watertable due to excessive rainfall and ten years of decline of watertable due to drought when there was less than average rainfall. On the basis of the average values, rate of rise of waterlogged area per mm of excessive rainfall was observed as 713 acres; similarly the decline rate of waterlogged area was little less, 611 acres per mm of decreased rainfall.

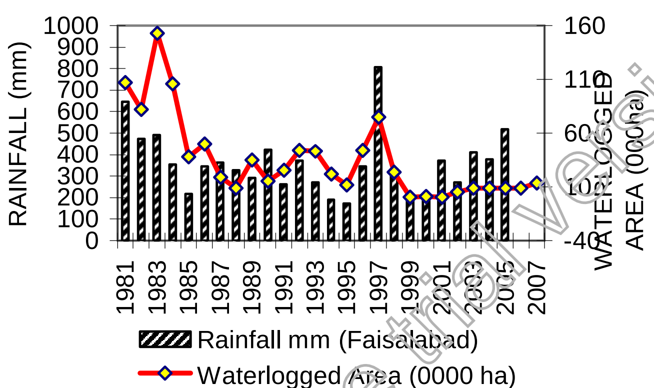


Figure-6(a) Rainfall and Waterlogged Area during 1981 to 2005

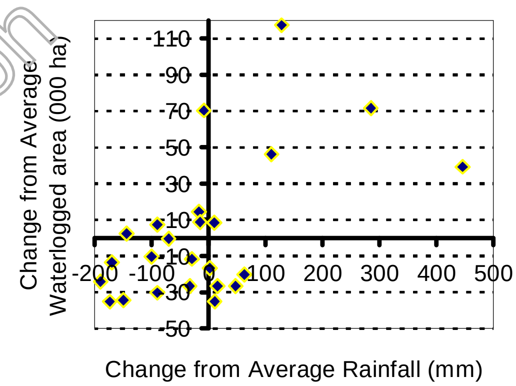
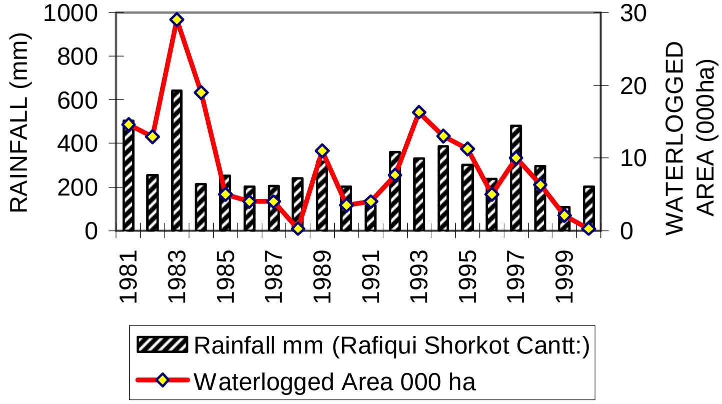


Figure-6(b) Watertable Response to Rainfall during 1981 to 2005

3.5 Haveli Canal

Haveli Canal irrigates area of Jhang district. In the past a network of surface drains and tubewells were provided under SCARP-V, Shorkot Kamalia. The temporal waterlogged area and rainfall are shown in Figure-7(a). The total surveyed area of the canal command was 77000 ha out of which the average waterlogged area remained 8960 ha. The average rainfall of Shorkot Cantt: was 293 mm. The watertable response to change in rainfall is presented in Figure-7(b). The data shows that inefficiency of the drainage tubewells was also one of reasons of waterlogging. There were seven events of rise of watertable due to excessive rainfall and nine years of decline of watertable due to drought when there was less than average rainfall. On the basis of the average values, rate of rise of waterlogged area per mm of excessive rainfall was observed as 114 acres, whereas the decline rate of waterlogged area was little more, 149 acres per mm of decreased rainfall.



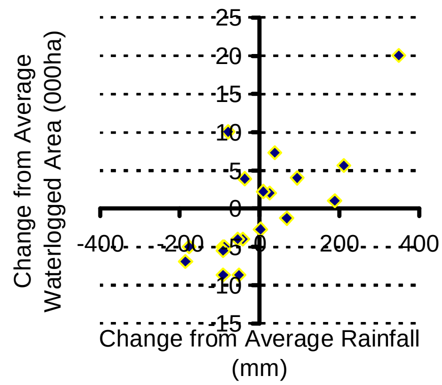


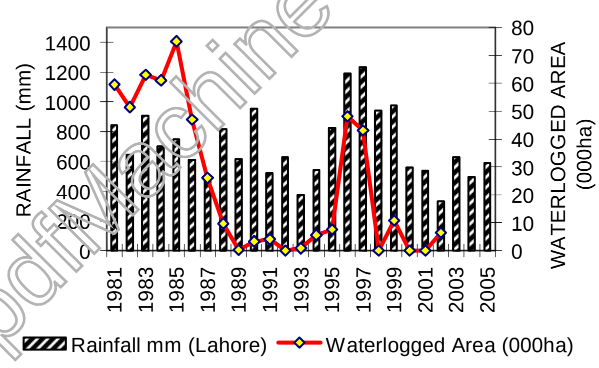
Figure-7(a) Rainfall and Waterlogged Area during 1981 to 2000

Figure-7(b) Watertable Response to Rainfall during 1981 to 2000

3.6 Central Bari Doab Canal (CBDC)

Central Bari Doab Canal (CBDC) serves areas of Lahore and Kasur districts. The existing surface drainage systems are Hadiara, Raiwind, Pandoki, and old Sukkh Beas. Under CBDC Phase-I Project, Pandoki Drainage System, and 101 No. drainage tubewells were installed alongwith construction of Pandoki Outfall drain, diverting the Sukh Beas Nullah near Kasur to Sutlej River. The temporal waterlogged area and rainfall of Lahore are shown in Figure-8(a). The total surveyed area of the canal command was 333000 ha out of which the average waterlogged area remained 22910 ha.

The average rainfall of Lahore was 708 mm. The watertable response to change in rainfall is presented in Figure-8(b). The data shows that operation of the drainage tubewells controlled the rise of waterlogging. There were five events of rise of watertable due to excessive rainfall and eight years of decline of watertable due to drought when there was less than average rainfall. On the basis of the average values, rate of rise of waterlogged area per mm of excessive rainfall was observed as 313 acres, whereas the decline rate of waterlogged area was much less, 99 acres per mm of decreased rainfall.



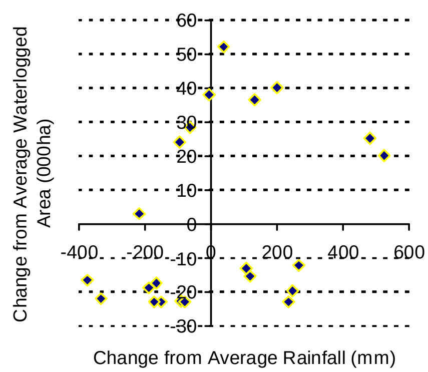


Figure-8(a) Rainfall and Waterlogged Area during 1981 to 2005

Figure-8(b) Watertable Response to Rainfall during 1981 to 2005

3.7 Rohri Canal

This canal serves the districts of Moro, Naushehro Feroz, Nawabshah and Hyderabad. In the past a total of 1214 fresh groundwater tubewells were installed under SCARP programme. The temporal waterlogged area and rainfall of Nawabshah are shown in Figure-9(a). The total surveyed area of the canal command was 1195,000 ha out of which the average waterlogged area remained 221310 ha. The average rainfall of Nawabshah was 127 mm. The watertable response to change in rainfall is presented in Figure-9(b). There were four events of rise of watertable due to excessive rainfall and six years of decline of watertable due to drought when there was less than average rainfall. On the basis of the average values, rate of rise of waterlogged area was 2018 acres per mm of excessive rainfall, whereas the decline rate of waterlogged area was almost double, 4688 acres per mm of decreased rainfall.

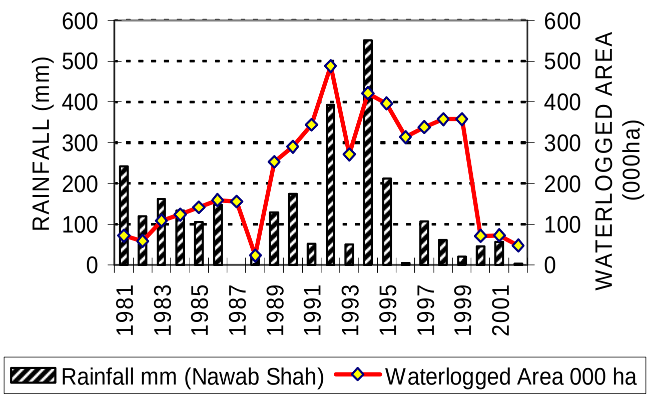


Figure-9(a) Rainfall and Waterlogged Area during 1981 to 2005

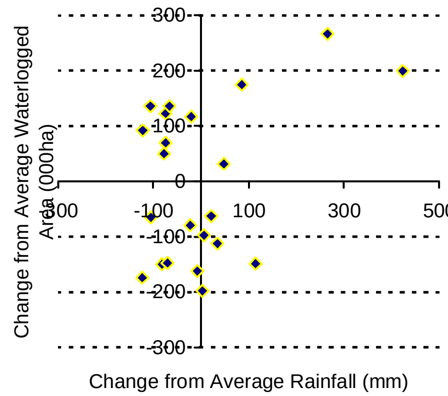


Figure-9(b) Watertable Response to Rainfall during 1981 to 2005

4. CONCLUSIONS AND RECOMMENDATIONS

The watertable behavior was different in the canal commands depending upon the climatic and hydrogeologic conditions of the area. The operation of the SCARP schemes also played a role in fluctuation of water table in canal commands. The increase/decrease rates of waterlogged area analyzed for response to rainfall are summarized in Fgure 10. The following conclusions and recommendations are drawn:

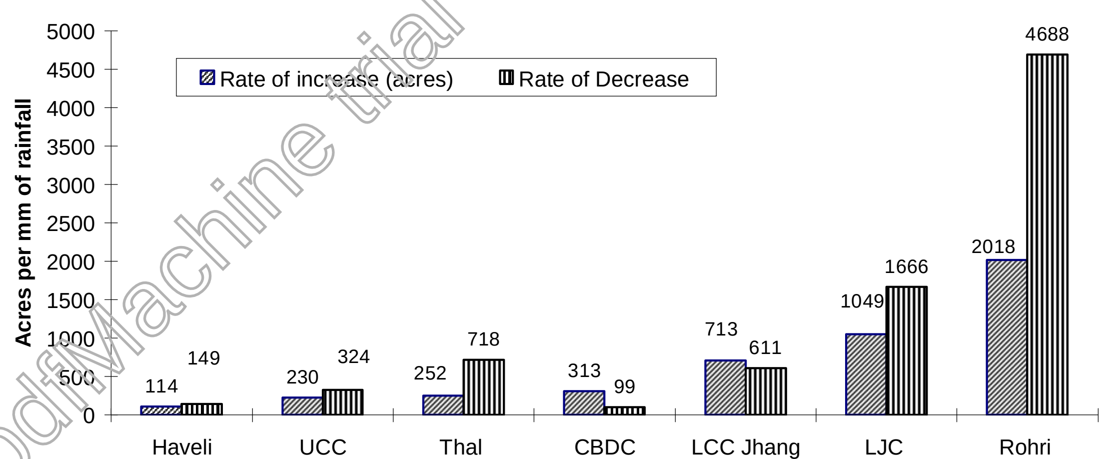


Figure-10 Rate of Increase or Decrease of Waterlogged Area in Response to Rainfall Fluctuations.

i. The rise of waterlogged area in response to rainfall in selected canal commands ranged from 114 to 2018 acres per mm of excessive rainfall.

ii. The decrease of waterlogged area was observed ranging from 99 to 4688 acres per mm of decrease in average rainfall.

iii. The watertable response was significant in canal commands of LCC-Jhang Branch, LJC and Rohri Canal; increase ranging from 713 to 2018 acres per mm of excessive rainfall and decrease ranging from 611to 4688 acres per mm of decreased rainfall. It is, therefore, necessary to keep the surface drains clean and functional for rapid disposal of rainfall runoff.

iv. The decline rate was more than rise except in CBDC and LCC-Jhang Branch. This indicates poor drainablity of these areas. Cleaning of surface drains can improve the clearing of swamps and runoff.

v. Over all the decline rate of water table during droughts was observed 50 % more than the increase due to rainfall recharge.

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