Spatial and Temporal Assessment of Groundwater Behaviour in the Soan Basin of Pakistan

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Abstract-The assessment of groundwater potential for any region is very important for its sustainable management. However, the groundwater potential of the Soan basin - a sub basin of the Indus basin, has not been assessed after 1981, though large scale water resources development and exploitation activities have been carried out during the last two decades. A study was undertaken in the Soan basin to assess its spatial and temporal variability of groundwater potential and to propose measures for its sustainable management. Water-table data at 193 monitoring points were collected from 2003-2006. Long-term records 1960-2005 of rainfall at different stations, basin outflows and data on water resources development in the area were collected. There is a high spatial and temporal variation in rainfall over the basin. The rainfall pattern has changed over the basin, resulting in reduced basin outflow especially after 1984. After the drought of 1997-2000, the rainfall situation improved however, no significant increase in the basin outflows was observed. Since 1981, the groundwater utilization has increased significantly due to about 95% increase in the population. The number of open wells, hand pumps and tube wells has increased by 39, 186 and 96%, respectively over the last two decades. The increased abstractions of groundwater, reduced rainfall, and basin outflow have resulted in depletion of groundwater. The average water-table drop in the basin is 3.75 m over the last 25 years with an average drop rate of 0.15 m per year. However, in areas away from the river and recharging sources, the water-table drop is much higher, mainly due to more abstraction than recharge. In the areas, where water storage facilities such as small dams, mini dams and ponds were developed, a rise in water table has also been observed. On an average, the annual rainwater potential of the basin is 3.44 x 10^9 m^3, whereas only 80 x 10^6 m^3 (less than 3%) have been harnessed so far through construction of small dams, mini dams and ponds. Under the present water scarcity conditions, there is a need to initiate integrated water resources management programs with a site specific focus on rainwater harvesting. If no mitigation measures are undertaken, the groundwater depletion is expected to jeopardize the future agriculture and socio-economic development.

Keywords—Water-table depletion, Rain water, Basin outflow, Sustainable management

I. INTRODUCTION

Globally, groundwater comprises one third of the freshwater resources. However, the rapidly shrinking surface water resources due to over exploitation, all over the world, has placed tremendous pressure on groundwater, which is now depleting in many parts of the world [1]-[9]. Pakistan has the largest contiguous irrigation system of the world, where 75% agricultural lands, mostly in the Indus basin are irrigated. The annual water supply through this network is around 163 x 10^9 m^3, commanding an area of about 16 million hectares (Mha). The irrigation system was designed for about 60% cropping intensity which is now over 170%. The increase in cropping intensity could have become possible by exploiting groundwater. Due to increased population, urbanization, and industrialization, the per capita water availability has reduced from 5600 m^3 to 1200 m^3 over the last fifty years [10]. Surface water supplies and rainfall have become inadequate to meet the crop water requirement. As a result, the groundwater resources are being exploited to supplement the irrigation supplies. The recent drought 1997-2000 in the country reduced the canal water supplies and further increased the pressure on the groundwater. About 25% of the cultivated area is rainfed as it entirely depends on rainfall for crop production. Rainfed areas are concentrated in Pothwar Plateau, northern mountains and northeastern plains forming the largest contiguous block of dry-land farming in the country. The Pothwar region lies between the Indus and Jhelum rivers stretching over an area of 18,200 km^2, out of which about 6,100 km^2 is cultivated [11]. The rainfall occurrence in the area is quite erratic with a high spatial and temporal variation, causing great difficulties in raising crops due to uncertainty in water supplies [12], [13].

Only a few studies have been conducted in the past to asses the groundwater potential in the Pothwar plateau [14], [15], [16]. Since then a number of water resources development and exploitation activities such as construction of small dams (610,000-9,130,000 m^3 storage capacity), mini dams (12,000-120,000 m^3 storage capacity), ponds (<12,000 m^3 storage capacity), soil and water conservation activities, open wells, hand pumps and tubewells have been carried out by public and private sectors. However, out of the total rainwater potential of 4.32 x 10^9 m^3, all these efforts could harvest only 120 x 10^6 m^3 [17], [9], [18] and a large amount of water (about 4.2 x 10^9 m^3) is lost as surface runoff annually. This not only results in loss of precious water, but also causes erosion of the top fertile soil [18], [19], [20]. Due to implementation of water resources development and management schemes particularly after 80s, the groundwater has developed mostly in small pockets (mainly perched water), especially in the vicinity of completed dams [21], [18]. The number of open wells has therefore, increased manifolds due to availability and accessibility groundwater [18]. However, due to irrational pumping/withdrawal of water, and decreased rainfall during the last decade, the water table has been falling rapidly [22]. Moreover, the status of groundwater has not been investigated in the area after 1981. The assessment of groundwater potential is very important for its sustainable management and future planning particularly, after continuous agricultural development, population growth, urbanization and changing hydrological regimes. This study was conducted in the Soan basin, a tributary of the Indus basin, to investigate the spatial and temporal Behaviour of groundwater and to propose measures for its sustainable management.

II. METHODOLOGY

2.1 Description of the Study Area

The Soan river basin is a major hydrological unit of Pothwar Plateau with a drainage area of 11,085 km^2 (55% of the Pothwar area).

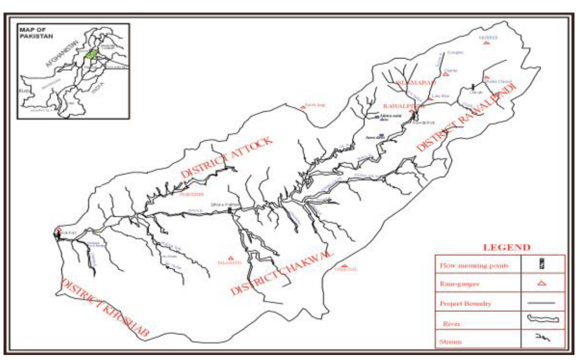

Fig. 1. Location map of the Soan basin

The basin falls between latitude 32° 45' to 33° 55' north and longitudes 71° 45' to 73° 35' east and is bounded by Haro basin, Murree-Jhelum Section, Pind Sultani and Makhad areas Fig. 1. The area falls in the districts of Attock, Chakwal, Khushab, Rawalpindi, and Islamabad having semi-arid to sub-humid climate with hot summers and cold winters except Murree, which has a humid climate. The average annual rainfall in the area varies from 250 mm to 1800 mm, the maximum in the north and minimum in the south-west. In the north-eastern parts of the area, the temperature falls below the freezing point from December to February, whereas in the western parts, the temperature is quite high in summer. However, the winter is relatively mild. The area has a complex geologic history of mountain-building, alluvial and loessial deposition and erosional cycles. The north-eastern part of the basin is covered by Himalayan foot-hills whereas the southern boundary is marked by salt range. The rest of the basin is formed by high upland Plateaue. The Soan river, a left bank tributary of the river Indus, drains most of the area. Almost all of its flow is generated within its boundaries forming a monsoon fed stream with a minor contribution from snow-melt and return flow. The Soan river originates in the south-western range of the Murree hills, flowing through hills, it enters the plains. Flowing in the south-west direction, it joins the river Indus at about 16 km upstream of Ka1abagh. Table I and II show the major perennial tributaries of the Soan river and the areas of the basin, respectively. The occurrence of groundwater in the area, as elsewhere, is controlled by climatic and geological conditions. Precipitation is the ultimate source of groundwater recharge, either taking place by direct infiltration or by lateral percolation from streams. The lithology varies significantly across the space and generally consists of alternate layers of clay, sand, and gravel with different combinations and depths. The depth of permeable material varies significantly from 7 to 174 m with an average of 64 m. The aquifer discharge varies from 0.016 to 0.6 lps, with an average of 0.19 lps. The permeability varies from 9.1 x 10^{-7} to 6.4 x 10^{-5} m/sec with an average of 1.22 x 10^{-5} m/sec, and the porosity varies from 4 to 42% with an average of 38% [16]. Agriculture is the main economic activity of the inhabitants having more than 60% rural population. The principal crops are wheat (*Triticum aestivum*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), barley (*Hordeum vulgare*), moong (*Vigna radiate*), masoor (*Lens culinaris*), groundnut (*Arachis hypogaea*) and fruits such as citrus (*Citrus aurantium*), olive (*Olea euopaea*), and guava (*Psidium guajava*). The soils are generally fertile however, undulating topography, high spatial and temporal variability of rainfall are the major limiting factors in agriculture and socio-economic development.

TABLE I
MAJOR TRIBUTARIES OF THE SOAN RIVER

Left Bank Tributaries		Right Bank Tributaries	
S.No.	Name	S.No.	Name
1	Ling River	1	Korang River
2	Pane and Nala	2	Sil-I (Fatehjang Sil)
3	Ghambhir River	3	Sil-II (Pindi Gheb Sil)
4	Ankar Kas	4	Lei Nullah
5	Leti Nala		
6	Gabhir River.		

Source: [16].

TABLE II
AREAS OF THE SOAN BASIN

S.No.	City	Total area (km^2)	Area in the Soan basin (km^2)	Area in Soan basin (%)
1	Islamabad	906	720	79.5
2	Rawalpindi	1682	1682	100
3	Kahuta	1096	388	35.4
4	Kotli Satian	304	276	90.6
5	Murree	434	221	50.9
6	Gujar Khan	1457	300	20.6
7	Chakwal	3120	1696	54.4
8	Talagang	2932	2701	92.1
9	Pindi Gheb	1865	1865	100.0
10	Jand	2043	321	15.7
11	Fateh Jang	1249	145	11.6
12	Khushab	4011	771	19.2

2.1 Data Collection

The groundwater data in terms of water-table fluctuation provide information about recharge and abstraction of the area. There is however, no permanent system in the basin to monitor the groundwater. The basin was divided into grids of 7 km x 7 km and 193 groundwater monitoring points were selected (at least one in each grid), including open wells, tubewells and hand pumps, depending upon the topographic and hydrologic features of the area. The locations of these points were marked by Global Positioning System (GPS) and the water table was recorded with a water-table recorder from 2003 to 2006. Reference [16] carried out monitoring of water table in the basin from 1976 to 1981 by selecting 127 open wells. These water-table data were used as benchmarks for the present study. The primary data were collected from the field and secondary from various agencies working in the area. The daily rainfall data were collected from nine stations; seven being operated by Irrigation and Power Department, one by Pakistan Meteorological Department and one by Water Resources Research Institute (WRRI), National Agricultural Research Council. The long-term historical record was also available at these stations. The data were analyzed to determine the trends of rainfall over the years as well as in different parts of the basin. The discharge data were collected from Water and Power Development Authority (WAPDA).

III. RESULTS AND DISCUSSIONS

3.1 Groundwater Status

The groundwater contours (water level above mean sea level) show that the groundwater flow follows the topography of the area as well as the drainage pattern Fig. 2.

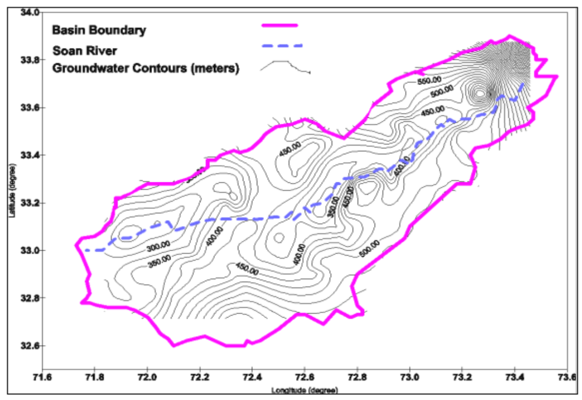

Fig. 2. Groundwater levels and flow behaviour in the Soan basin

The water table varies significantly in the basin and may be categorized in five different zones Fig. 3.

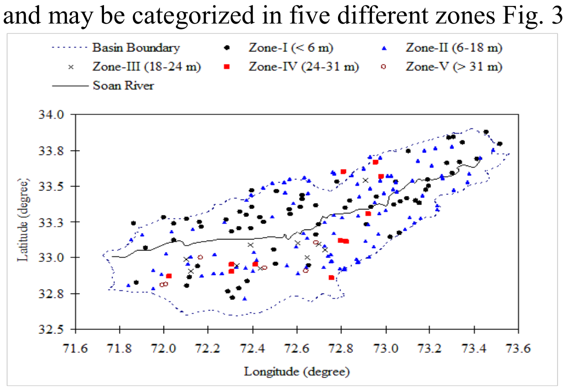

Fig. 3. Zoning of groundwater in the Soan basin after monsoon 2004

The Zone-I consists of shallow wells having water table within 6 m. The zone occupies about 34% of the monitoring points and are scattered all over the basin. However, these points are mostly near the main river and its tributaries or in the vicinity of recharge sources such as dams and ponds. The groundwater is pumped mostly by centrifugal pumps. In Zone-II, the water-table depth varies from 6 to 18 m, comprising about 53% of the monitoring points. These groundwater sources are generally located away from the main river and are scattered near the basin boundary. Rawalpindi and Islamabad also fall in this zone. In Zone-III, the water table varies from 18 to 24 m and is mainly located in tubewell pumping areas. The water-table depth in Zone-IV is from 24 to 31 m, mostly pumped with tubewells. This zone extends towards basin boundary and south-western parts, including Pindi Gheb, Talagang and Chakwal. The wells having water-table depth more than 31 m are in Zone-V, which are mainly located on the western side of the basin. The maximum water-table depth of 61 m has been recorded in this zone. The water-table data measured through 127 open wells, monitored by the WAPDA in 1981 [16] were also analyzed. Fig. 4 shows that the groundwater level varies over the entire area and may be categorized into three zones.

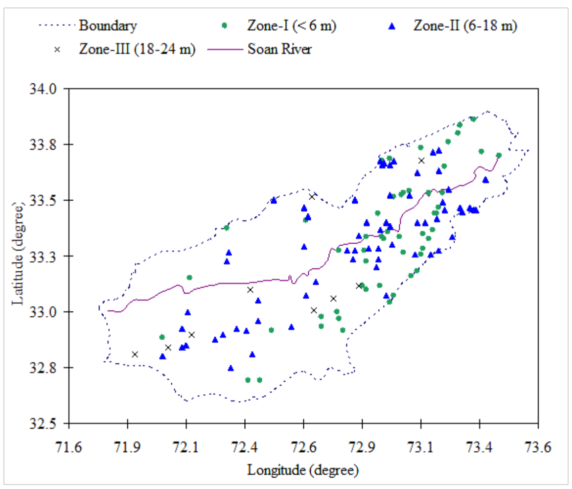

Fig. 4. Zoning of groundwater in the Soan basin after 1981

In Zone-I, the water table lies within 6m depth and about 41% of the monitoring points fall in this zone. These sources are mainly located near the rivers, in the upper parts of the basin, and a few in the south-western areas. About 50% of the monitoring points had water table within 6-18m depth (Zone-II). These sources were scattered over the entire basin, most of these are located near the river. Zone-III represents the water table up to 24m depth. These points were located in Rawalpindi, Islamabad, and south-western areas. The maximum water-table depth observed in 1981 was 24m towards the south-western boundary, whereas in the present study, it is up to 61m depth, indicating a significant water-table decline in the basin.

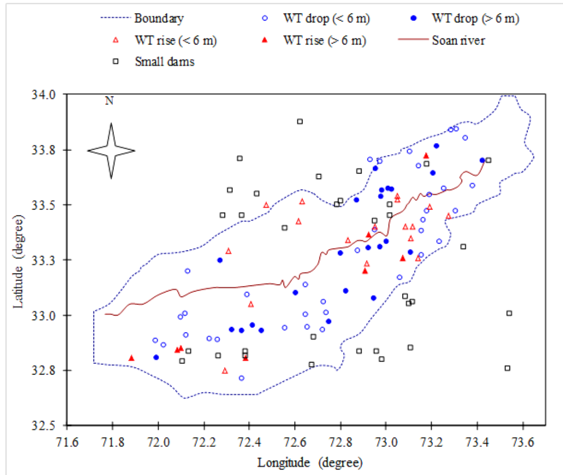

Fig. 5. Groundwater behaviour (depletion and rise) in the Soan basin (WT: water table)

Many studies in different parts of the world have shown that the groundwater exhibits significant spatial and temporal variability relative to other water-cycle variables [23], [24], [25]. A comparative analysis of the water tables in the years 2004 Fig. 3 and 1981 Fig. 4 shows significant changes during the last two decades Fig. 5. In some areas, the water table has dropped significantly being close to the basin boundary and being away from the recharging sources (river, dam etc.) such as Talagang, Chakwal, and most parts of Rawalpindi and Islamabad. The average drop observed during the first two years of monitoring i.e. 2003 and 2004, is more than 0.40 m. The major areas of depletion are under tubewell pumping such as Islamabad and Rawalpindi, where more than 300 tubewells are pumping water. Similarly, due to significant water-table drop in southern-western part of the basin, there is an increasing trend for the installation of deep wells to meet water requirements. [22] and [26] also indicated that the water table dropped by 12.5 to 23 m in Rawalpindi and by 10 to 20m in Islamabad. However, in areas where rainwater harvesting activities were implemented, a rise in groundwater level has also been observed [18], [21]. The water table recorded in 1981 and from 2003-2006 is given in Fig. 6.

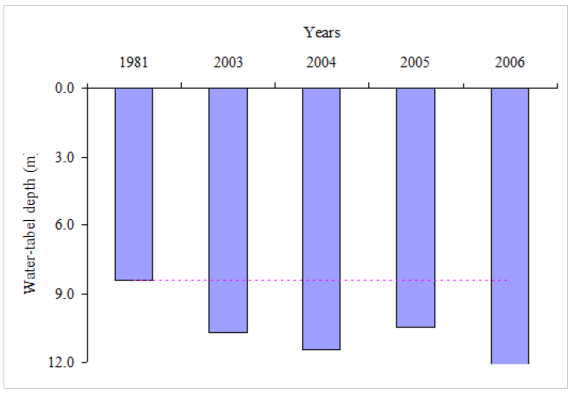

Fig. 6. Average water-table behaviour in the Soan basin from 1981 to 2006

The water-table decline in the basin is 3.75 m over the last 25 years showing an average drop of 0.15m per year. However, in some areas, the drop is more than 6m. This may be attributed to the changing rainfall pattern and continuous increase in abstraction rate due to growing population and urbanization.

3.2 Rainfall Pattern in the Study Area

A detailed knowledge of the rainfall behaviour, in both time and space, is vital for better design and planning of water resources development and management activities as well as conservation of moisture in the soil. The average monthly rainfall pattern was studied from 1960-2005 by dividing the data in two periods i.e. 1960-80 and 1981-2005. The reason for this fragmentation is the significant development in socio-economic conditions that took place in the later period. The monthly rainfall data at different stations from 1960-1980 and 1981- 2005 are given in Tables III and IV, respectively.

TABLE III
AVERAGE MEAN MONTHLY AND MEAN ANNUAL RAINFALL AT THE MONITORING STATIONS IN THE SOAN BASIN (1960-1980)

Stations	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Murree	119	146	143	133	90	147	322	282	145	74	31	54	1685
Rawalpindi	55	78	79	49	47	59	233	263	93	24	18	32	1028
Fatehjang	30	49	56	35	23	33	195	221	47	14	12	25	738
Chakwal	30	37	50	32	33	30	147	133	51	15	9	18	583
Talagang	23	29	48	26	30	34	147	141	51	8	9	15	559
Kahuta	47	60	62	43	25	38	175	203	75	18	12	22	781
Pindi Gheb	26	30	47	33	23	27	121	73	43	12	8	17	459
Tamman	17	17	29	12	10	13	75	83	11	12	8	5	291
Lawa	13	15	15	19	9	18	63	70	20	15	5	5	267
Minimum	13	15	15	12	9	13	63	70	11	8	5	5	267
Maximum	119	146	143	133	90	147	322	282	145	74	31	54	1685
Average	40	51	59	42	32	44	164	163	59	21	12	21	710
Standard deviation (±)	32	41	37	36	25	41	80	82	41	20	8	15	438

TABLE IV
AVERAGE MEAN MONTHLY AND MEAN ANNUAL RAINFALL AT THE MONITORING STATIONS IN THE SOAN BASIN (1981-2005)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Murree	29	44	128	122	69	102	300	261	115	76	34	27	1307
Rawalpindi	52	80	83	51	28	61	257	307	94	29	12	32	1088
Fateh Jang	43	71	75	50	28	43	184	209	85	29	12	26	854
Chakwal	22	30	41	42	14	14	63	91	53	18	5	16	411
Talagang	29	46	60	28	24	45	101	96	57	15	5	24	531
Dhoke Chiniot	63	92	98	64	34	64	296	274	119	50	29	57	1241
Chattar Bagh	76	104	110	88	42	87	348	367	128	46	23	48	1466
Lohi Bher	57	92	78	58	24	65	226	294	100	37	13	46	1087
Makhad	42	54	87	57	39	35	97	126	54	28	18	22	659
Minimum	22	30	41	28	14	14	63	91	53	15	5	16	411
Maximum	76	104	128	122	69	102	348	367	128	76	34	57	1466
Average	46	68	84	62	34	57	208	225	89	37	17	33	960
Standard deviation (±)	18	26	26	28	16	27	102	100	29	19	10	14	367

There are high spatial and temporal variations of rainfall over the basin. About 70% rainfall occurs during the monsoon season (July to September) whereas rest falls in spring and winter seasons. Fig. 7 and 8 show a general trend of reduced rainfall in the later period i.e. 1981-2005, particularly for Chakwal, the trend of reduction in rainfall is pronounced from May to August. In Murree, the reduction in rainfall is more in the months of January and February as compared to other months. However, in Rawalpindi, an increase in rainfall is pronounced in the later period during the months of July and August, whereas in other months of the year, the rainfall is almost the same in both periods Fig. 9.

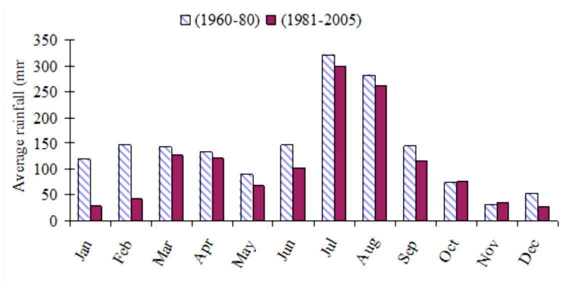

Fig. 7. Average mean monthly rainfall pattern at Murree

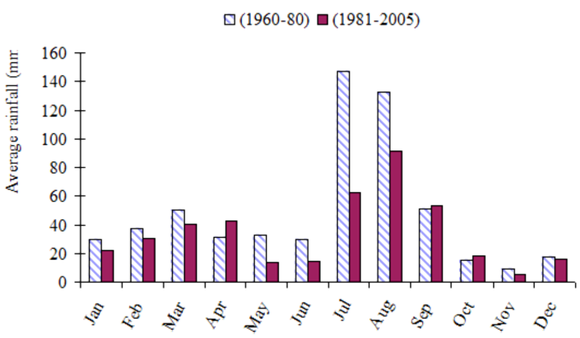

Fig. 8. Average mean monthly rainfall pattern at Chakwal

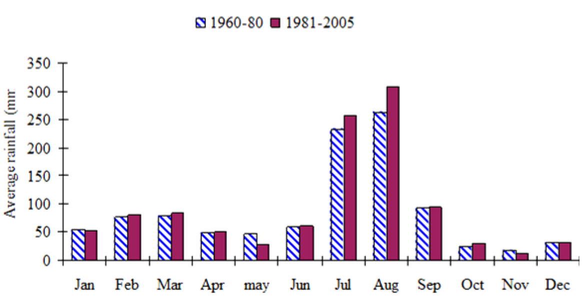

Fig. 9. Average monthly rainfall pattern at Rawalpindi

Fig. 10 and 11 show the long-term average annual rainfall at Murree and Chawkal during the two periods. At Murre (high rainfall area), the average rainfall from 1981-2005 is 366 mm less than the average rainfall of 1960-1980. However, at Chakwal, the reduction in average rainfall during the later period is 140 mm. The overall change in rainfall pattern over the entire basin Fig. 12 shows a decrease in rainfall in the south-eastern parts, especially in Murree (-38%), Chakwal (-29%) and Talagang (-5%) areas, and an increase in rainfall in the north-western parts i.e. Fatehjang (+18), Rawalpindi (+10%) and Makhad (+24%) areas. The change in rainfall pattern extends over the entire basin and may be attributed to population growth, urbanization, deforestation, and land use changes etc. The impacts of these changes are well reflected in the stream flows and resultant impact on groundwater resources.

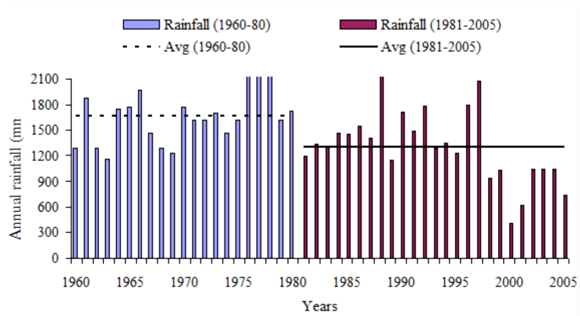

Fig. 10. Annual rainfall pattern at Murree from 1960-80 and 1981-05

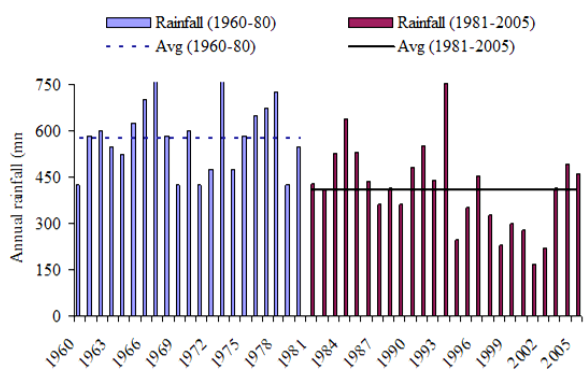

Fig. 11. Annual rainfall pattern at Chakwal from 1960-80 and 1981-05

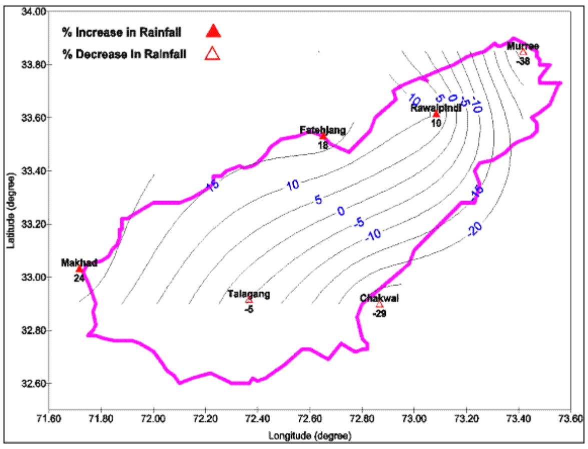

Fig. 12. Changes in rainfall pattern in the Soan basin from 1960-2005

3.3 Basin Inflow

The major stream draining the basin is the Soan river and several small streams and rivers, which join it before its confluence with the Indus river. The drainage basin is so formed that all runoff is generated within the boundaries of the study area, either through overland flow or stream base flow. The discharge measuring points were selected in a way to get maximum information about the runoff potential of the basin as well its various sub-basins. These points were Chirah, Rawalpindi, Dhoke Pathan, and Makhad which are located at 32, 64, 192, and 264 km along the length of the Soan river, respectively. The annual discharge at these points from 1960 to 2005 is given in Fig. 13. The long-term annual flow pattern at these stations shows that the flow rate increases as the river flows towards the basin outflow point. The mean annual discharge at Makhad varies from 38 to 228 m^3/sec.

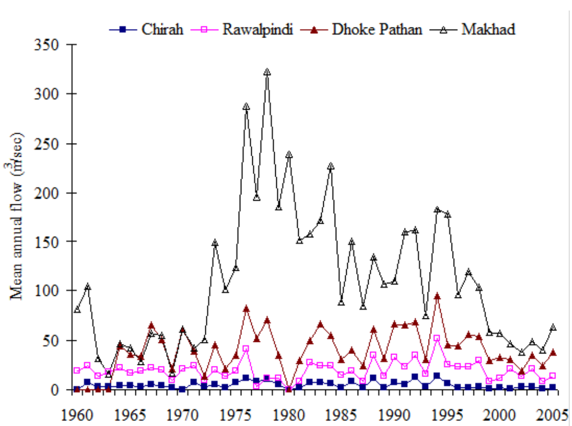

Fig. 13. Annual flow pattern at different sections of the Soan river

The flow at Makhad was the highest between 1975 and 1980, since then it is gradually decreasing mainly due to reduced rainfall and development of rainwater harvesting storages in the catchment.

3.4 Basin Outflow

The historical data on basin outflow were analyzed from 1960 to 2005. The mean annual outflow at Makhad, the basin outlet Fig. 14 shows that the discharge varies over the entire period with an average annual discharge of 109 m^3/sec, whereas the average annual runoff potential is estimated at 3.44 x 10^9 m^3.

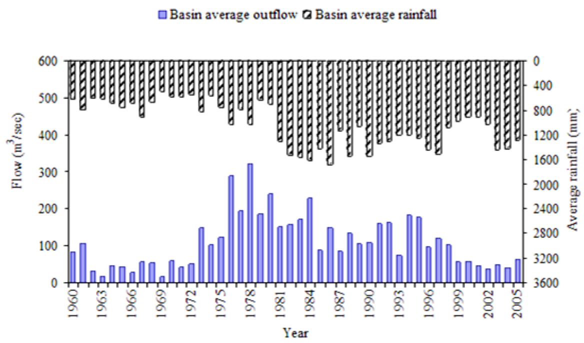

Fig. 14. Average annual rainfall and outflow of the Soan basin at Makhad

However, a continuous decrease in discharge has been observed especially after 1984 and the lowest outflow was observed during the last few years, which reached upto 50% of the average annual flow (average of 45 years). Although an increase in the basin rainfall is seen after drought period 1997-2000 however, there is no significant rise in the basin outflow. The reduced outflow and changing rainfall pattern has significant impacts on groundwater potential in the basin.

3.5 Rainwater Potential and Storage

On the basis of average annual basin outflow (109 m^3/sec), about 3.44 x 10^9 m^3 leaves the area every year, nearly 70% during the months of July to September. In order to utilize this rainwater, many water harvesting and water resources development activities have been carried out by various organizations. There are 32 small dams in the area with a storage capacity of 120 x 10^6 m^3, out of which 40% dams fall in the Soan basin with a storage capacity of about 80 x 10^6 m^3 (less than 3% of the total potential). Therefore, a large proportion of water is still being drained without any use. Similarly, Soil Conservation Department has constructed mini dams and ponds, mainly for agricultural uses, especially after 90s Table V.

TABLE V
Water resources development by the provincial agencies in Pothwar (Nos.) after 1990

Mini Dams	Ponds	Open wells	Hand Pumps	Tubewells	Lift pumps
1,000	1,100	2,163	1,722	159	979

Source: Sattar (personal communication, 2008)

The present storage capacity of mini dams in the basin is about 3.21 x 10^6 m^3. Due to construction of these dams and ponds, significant changes in cropping pattern took place in the area that further led to increased groundwater exploitation [18]. No significant increase in agricultural area however, occurred during the last twenty five years although some of the rainfed areas came under irrigation due to construction of small and mini dams as well as open wells. Most of the agriculture is practiced by traditional methods and is dependent on rainfall, as the developed storage facilities are not being utilized properly [18]. The development of housing societies during the last decade has been the major factor for limited agriculture development in the region.

3.6 Increased Groundwater Utilization

[16] reported that in 1981, the groundwater pumped through open wells and tubewells was 72 x 10^6 m^3. The groundwater utilization however, has now increased manifolds by installation of tubewells, open wells and hand pumps Table III. Moreover, large scale groundwater utilization activities have also taken place by the private sector. The participatory appraisal survey in the area has indicated that the number of tubewells, open wells and hand pumps have increased by 39, 185 and 96%, respectively during the last 25 years. The population increased from 2.49 million to 4.84 million during this period. The population and socio-economic activities that increased markedly during the 25 years, are heavily dependent on groundwater resources. As there is no groundwater regulatory framework in Pakistan, therefore, any farmer (mostly large farmers) can install any number of tubewells, anywhere, at any depth and can pump any quantity of water at any time. Due to indiscriminate installation of tubewells, the groundwater is depleting, resultantly increasing the tubewell installation and operational costs. In certain cases, the most commonly used centrifugal pumps become uneconomical due to increased water-table depth, making it inaccessible to every farmer. The small farmers therefore, have to depend on other farmers for purchase of water. They do not get water at the time of their need due to one or the other reasons. Moreover, the dugwells, which are mostly owned by small farmers, and are the sole source of water for their domestic use, and small-scale agriculture, are drying up, forcing the farmers, either to sell their land or fetch water from far away places. The mini dams and ponds have been constructed by the individual farmers with the financial assistance of the government. These can only be constructed by those farmers who can afford to spare land and can share the cost of construction (30% of the total cost). Mostly, the small and poor farmers are unable to avail such facilities. However, the small dams are constructed by the government completely. After construction, the government establishes the water rights (*warabandi*) for the farmers of the command area depending upon their land holdings, and charges them based on the area irrigated [18]. The projected estimates (at a growth rate of 1.9%) show that the population would double in the next 25 years and the water demand would increase accordingly Fig. 15.

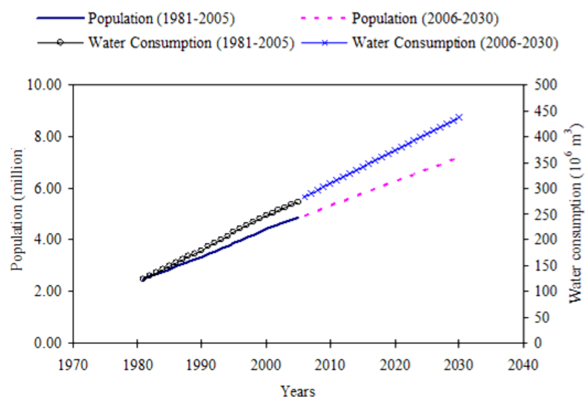

Fig. 15. projected population growth and drinking water demand

The maximum increase in population would be in Islamabad and Rawalpindi cities (heavily urbanized areas), accommodating about 52% of the basin population in 12% of the geographical area. The groundwater is mainly being used for domestic and agricultural purposes followed by livestock, poultry and industry. About 50% of human water demand is being met from groundwater, 47% from dams and 3% from springs. Since surface water resources are mostly unsuitable for human consumption due to various contaminants such as agricultural chemicals, animal and human waste, therefore, the groundwater is the only sources for potable water.

According to the assessment survey in 1981 [16], the sustainable usable potential of the groundwater in the basin was 99 x 10^6 m^3 against the then annual use of 74 x 10^6 m^3. Considering a water table drop of 3.75 m since 1981 and construction of open wells, hand pumps and tubewells Table V associated with about 95% population increase Fig. 15, it may be concluded that the present status of groundwater utilization in the area is beyond its sustainable limit.

To plan proper exploitation, management and utilization of water resources in a rational way, proactive administration of future groundwater depletion is essential [27]. [28] sees high potential in local groundwater management, in addition to other measures that regulate groundwater. A regular groundwater monitoring system however, is very important. This will help identify the most depleting zones and to plan remedial measures accordingly.

IV. Remedial Measures

Sustainable groundwater management requires a balance between recharge and abstraction. This can be achieved by enhancing the groundwater recharge through rainwater harvesting (construction of small and mini dams etc.), soil and water conservation measures, watershed management activities etc. and by adopting high efficiency irrigation systems such as drip and sprinkler.

4.1 Rainwater harvesting

There are many suitable sites in the area where small dams could be constructed. The government of Punjab has constructed 32 small dams in the regions and 19 more are under construction. These dams could irrigate more than 1470 ha, in addition to meeting the domestic and livestock needs. Besides supplying water for irrigation, these dams have many indirect benefits such as; recharge the groundwater, provide water for domestic and municipal purposes, control floods and soil erosion, develop fish culture, and also provide recreational activities [18]. Low-lying areas of the Pothwar Plateau also contain many perennial and non-perennial channels. Mini dams/ponds may be constructed every few kilometers to cut off these channels and to collect some low-lying surface flow. These dams also act as delay action dams and fulfill the purpose of check dams. Mini dams/ponds are generally earth filled with masonry control structure and spillway.

4.2 Watershed management

A major feature of watershed management is the construction of contour bunds/trenches and the plantation of appropriate plant species within the catchments. This reduces the rate of runoff by trapping and delaying the water, some of which is taken up by the plants, consequently reducing the level of silt carried in the overland flow. The watershed management practices also enhance recharge to the groundwater aquifer by increasing infiltration.

4.3 Soil-water conservation

The occurrence of rainfall in the area is quite erratic and its spatial and temporal variation is very high. Several options are available to conserve and to efficiently utilize the moisture depending upon the frequency and intensity of rainfall, topography of the area, soil type, and crops grown etc. Retention of rainfall as soil moisture mainly depends on the infiltration characteristics of the soil, opportunity time, the moisture storage capacity of the soil, soil surface conditions, vegetative cover and land slope. In general, all cultural practices which reduce runoff and erosion result in increased storage of the soil moisture. Contour farming, strip cropping and conservation tillage are important mechanical practices employed to store soil moisture.

4.4 Improving irrigation efficiency

Another way to reduce the stress on the groundwater is to improve the efficiency of the irrigation system. Presently, the farmers use obsolete methods of irrigation resulting in poor application and distribution efficiencies. The most of the barani areas are undulated and e most of the irrigation systems are surface or gravity systems, which typically have efficiency less than 50%. This means that less than 50% of the water applied to the field is used by the crop, while more than 50% is lost by surface runoff, evaporation, and deep percolation of water that moves through the root zone. Therefore, gravity irrigation is not feasible in these areas. Moreover, cost of pumped water is quite high and the available water is not only inadequate but is also unreliable. Therefore, this scarce resource should be utilised most judiciously and efficiently.

The sprinkler and drip irrigation techniques have been successfully introduced in Pakistan, and are particularly well suited to such water scarce barani (rainfed) areas. The higher cost of these systems is justified through associated production of high value vegetable and orchard crops. Application efficiencies can be very high, in the order of 75 to 90%, permitting almost full use of the scarce available water supplies. An additional advantage as compared with surface irrigation is that, efficient irrigation can be carried out even where topography is undulated and soil is of light texture, as is the case in most of the barani areas. However, an integrated approach is required to harness the maximum rainwater and to minimize the groundwater use.

V. Conclusions

Large scale water resources development and exploitation have taken place in the Soan basin associated with about 95% increase in population during the last 25 years. The long-term rainfall data 1960-2005 have shown that rainfall pattern over the basin is changing and the basin rainfall and outflow is decreasing particularly after 1984. Although after drought period 1997-2000, the rainfall situation improved but no significant rise in basin outflow is observed. The utilization of groundwater has increased for domestic and agriculture purposes followed by livestock, poultry and industry. The increased use of groundwater associated with changing rainfall pattern and declined basin outflow, have resulted in drop of water table. On an average, the water table has dropped by 3.75 m in the basin from 1981-2006 with an average drop of 0.15 m per year. However, in the areas away from river and recharge sources, the water-table drop is much higher mainly due to installation of deep wells. Therefore, the present groundwater abstraction is beyond its sustainable level. In the areas, where rainwater harvesting/storage activities were carried out, water table has raised leading to development of more number of open wells, tubewells and hand pumps. On an average, the annual rainwater potential of the basin is 3.44 x 10^9 m^3, whereas only 80 x 10^6 m^3 (less than 3%) could have been harnessed so far through small/mini dams and ponds. There is need to harness the maximum rain water through integrated water resources management approaches. This would not only contribute to groundwater recharge in the basin but would also supplement the water supplies to meet future water demand for various uses.

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