AN OVER VIEW OF GROUND WATER RECHARGE POTENTIAL IN IRRIGATED AREAS OF PUNJAB AND PAKHTUNKHWA

By

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Abstract

Pakistan is facing an acute shortage of surface irrigation supplies. Canal irrigation water is not fulfilling the irrigation requirements. Therefore, farmers are supplementing their crop irrigation by pumping groundwater all over the country. Due to excessive groundwater pumping, water table level is dropping day by day. In some areas of Balochistan, Punjab and KPK provinces, groundwater is falling rapidly due to its excessive abstraction. The water table has gone so deep that small farmers cannot use groundwater as pumping has become uneconomical for them. Shortage of water is being experienced during major part of the year. Water level in the wells is also dropping.

The situation has become alarming in respect of groundwater abstraction in the country. With the reduction in supplies of canals, distributaries, minors and watercourses, recharge to groundwater from irrigation channels has been reduced and excessive pumping of groundwater has increased. Therefore, ground water table has dropped in many parts of the country.

Groundwater in Pakistan is under increasing threat from over-exploitation, pollution and lack of proper management to match the demand and supply patterns of this natural resource base. Pakistan, still being a developing country and equipped with weakened water research, development and management institutions, is considerably lagging behind in converting the existing knowledge base into state of-the-art management policy. At present, no groundwater management approach has been developed to control over-exploitation.

The main objectives are to identify areas of groundwater depletion and suggest measures for sustainable use of groundwater. In different areas of Indus Basin were analyzed where groundwater depletion had occurred. It was observed from the data that maximum depletion was occurred in Bari Doab i.e. 46.10 MAF during October 2012. In Rechna Doab the depletion observed as 14.38 MAF and in Thal Doab it was 7.21 MAF. In Bannu and D. I. Khan area the groundwater recharge potential was 10.84 and 10.43 MAF espectively during October 2012. In this way total groundwater recharge potential was calculated as 105.15 MAF during October 2012.

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1. INTRODUCTION

1.1 BACKGROUND

Importance of groundwater can be realized from the fact that out of the total fresh water resources available on the earth, 96% are located underground. Furthermore, groundwater resources provide great cushion against drought and Low River flows. Over the past few years, there has been tremendous increase in private tubewells and groundwater use.

Continued abstraction and extensive exploitation of groundwater has resulted in depletion of groundwater table, dwindling yield, drying up of wells and water quality deterioration in many areas of Pakistan. The problem has become more acute in recent years due to continued and extended drought faced by the country. To meet this challenge in an effective manner, programmes of artificial recharge to groundwater are immediately required to be undertaken.

Groundwater is considered as a gift of Almighty Allah. Every one, in Pakistan, is at his liberty to install tubewells anywhere in his land and abstract any volume of water at any time without any consideration of its harmful consequences. As a result of unregulated and unplanned pumping in various areas, the water levels are falling and it has become uneconomical for exploitation by the poor farmers. Such areas have large potential for groundwater management and artificial recharge through various techniques. Considerable potential for groundwater recharge exists in riveraine and rain-fed areas where groundwater is deep. Large areas in Pakistan exist where artificial recharge may be economically feasible. During monsoon, large volume of surplus surface water flows to the Arabian Sea which can be utilized for recharging the aquifer.

The surface water potential of 13 river basins was estimated to be 10 MAF, while major Otherwise, Pakistan will be facing acute shortage of food, fibre and edible oil in the near future. The major issue, likely to be faced by the country in the coming years, is lack of management regime for groundwater leading to rapidly falling groundwater levels, pollution of both surface and groundwater. All these issues have impact on agricultural production, food security and the overall ability of the nation to improve the economic performance of irrigated agriculture sector.

The gravity of drop in aquifer levels, as seen presently in Pakistan, has proved that irrigators are now facing increased cost of pumping and in some areas, have to upgrade the pumping plant to cope with higher lifts. The time is fast approaching that groundwater may become beyond the reach of small/poor farmers. According to PPSGDP (2000), these areas with deeper groundwater levels, are generally located in tail reaches of the canal system. The reason being that there is relatively big shortfall between crop water requirement and irrigation water supply in comparison to head reaches (Basharat et al. 2008).

It is the need of the day to avoid declining groundwater table and deteriorating groundwater quality in fresh groundwater areas, and also to ensure equal access to this increasingly important natural resource. So, there is an urgent need to develop policies

and approaches for bringing groundwater withdrawals into balance with recharge a difficult process which is going to require action by the Government and informed and organized users. Since, much groundwater recharge in the Indus Basin is from the irrigation system, this requires an integrated approach for surface and groundwater.

Among the ADB member countries, Pakistan has the highest rate of utilization of the total available freshwater resources at 61%. In terms of groundwater withdrawal, Pakistan's annual rate of 489.5 m^3 per capita is also the highest by a wide margin (Raymond and Husaini, 2006). This information clearly indicates: (i) the high reliance that Pakistan has on its available water resources for irrigation, and (ii) the importance of increasing water use efficiency when there is limited scope for increasing the supply due to internal political differences between the provinces on construction of dams for storage.

1.2 Need of the Study

Groundwater in Pakistan is under increasing threat from over-development, over-extraction and pollution, due to increasing population pressure, increasing living standards, industrialization and lack of proper management to match the demands and use patterns with the natural resource base. Populous agricultural areas of Pakistan, especially Punjab province, has seen exponential growth rates, in terms of number of wells and estimated accumulated pumping volumes, giving an impression of an explosion in groundwater pumping rather than a steady and controlled evolution. The studies indicate that if the present trend of excessive pumping of groundwater through installation of tube wells continue, it will not be possible to pump groundwater by centrifugal pumping system by farmers even in canal-irrigated areas because of declining water table at a very fast rate. The farmers will have to install submersible pumps at a very high cost in order to irrigate the field crops. The main purpose of the study is to identify areas where groundwater aquifer is depleting rapidly and the areas where groundwater potential exists.

2 METHODOLOGY

2.1 Study Area

Mainly the study was conducted in irrigated areas of Indus Basin. The required data of depth to water table was collected from SMO. After screening, the data has been analysed for the study. The results pertaining to different areas of Indus Basin are presented in the paper.

2.2 Groundwater Rechrge Potential Depth Calculations Pattern

Groundwater recharge potential of the area was calculated on the basis of water table depletion during the year. The water table upto depth of 3m was considered as safe for the cultivation of crops. The water table beyond 3m depth was considered for recharge depth. The each range was averaged and this average value was added with the upper water table depth by excluding 3m depth from soil surface. In this way groundwater recharge depth was determind for the different areas.

3. RESULTS AND DISCUSSION

3.1 Area under Different Water table Depths

Keeping in view the current trend of groundwater depletion in various canal commands due to water scarcity in the country, revised ranges of depth to water table are proposed in Table 3.1. Groundwater recharge potential and depleted areas were declared on the basis of this table. Groundwater recharge potential was calculated of different doabs and areas of Indus Basin.

Table 3.1 Classification of Area Based on Revised Ranges of Depth to Water table

Revised DTW Range		**Classified as**
Meter	**Feet**	
0 – 1.5	0 – 5	Waterlogged
1.5 – 3	5 – 10	Likely to be Waterlogged
3 – 6	10 – 20	Normal
6 – 9	20 – 30	
9 – 13	30 – 43	Likely to be Depleted
13 – 18	43 – 59	Depleted
> 18	> 59	Highly Depleted

3.2 Groundwater Recharge Potential of Bari Doab

Data of area under different water table depths for Bari Doab collected in October 2010 (post-monsoon) have been analysed using GIS. The results are summarized in Table 3.2 and shown in Figure 3.1. The pertinent results show that out of the total Bari Doab area of 2.907 Mha, 5.28 percent is classified as “Highly Depleted” having depth to water table (DTW) below 18 m. This area is located mostly in tail reach of Mailsi Canal (Lodhran District). Area under DTW range of 13-18 m works out as 49.44 percent of the total area. This area, classified as “Depleted”, is located in the commands of Lower Bari Doab Canal (tail reach), Lower Depalpur Canal (middle and tail reach), Pakpattan Canal (middle and tail reach), Sidhnai Canal (head, middle and tail reach) and Mailsi Canal (head and middle reach). This area falls in the districts/tehsils of Depalpur, Pakpattan, Arifwala, Burewala, Vehari, Mian Channu, Khanewal, Jahanian, Shujabad, Mailsi and town of Jalalpur (Saeed et al., 2011a).

Table 3.2 Areas under Water table Depth Ranges in Bari Doab (October 2010 & 2012)

S. No.	**WTD Ranges (m)**	**Area (acres)**	**% of Total Area (Oct. 2010)**	**% of Total Area (Oct.-2012)**	**Classified As**
1	0– 1.5	5854	0.08	0.68	Waterlogged
2	1.5– 3	93101	1.30	2.35	Likely to be Waterlogged
3	3– 6	590468	8.22	8.07	Normal

S. No.	WTD Ranges (m)	Area (acres)	% of Total Area (Oct. 2010)	% of Total Area (Oct.-2012)	Classified As
4	6– 9	820476	11.43	13.06	Normal
5	9– 13	1741243	24.25	16.70	Likely to be depleted
6	13– 18	3550290	49.44	52.48	Depleted
7	> 18	379266	5.28	6.66	Highly Depleted
	Total:	7180698	100.00	100.00	

Again the area of Bari Doab was analyzed during October 2012; there was slightly change in water table depth during two years toward depletion. It was observed that area was 24% during October 2010 and it became 16.70% during October 2012 in the range from 9 to 13 m water table depth in Bari Doab. The area was 49% during October 2010 and it was 52% during October 2012 in the range of 13 to 18 m water table depth. It means in two years 4% area was more depleted in this range. In the highly depleted range the area was depleted by 1.38% in two years as shown in Tables 3.2. The different ranges of water table depth of Bari Doab in percentage were shown in Figure 3.1. The groundwater recharge potential in Bari Doab during October 2012 was 46.10 MAF as shown in Table 3.3. The water table contour map of Bari Doab during October 2012 is shown in Figure 3.2.

Table 3.3 Groundwater Recharge Potential in Bari Doab during October, 2012

Recharge Depth (m)	Area (acres)	Sp. Yield	GW Recharge Volume (acft)
1.5	582648.52	0.20	573326.14
4.5	942338.89	0.20	2781784.40
8	1205375.55	0.20	6325810.88
12.5	3787799.22	0.20	31059953.61
17	480679.83	0.20	5360541.48
Total Volume (acft)			**46101416.50**
Total Volume (MAF)			**46.10**

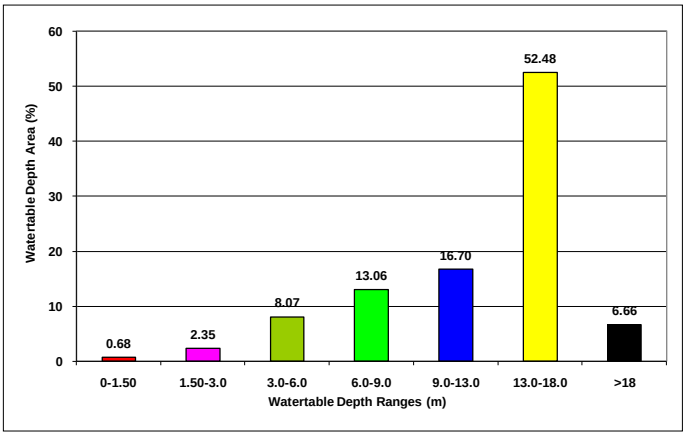


Figure 3.1 Different Water table Depth Ranges in Bari Doab during October, 2012

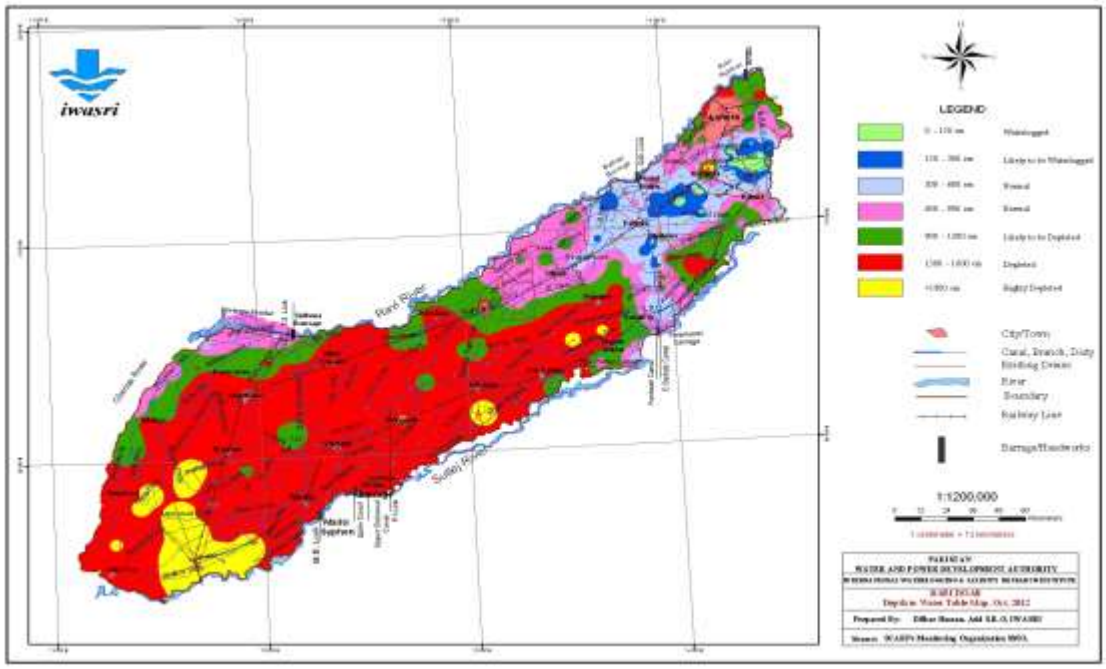


Figure 3.2 Water table Depth Contour Map of Bari Doab, Oct. 2012

3.4 GROUNDWATER RECHARGE POTENTIAL IN RECHNA DOAB

Recharge potential in Rechna Doab is gradually increasing due to decreasing canal supplies and less rainfall. The abstraction of groundwater by farmers is also increased to meet the crop water requirement due to less surface water supplies. Maximum area of Rechna Doab falls in the category of 3-6 m, which is 42% of total area of Doab. The minimum area falls in the range of greater than 18 m which is less than one percent i.e. 0.22 % of toal area of the doab. To maintain the equilibrium of aquifer it is essential to recharge the aquifer by surplus surface water during flood season. In case of Rechna Doab it should be recharged from 13-18 m water table depth i.e. 4.84% of total area of whole Doab. Table 3.4 and Figure 3.3 show the different water table depth ranges in Rechna Doab during October, 2010 Saeed et al., 2011b).

During October 2012, the area of Rechna Doab was again analyzed and it was observed that slightly change occurred in the water table depth in October 2012 as it was compared in October 2010 as shown in Table 3.4. The different water table ranges in percentage were also shown in Figure 3.4. The groundwater recharge potential in Rechna Doab was calculated as 14.38 MAF during the year October 2012 as shown in Table 3.5. The observation wells location and water table contour maps of Rechna Doab during October 2012 is shown in Figure 3.6.

Table 3.4 Different Water table Depth Ranges of Rechna Doab in Percent during October, 2010 & 2012

S.No.	WTD Ranges (m)	Area (acres)	Oct. 2010	Oct. 2012	Classified As
			Area (%)	Area (%)	
1	0-1.50	214712.10	2.04	3.12	Waterlogged
2	1.50-3.0	933402.51	9.57	13.57	Likely to be Waterlogged
3	3.0-6.0	2951372.60	42.23	42.92	Normal
4	6.0-9.0	1765120.33	30.19	25.67	Normal
5	9.0-13.0	696907.56	10.90	10.13	Likely to be depleted
6	13.0-18.0	305611.66	4.84	4.44	Depleted
7	>18	9377.54	0.22	0.14	Highly Depleted
	Total	6876504.29	100	100	

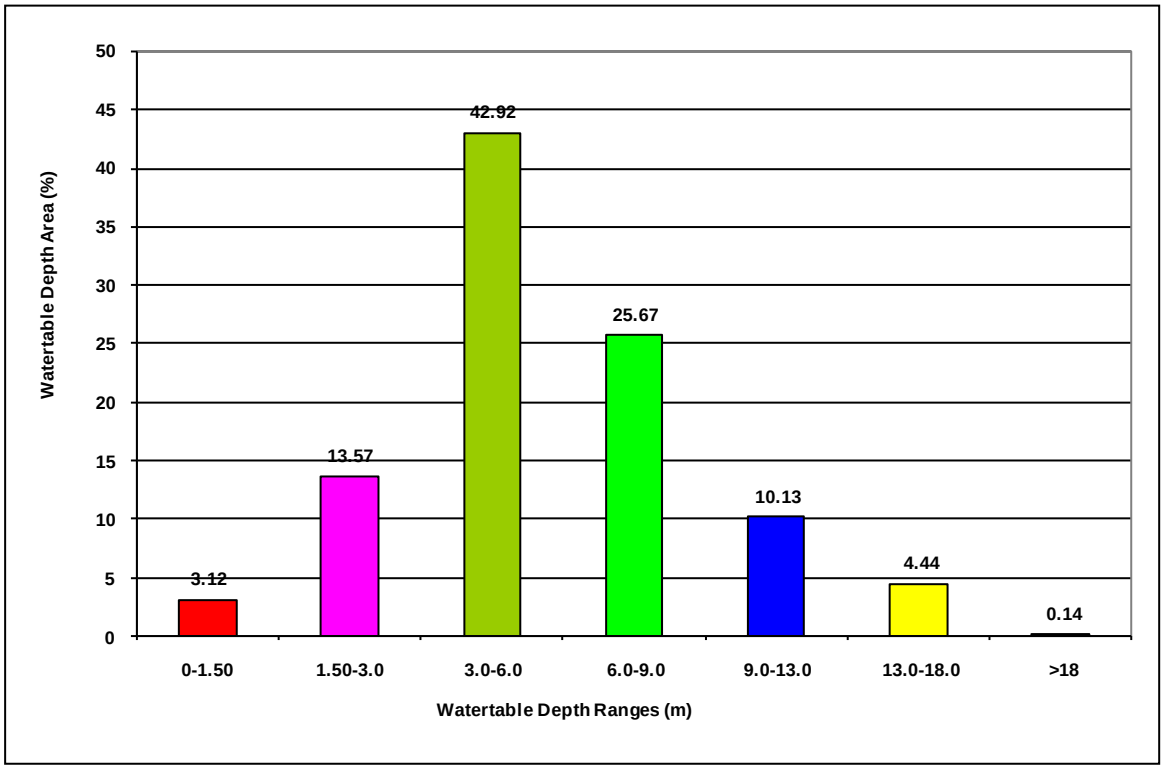


Figure 3.4 Different Water table Depth Ranges in Rechna Doab during October, 2012

Table 3.5 Groundwater Recharge Potential in Rechna Doab during October, 2012

Recharge Depth (m)	**Area (acres)**	**Sp. Yield**	**GW Recharge Volume (acft)**
1.5	2951372.60	0.20	2904150.64
4.5	1765120.33	0.20	5210635.21
8	696907.56	0.20	3657370.85
12.5	305611.66	0.20	2506015.63
17	9377.54	0.20	104578.31
Total Volume (acft)			**14382750.64**
Total Volume (MAF)			**14.38**

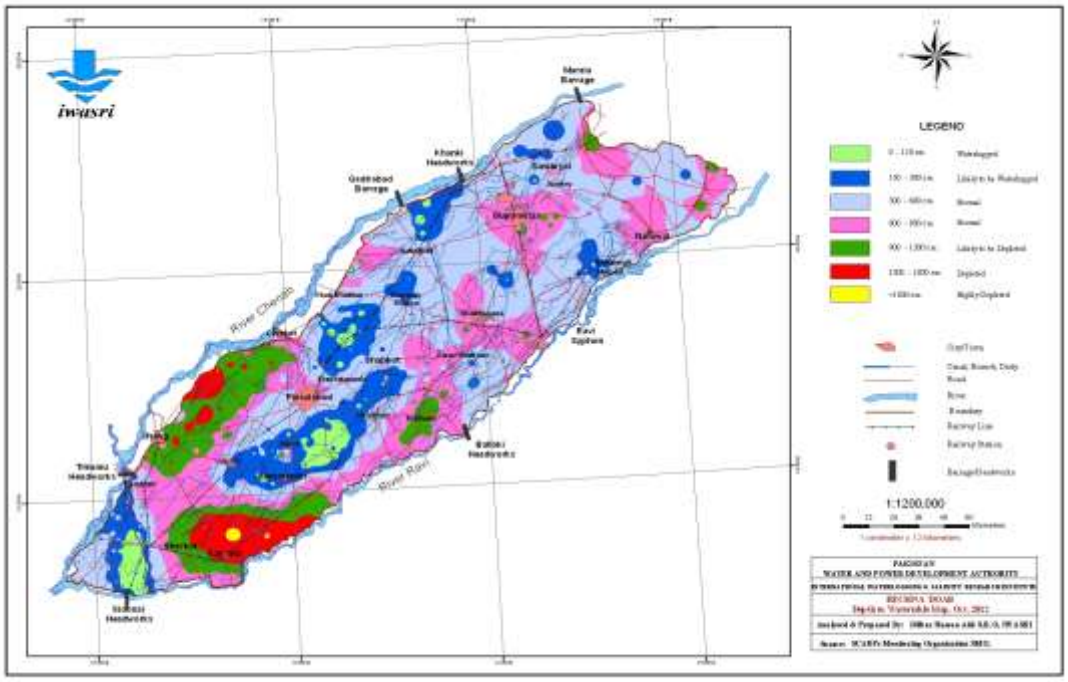


Figure 3.6 Water table Depth Contour Map of Rechna Doab, Oct. 2012

3.5 GROUNDWATER RECHARGE POTENTIAL OF CHAJ DOAB

Recharge potential in Chaj Doab is gradually increasing due to decreasing canal supplies and less rainfall. The abstraction of groundwater by farmers is also increased to meet the crop water requirement due to less surface water supplies. Maximum area of Chaj Doab falls in the category of 3-6 m, which is 41% of total area of Doab. The minimum area falls in the range of 13-18 m which is less than one percent i.e. 0.03% and 0.07% during the years October 2010 & 2012 as shown in Table 3.6. In Chaj Doab no area falls in the range of greater than 18 m depth. To maintain the equilibrium of aquifer it is essential to recharge the aquifer by surplus surface water during flood season (Saeed et al., 2010).

Figure 3.7 shows water table depth ranges in percentages during October 2012. A 10 ft. (3 m) water table depth is safe for agriculture crops. Therefore beyond the area of 3 m water table depth is considered for artificial groundwater recharge. The soil of the Chaj Doab is medium and its specific yield of water is 0.20, on an average basis (Zahir & Ijaz 1969). It is analyzed from the data that total potential of artificial recharge to groundwater in Chaj Doab during October 2012 was 3.97 MAF on the basis of groundwater depletion as shown in Table 3.7. The water table contour map of the Chaj Doab is shown in Figure 3.8.

Table 3.6 Different Water table Depth Ranges of Chaj Doab in Percent during October, 2010 & 2012

S. No.	WTD Ranges (m)	Area (acres)	Oct. 2010 Area (%)	Oct. 2012 Area (%)	Classified As
1	0-1.50	334380.37	8.80	9.70	Waterlogged
2	1.50-3.0	920753.65	24.21	26.70	Likely to be Waterlogged
3	3.0-6.0	1403014.00	41.20	40.68	Normal
4	6.0-9.0	680721.42	22.04	19.74	Normal
5	9.0-13.0	107236.58	3.73	3.11	Likely to be depleted
6	13.0-18.0	2539.22	0.03	0.07	Depleted
7	>18	-	-	-	Highly Depleted
	Total	3448645.24	100.00	100.00	

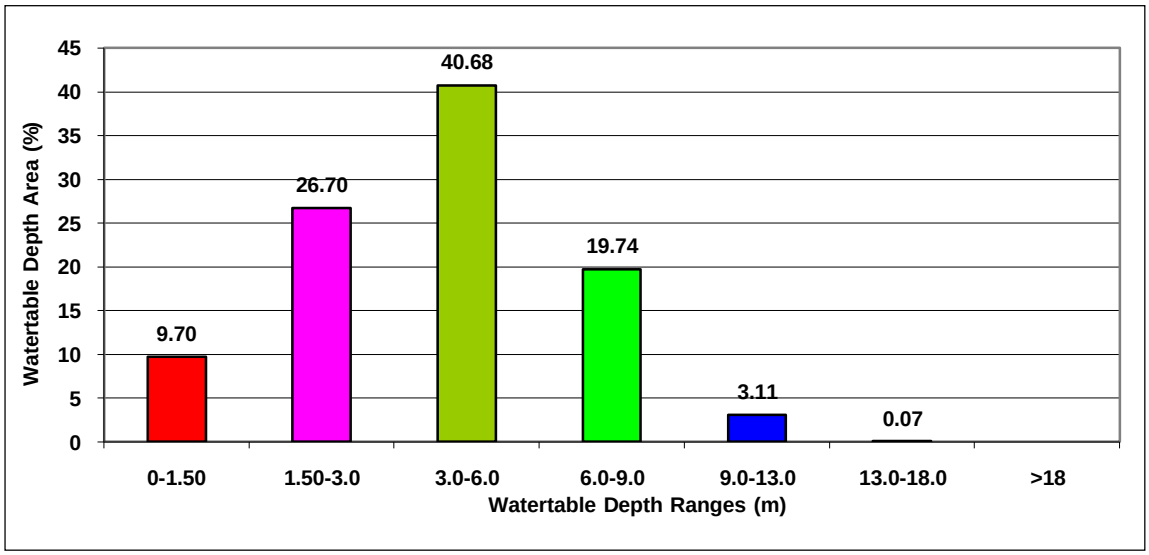


Figure 3.9 Different Water table Depth Ranges in Chaj Doab during October, 2012

Table 3.7 Groundwater Recharge Potential in Chaj Doab during October, 2012

Recharge Depth (m)	Area (acres)	Sp. Yield	GW Recharge Volume (acft)
1.5	1403014.00	0.20	1380565.77
4.5	680721.42	0.20	2009489.63

8	107236.58	0.20	562777.55
12.5	2539.22	0.20	20821.64
17	-	-	-
Total Volume (acft)			**3973654.58**
Total Volume (MAF)			**3.97**

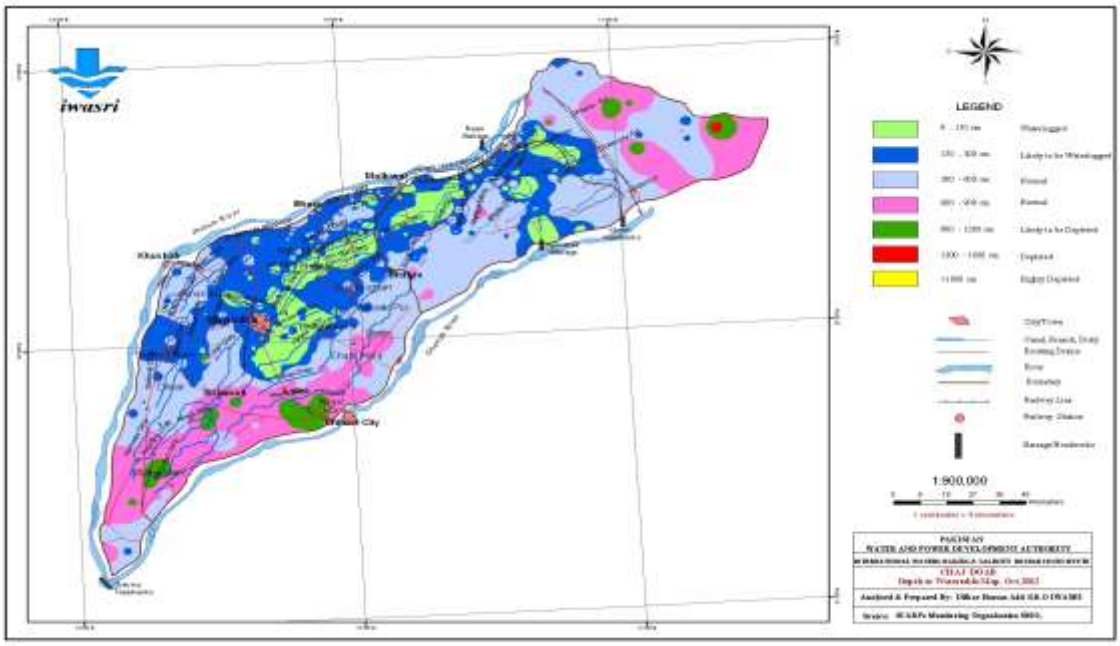


Figure 3.10 Water table Depth Contour Map of Chaj Doab, Oct. 2012

3.6 RECHARGE POTENTIAL IN THAL DOAB

It was observed from the anlysis of water table depth data that maximum area of Thal Doab falls in the category of 3-6 m, which is 49% of total area of Doab. The minimum area falls in the range of 13-18 m which is 0.17% during the year October 2012. In Thal Doab no area falls in the range of greater than 18 m depth as shown in Table 3.8 and Figure 3.11.

Table 3.8 shows the different water table ranges in Thal Doab during October, 2012 and Figure 3.11 shows water table depth ranges in percentages during October 2012. A 10 ft. (3 m) water table depth is safe for agriculture crops. Therefore beyond the area of 3 m water table depth was considered for artificial groundwater recharge. To maintain the equilibrium of aquifer it is essential to recharge the aquifer by surplus surface water during flood season. It is analyzed from the data that total potential of artificial recharge to groundwater in Thal Doab during October 2012 was 7.21 MAF on the basis of groundwater depletion as shown in Table 3.9. The water table contour map of Thal Doab is shown in Figure 3.12.

Table 3.8 Different Water table Depths of Thal Doab in Percent during October, 2012

S.No.	WTD Ranges (m)	Area (acres)	Area (%)	Classified As
1	0-1.50	582745.24	9.18	
2	1.50-3.0	1330715.19	20.97	Waterlogged
3	3.0-6.0	3116429.64	49.11	Likely to be Waterlogged
4	6.0-9.0	1214810.55	19.14	Normal
5	9.0-13.0	89859.65	1.42	Normal
6	13.0-18.0	10956.17	0.17	Likely to be depleted
7	>18	-	-	Depleted
	Total	6345516.43	100.00	

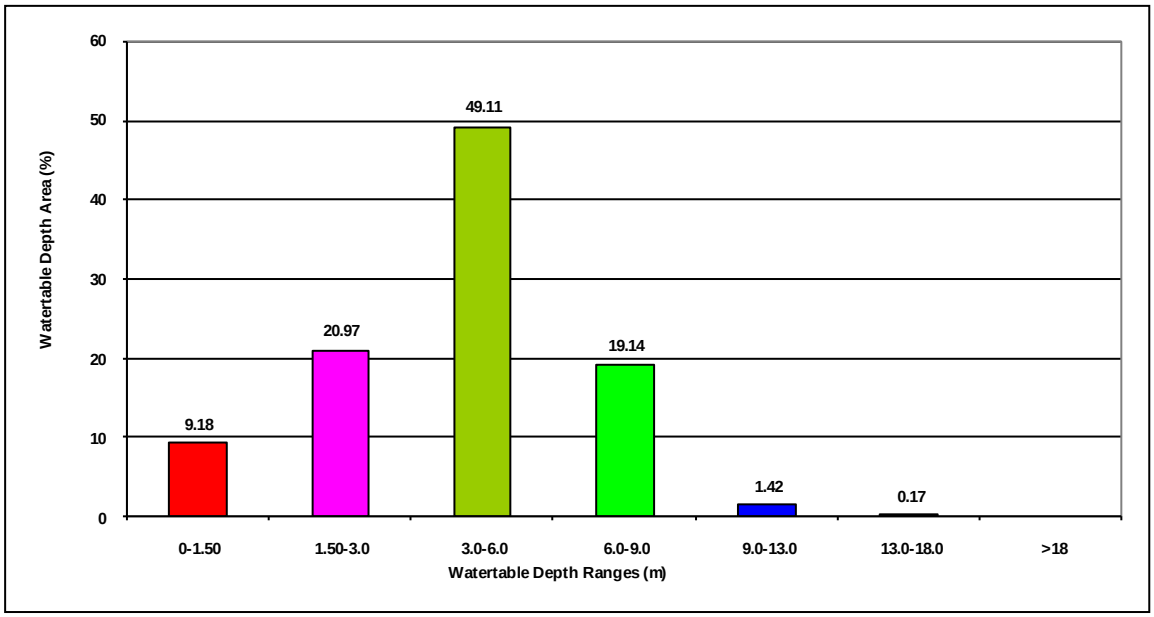


Figure 3.11 Different Water table Depth Ranges in Thal Doab during October, 2012

Table 3.9 Groundwater Recharge Potential in Thal Doab during October, 2012

Recharge Depth (m)	Area (acres)	Sp. Yield	GW Recharge Volume (acft)
1.5	3116429.64	0.20	3066566.76
4.5	1214810.55	0.20	3586120.75

Recharge Depth (m)	Area (acres)	Sp. Yield	GW Recharge Volume (acft)
8	89859.65	0.20	471583.43
12.5	10956.17	0.20	89840.59
17	-	-	-
Total Volume (acft)			**7214111.53**
Total Volume (MAF)			**7.21**

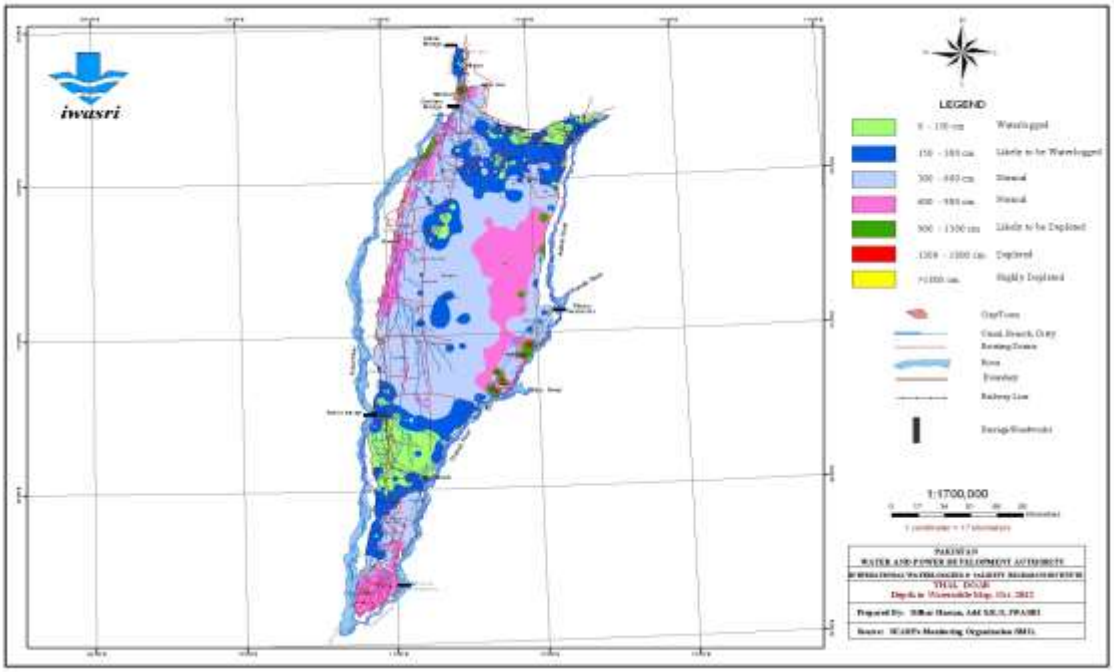


Figure 3.12 Water table Depth Contour Map of Thal Doab, Oct. 2012

3.7 RECHARGE POTENTIAL IN BAHAWALPUR AREA

In Bahawalpur area watetable depth exists in different ranges, but there is no significant in any range, almost all the water table depth ranges are in same level ranging from 15.38% to 24.81% axcept last two ranges i.e 13-18m and >18m, these two ranges were 2.7% and 1.79% respectively of the total area as shown in Table 3.10 and Figure 3.13. The groundwater recharge potential was also calculated of the Bahawalpur area and was found as 6.73 MAF as shown in Table 3.11. The water table contour map is shown in Figure 3.14.

Table 3.10 Different Water table Depths of Bahawalpur Area in Percentage during October, 2012

WTD Ranges (m)	**Area (acres)**	**Area (%)**
0-1.50	447918.34	15.38
1.50-3.0	488142.16	16.76
3.0-6.0	591287.68	20.30
6.0-9.0	722654.59	24.81
9.0-13.0	531788.53	18.26
13.0-18.0	78549.99	2.70
>18	52190.20	1.79
Total	2912531.50	100

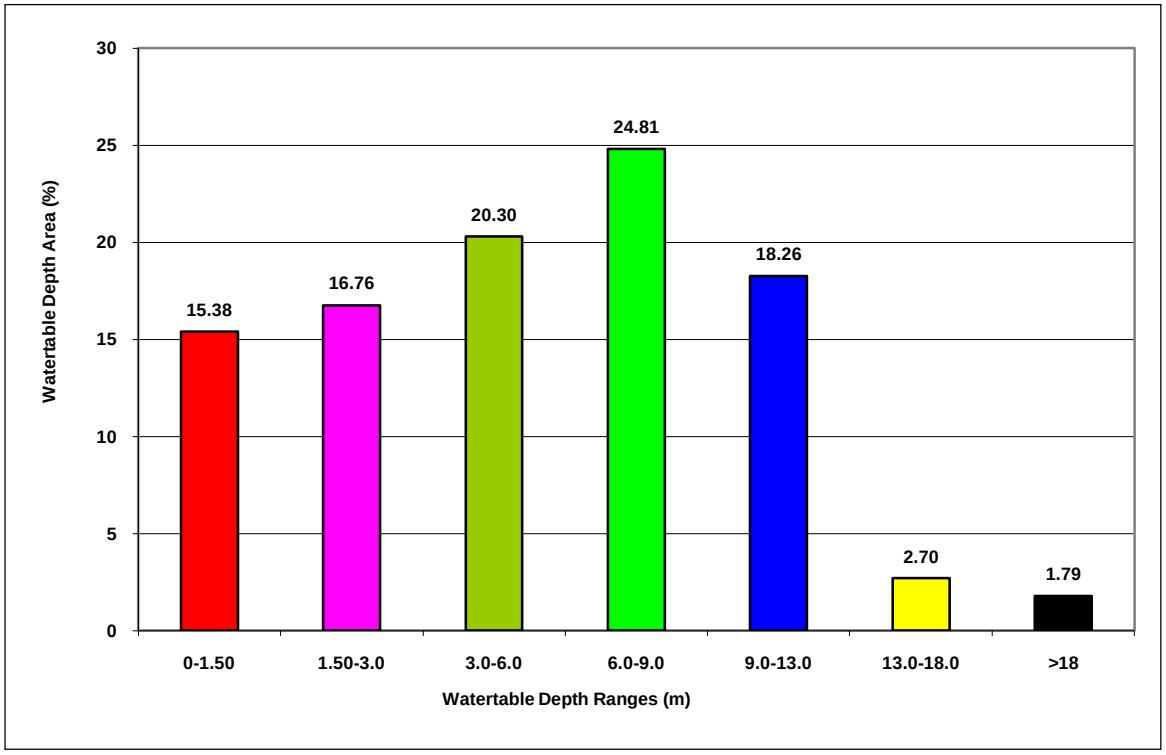
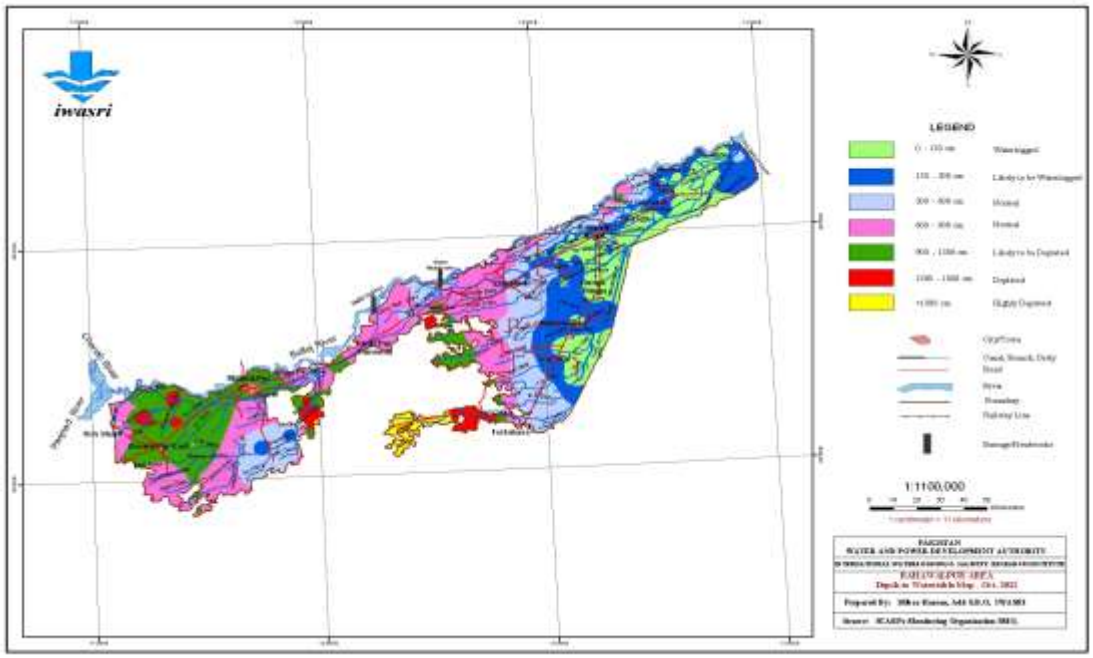


Figure 3.13 Different Water table Depth Ranges in Bahawalpur Area during October-2012

Table 3.11 Groundwater Recharge Potential in Bahawalpur Area during October, 2012

Recharge Depth (m)	Area (acres)	Sp. Yield	GW Recharge Volume (acft)
1.5	591287.68	0.20	581827.07
4.5	722654.59	0.20	2133276.36
8	531788.53	0.20	2790826.20
12.5	78549.99	0.20	644109.93
17	52190.20	0.20	582025.14
Total Volume (acft)			**6732064.71**
Total Volume (MAF)			**6.73**



3.14 Water table Depth Contour Map of Bahawalpur Area, Oct. 2012

3.8 RECHARGE POTENTIAL IN RAHIM YAR KHAN AREA

In Rahim Yar Khan Area water table depth which falls in the range of 0-1.5m that was 8.86% of total area and it is also known as waterlogged area. Maximum area i.e. 37.02% falls in the range of 1.5 to 3m. In this region two ranges are absent which are 13-18m and >18m. In this area, there was no groundwater depletion problem. Area in different ranges is shown in percentages in Table 3.12 and Figure 3.15. Groundwater recharge potential was also calculated and it was 3.02 MAF as shown in Table 3.13. The water table contour maps of Rahim Yar Khan Area is shown in Figure 3.16.

Table 3.12 Different Water table Depths of R.Y. Khan Area in Percent during October, 2012

WTD Ranges (m)	**Area (acres)**	**Area (%)**
0-1.50	162057.20	8.86
1.50-3.0	676797.47	37.02
3.0-6.0	340940.78	18.65
6.0-9.0	312230.49	17.08
9.0-13.0	336409.64	18.40
13.0-18.0	-	-
>18	-	-
Total	1828435.59	100.00

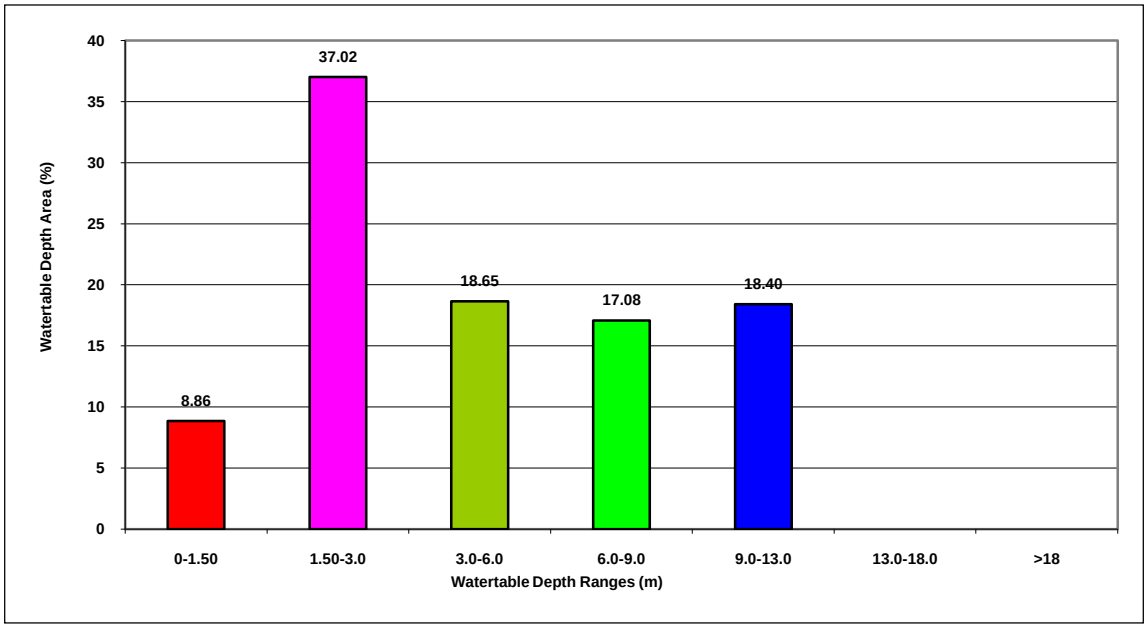
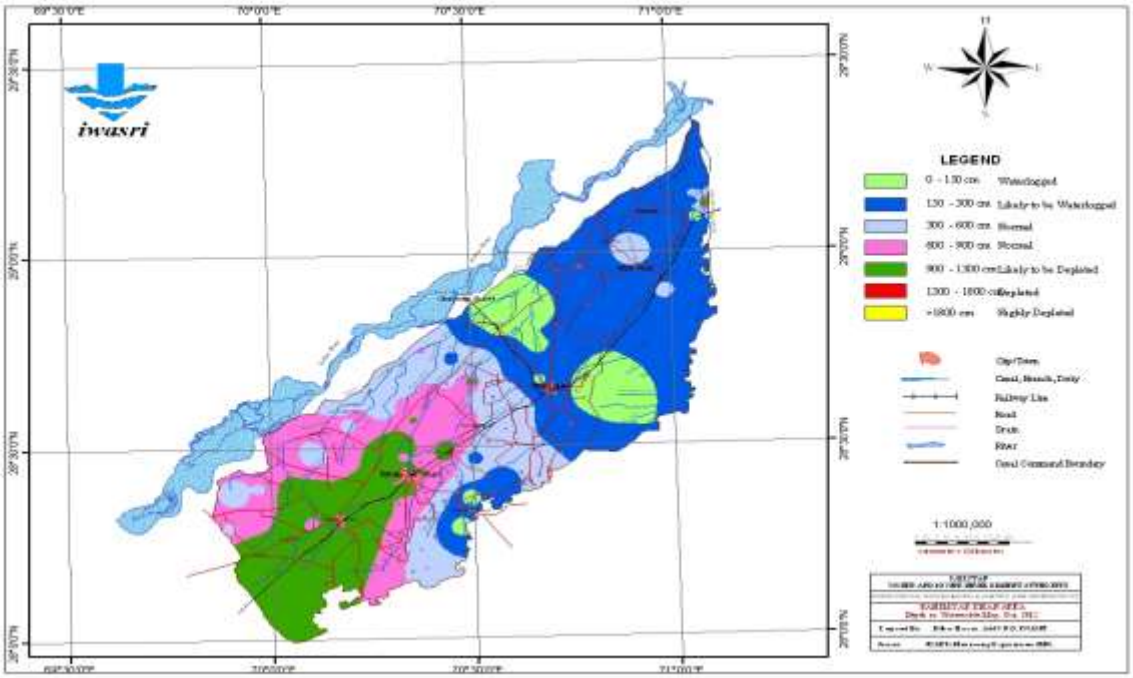


Figure 3.15 Different Water table Depth Ranges in R.Y. Khan Area during October, 2012

Table 3.13 Groundwater Recharge Potential in R.Y. Khan Area during October, 2012

Recharge Depth (m)	**Area (acres)**	**Sp. Yield**	**GW Recharge Volume (acft)**
1.5	340940.78	0.20	335485.73
4.5	312230.49	0.20	921704.39

8	336409.64	0.20	1765477.80
12.5	-	-	-
17	-	-	-
Total Volume (acft)			**3022667.92**
Total Volume (MAF)			**3.02**



3.16 Water table Depth Contour Map of R.Y. Khan Area, Oct. 2012

3.9 RECHARGE POTENTIAL IN D.G. KHAN AREA

In Dera Ghazi Khan Area 18.3% of total area falls in the water table depth range of 0-1.5m. The maximum area i.e. 42.72% of total D. G. Khan area falls in the range of 3-6m water table depth. A very minor area falls in the ranges of 9-13m and 13-18m water table depth. No area falls in the range of >18m water table depth as shown in Table 3.14 and Figure 3.17. Very nominal groundwater potential exists in this area. Actually in D. G. Khan area there was no depletion problem but waterlogging problem. The recharge potential was also calculated in D.G. Khan Area was 0.77 MAF as shown in Table 3.15. The water table contour map is shown in Figure 3.18.

Table 3.14 Different Water table Depths of D.G. Khan Area in Percent during October, 2012

S.No.	WTD Ranges (m)	Area (acres)	Area (%)
1	0-1.50	194941.00	18.30
2	1.50-3.0	318233.47	29.88
3	3.0-6.0	455076.70	42.72
4	6.0-9.0	83114.49	7.80
5	9.0-13.0	13532.57	1.27
6	13.0-18.0	263.04	0.02
7	>18	-	-
	Total	1065161.27	100.00

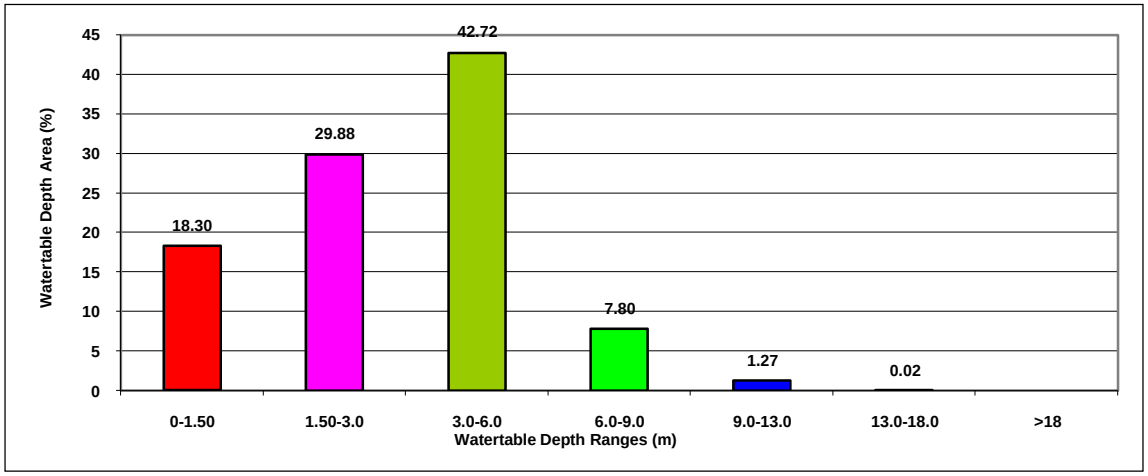
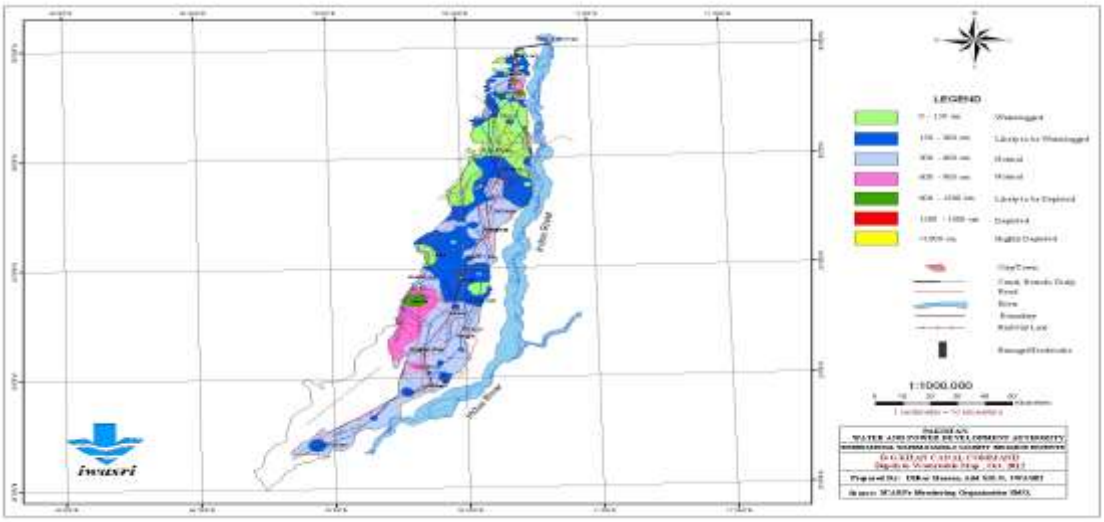


Figure 3.17 Different Water table Depth Ranges in D.G. Khan Area during October, 2012

Table 3.15 Groundwater Recharge Potential in D.G. Khan Area during October, 2012

Recharge Depth (m)	Area (acres)	Sp. Yield	GW Recharge Volume (acft)
1.5	455076.70	0.20	447795.47
4.5	83114.49	0.20	245353.96
8	13532.57	0.20	71018.95
12.5	263.04	0.20	2156.91
17	-	-	-
Total Volume (acft)			766325.30
Total Volume (MAF)			0.77



3.18 Water table Depth Contour Map of D. G. Khan Area, Oct. 2012

3.10 GROUNDWATER RECHARGE POTENTIAL IN BANNU AREA

The watetable depth was analysed of the Bannu area and it was observed that maximum of the Bannu area falls in the ranges of 9-13 m, 13-18 m and > 18 m i.e. 23.49, 18.34 and 26.81% respectively as shown in Table 3.16. The different water table depth ranges are also shown in Figure 3.19. The groundwater recharge potential of the Bannu area was also calculated and it was found as 10.84 MAF and it is also shown in Table 3.17. The water table contour map of Bannu area is given in Figure 3.20.

Table 3.16 Different Water table Depths of Bannu Area in Percentage during October, 2012

WTD Ranges (m)	**Area (acres)**	**Area (%)**
0-1.50	64670.82	3.65
1.50-3.0	157548.52	8.89
3.0-6.0	145496.82	8.21
6.0-9.0	187750.29	10.60
9.0-13.0	416164.44	23.49
13.0-18.0	324828.13	18.34
>18	474993.50	26.81
Total	1771452.52	100.00

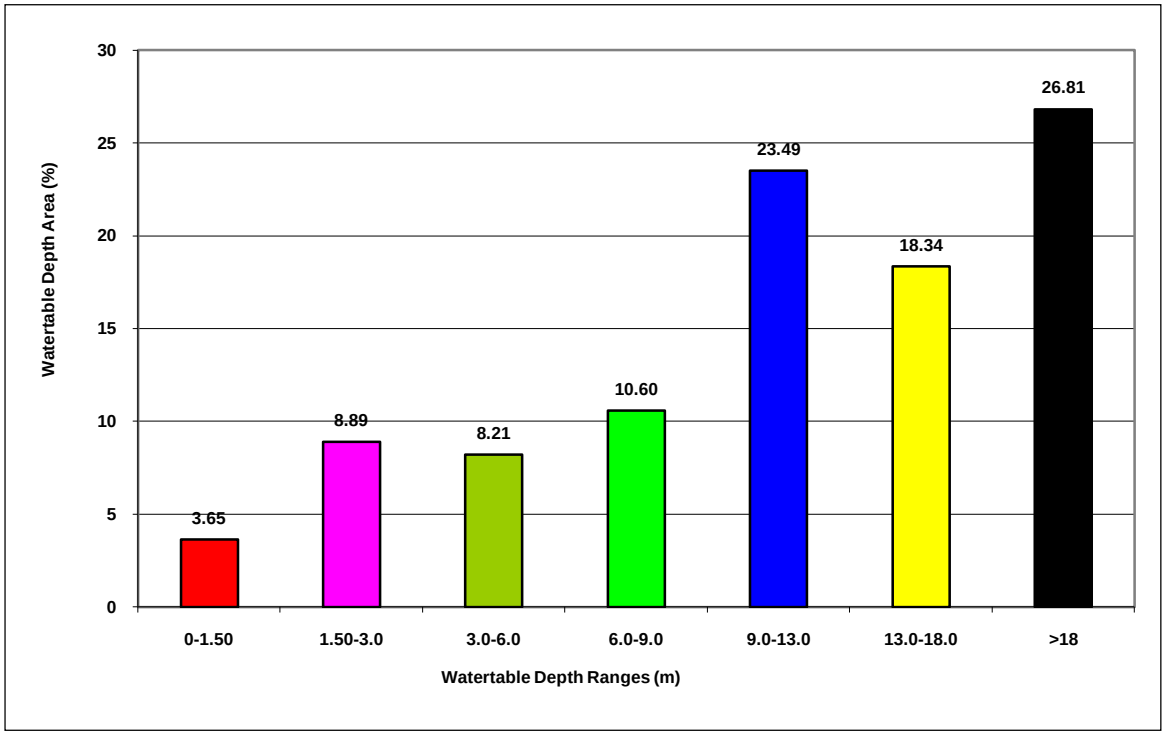


Figure 3.19 Different Water table Depth Ranges in Bannu Area during October, 2012

Table 3.17 Groundwater Recharge Potential in Bannu Area during October, 2012

Recharge Depth (m)	**Area (acres)**	**Sp. Yield**	**GW Recharge Volume (acft)**
1.5	145496.82	0.20	143168.87
4.5	187750.29	0.20	554238.85
8	416164.44	0.20	2184031.01
12.5	324828.13	0.20	2663590.70
17	474993.50	0.20	5297127.55
Total Volume (acft)			10842156.97
Total Volume (MAF)			10.84

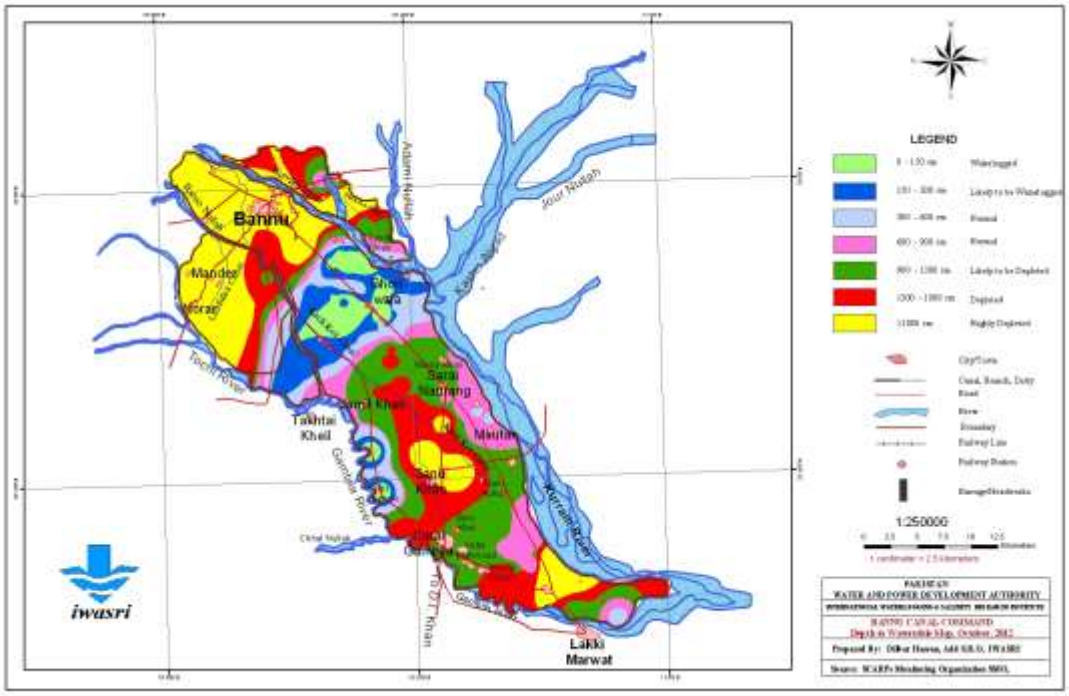


Figure 3.20 Water table Depth Contour Map of Bannu Area, Oct. 2012

3.11 GROUNDWATER RECHARGE POTENTIAL IN D.I. KHAN AREA

It was observed from the data that maximum area of D. I. Khan falls in the range of 13-18m water table depth and it was 26.02% of the total area. Minimum area falls in the range of 0-1.50m and it was 2.18% of total area of D. I. Khan. The different percentages of area are shown in Table 3.18 and in Figure 3.21.

The groundwater recharge potential was also calculated and it was found as 10.43 MAF as it is shown in Table 3.19. The water table contour map of D. I. Khan Area is also given in Figure 3.22.

Table 3.18 Different Water table Depths of D .I. Khan Area in Percent during October, 2012

WTD Ranges (m)	**Area (acres)**	**Area (%)**
0-1.50	48844.94	2.18
1.50-3.0	391699.45	17.52
3.0-6.0	384901.05	17.21
6.0-9.0	163383.81	7.31
9.0-13.0	581751.69	26.02

13.0-18.0	305171.58	13.65
>18	360122.69	16.11
Total	2235875.20	100.00

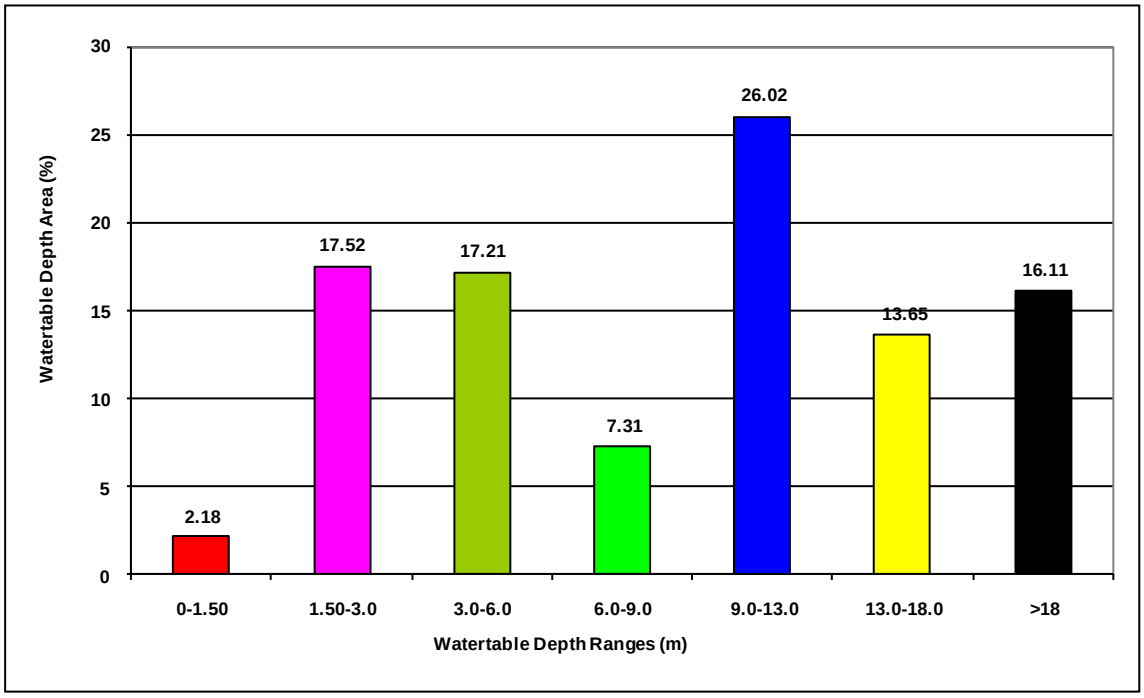
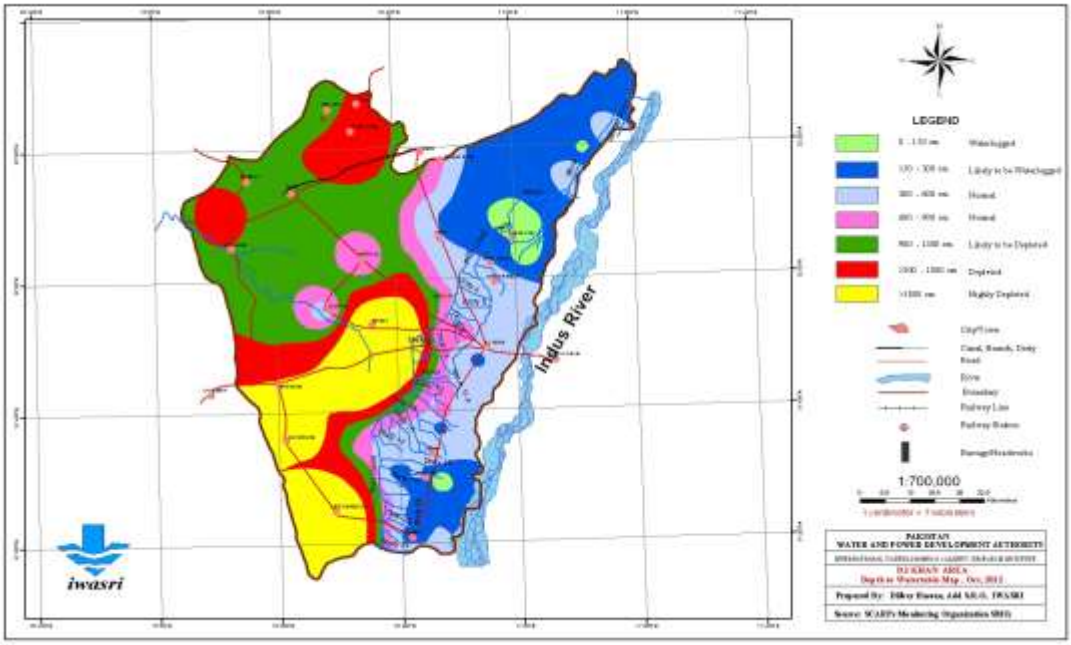


Figure 3.21 Different Water table Depth Ranges in D. I. Khan Area during October, 2012

Table 3.19 Groundwater Recharge Potential in D. I. Khan Area during October, 2012

Recharge Depth (m)	**Area (acres)**	**Sp. Yield**	**GW Recharge Volume (acft)**
1.5	384901.05	0.20	378742.63
4.5	163383.81	0.20	482309.00
8	581751.69	0.20	3053032.87
12.5	305171.58	0.20	2502406.92
17	360122.69	0.20	4016088.24
Total Volume (acft)			**10432579.67**
Total Volume (MAF)			**10.43**



3.22 Water table Depth Contour Map of D.I. Khan Area, Oct. 2012

3.12 GROUNDWATER RECHARGE POTENTIAL IN MARDAN AREA

The Mardan Area was also analyzed and it was observed that maximum area of Mardan falls in the range of 3-6m, and it was 37.92% of total area during October 2012. Second largest area of Mardan falls in the range of 1.5-3m, which was 28.89% of total area. The different ranges of water table depth are shown in Table 3.20 and Figure 3.23 during October 2012.

It was observed from the water table data that in Mardan area there was no depletion problem of groundwater. Although recharge potential was calculated as 1.15 MAF as shown in Table 3.21. The watetable contour maps of Mardan Area during October 2012 is shown in Figure 3.24.

Table 3.20 Different Water table Depths of Mardan Area in Percent during October, 2012

WTD Ranges (m)	**Area (acres)**	**Area (%)**
0-1.50	26790.23	3.74
1.50-3.0	207135.24	28.89
3.0-6.0	271874.22	37.92
6.0-9.0	119848.93	16.72

9.0-13.0	75097.91	10.48
13.0-18.0	14513.32	2.02
>18	1640.01	0.23
Total	716899.87	100.00

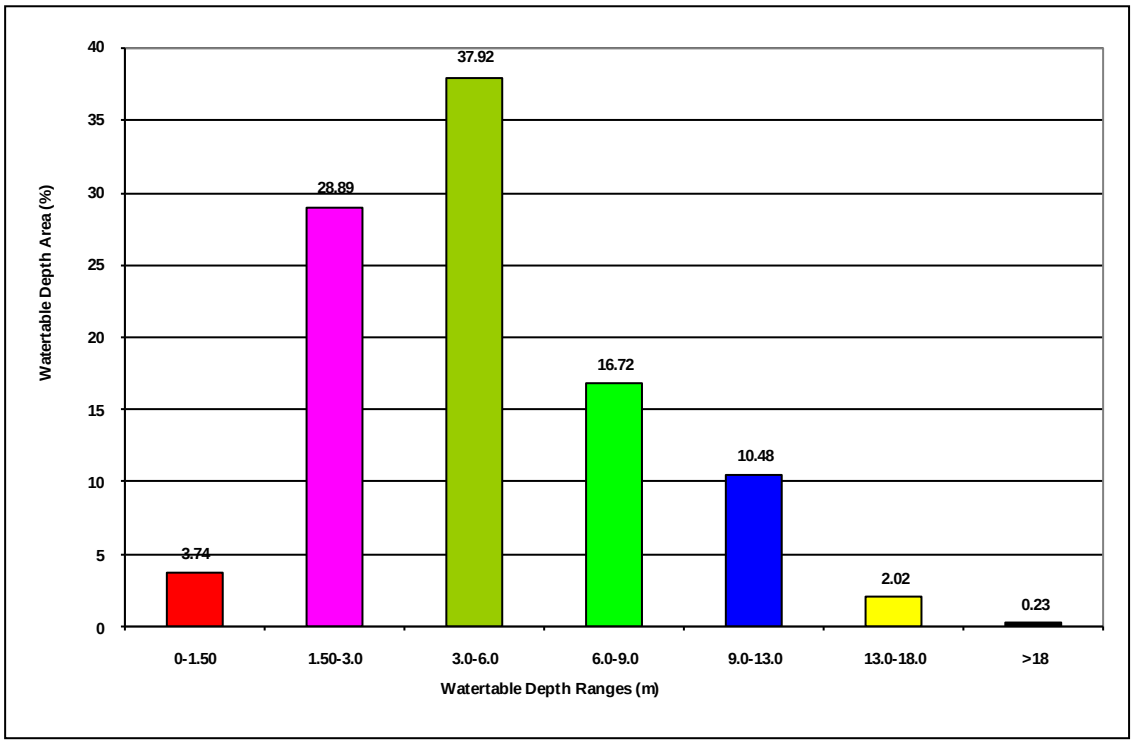
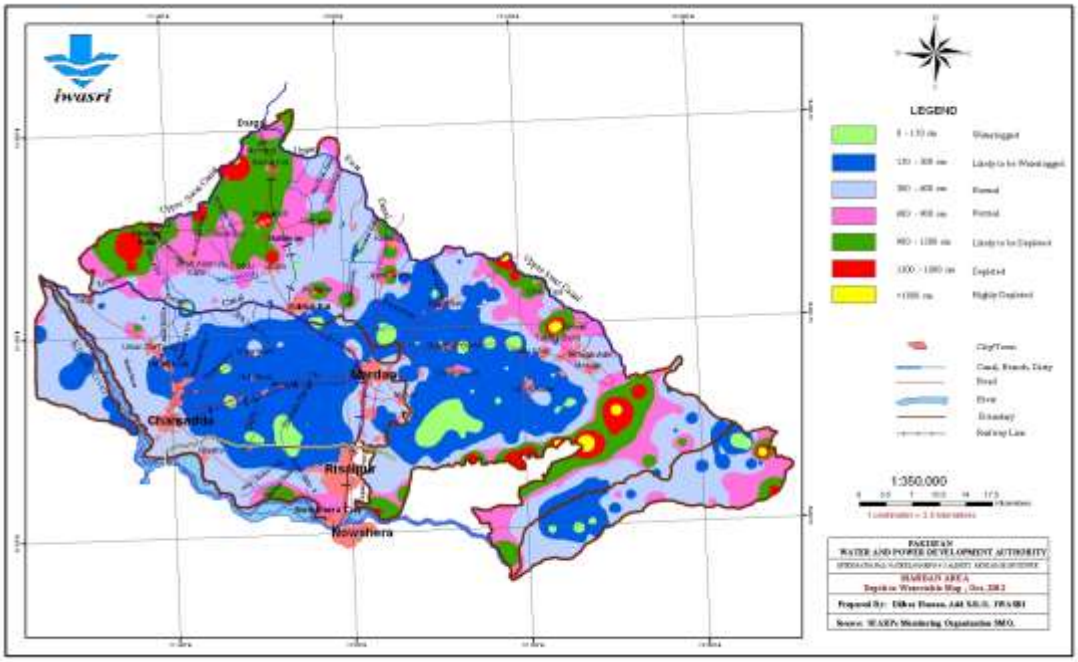


Figure 3.23 Different Water table Depth Ranges in Mardan Area during October, 2012

Table 3.21 Groundwater Recharge Potential in Mardan Area during October, 2012

Recharge Depth (m)	**Area (acres)**	**Sp. Yield**	**GW Recharge Volume (acft)**
1.5	271874.22	0.20	267524.23
4.5	119848.93	0.20	353794.06
8	75097.91	0.20	394113.82
12.5	14513.32	0.20	119009.25
17	1640.01	0.20	18289.41
Total Volume (acft)			**1152730.77**
Total Volume (MAF)			**1.15**



3.24 Water table Depth Contour Map of Mardan Area, Oct. 2012

3.13 GROUNDWATER RECHARGE POTENTIAL IN PESHAWAR AREA

The water tabe depth data of Peshawar Area was analyzed in different water table depth ranges. It was observed from the water table depth data that maximum area falls in the range of 1.5-3 m which is 36.85% of total area. The second largest area falls in the range of 3-6m and it was 28.05% of total area during October 2012. In Peshawar area water table also existed below 18 m depth and which was 5.61% of total area. All the water table depth ranges are shown in Table 3.22 and Figure 3.25.

The groundwater recharge potential was also calculated as 0.55 MAF of Peshawar area during October 2012 as shown in Table 3.23. The water table depth contour map is shown in Figure 3.26.

Table 3.22 Different Water table Depths of Peshawar Area in Percent during October, 2012

WTD Ranges (m)	**Area (acres)**	**Area (%)**
0-1.50	11262.75	4.24
1.50-3.0	97815.44	36.85
3.0-6.0	74452.40	28.05
6.0-9.0	34318.03	12.93

WTD Ranges (m)	Area (acres)	Area (%)
9.0-13.0	20127.53	7.58
13.0-18.0	12555.91	4.73
>18	14897.28	5.61
Total	265429.34	100.00

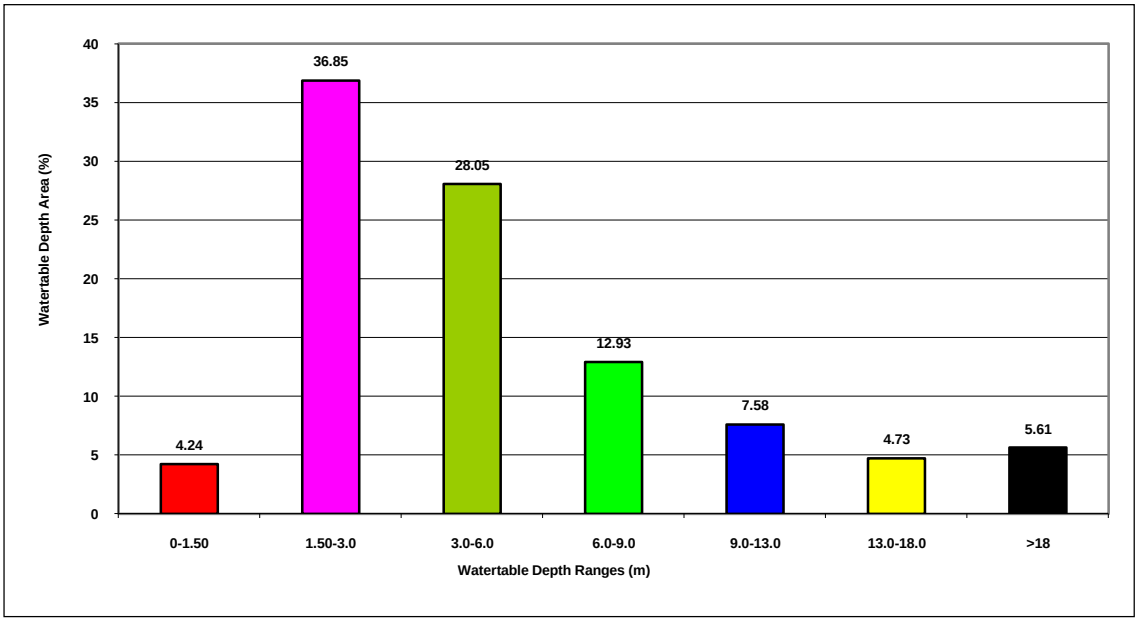
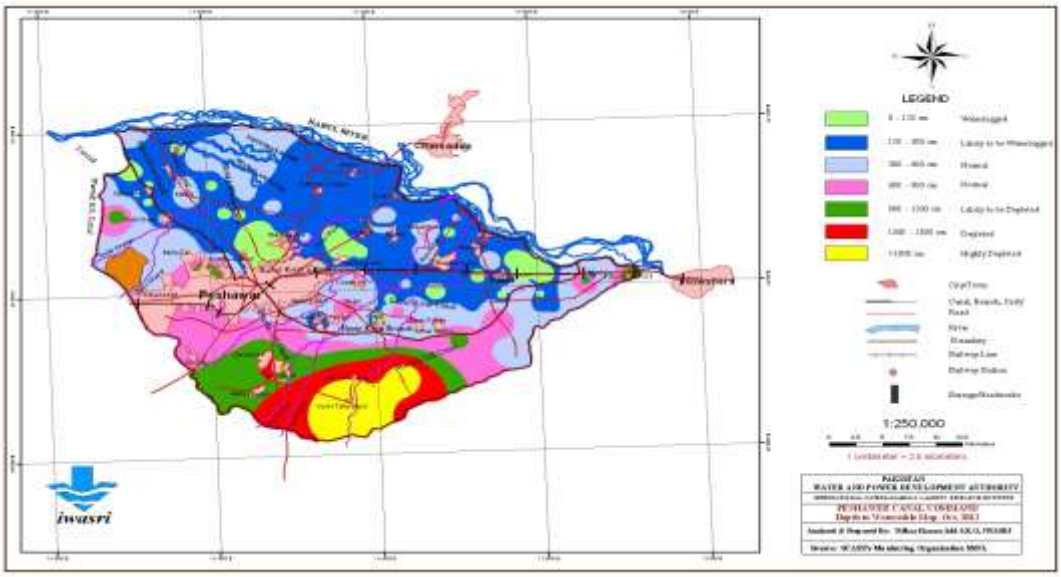


Figure 3.27 Different Water table Depth Ranges in Peshawar Area during October, 2012

Table 3.23 Groundwater Recharge Potential in Peshawar Area during October, 2012

Recharge Depth (m)	Area (acres)	Sp. Yield	GW Recharge Volume (acft)
1.5	74452.40	0.20	73261.16
4.5	34318.03	0.20	101306.81
8	20127.53	0.20	105629.27
12.5	12555.91	0.20	102958.48
17	14897.28	0.20	166134.51
Total Volume (acft)			**549290.24**
Total Volume (MAF)			**0.55**



3.28 Water table Depth Contour Map of Peshawar Area, Oct. 2012

3.14 GROUNDWATER RECHARGE POTENTIAL IN INDUS BASIN

Different areas of Indus Basin were analyzed where groundwater depletion was occurred. It was observed from the data that maximum depletion was occurred in Bari Doab i.e. 46.10 MAF during October 2012. In Rechna Doab the depletion was observed as 14.38 MAF and in Thal Doab it was 7.21 MAF. In Bannu and D. I. Khan area the groundwater recharge potential was 10.84 and 10.43 MAF respectively during October 2012. In this way total groundwater recharge potential was calculated as 105.15 MAF during October 2012 as shown in Table 3.24.

Table 3.24 Groundwater Recharge Volume in Different Parts of Indus Basin

S. No.	Area	Recharge Potential (MAF)
1	Bari Doab	46.10
2	Rechna Doab	14.38
3	Chaj Doab	3.97
4	Thal Doab	7.21
5	Bahawalpur Area	6.73
6	R. Y. Khan Area	3.02
7	D. G. Khan	0.77
8	Bannu Area	10.84
9	D. I. Khan Area	10.43
10	Mardan	1.15
11	Peshawar Area	0.55
Total Recharge Potential in Indus Basin		**105.15**

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Bari Doab
Data analysis using GIS indicates that "highly depleted" area of Bari Doab is 5 percent, having depth to water table (DTW) below 18 m and 49 percent is "depleted" falling under DTW range of 13-18 m. It is further noted that 54% area of Bari Doab can be artificially recharged. Maximum depletion (18-25 m) is in lower part of Bari Doab and its recharge potential is 45 & 47 MAF during 2010 and 2012 respectively.

Chaj
Maximum area of Chaj Doab falls in the category of 3-6 m, which is 41% of total area of Doab. The minimum area falls in the range of 13-18 m which is less than one percent i.e. 0.03%. In Chaj Doab no area falls in the range of greater than 18 m depth. To maintain the equilibrium of aquifer it is essential to recharge the aquifer by surplus surface water during flood season. In case of Chaj Doab it should be recharged from 9-13 m water table depth i.e. 3.73% of total area of whole Doab. The area of Chaj Doab is 41% in the range of 3 to 6 m depth. The recharge potential is 4.32 & 4.675 MAF during 2010 and 2012 respectively.

Rechna
It is noted that 42% area falls in the range of 3-6 m and 30% area falls in the range of 6-9 m and 5% area is in the range of 13-18 m depth in the canal command of Rechna Doab. These areas are mostly located in the lower parts of Rechna Doab. The recharge potential is 15.80 & 16.381 MAF during 2010 and 2012 respectively.

Bannu
In Bannu 41% area falls in the range of 9-18 m and 27% area falls in the range >18 m water table depth. The recharge potential in Bannu area is calculated as 10.84 MAF.

D. I. Khan
In D. I. Khan 40% area falls in the range of 9-18 m and 16% area is in the range of >18 m water table depth. The recharge potential in D. I. Khan area is calculated as 10.43 MAF.

4.2 RECOMMENDATIONS
To meet the challenge of irrigation water shortage, suitable surface and groundwater management techniques should be adopted by the farmers.

Programmes of artificial recharge to groundwater are immediately required to undertake the highly depleted areas throughout the country and it should be managed during the flood season.

In shallow groundwater areas, surface irrigation water allowance may be decreased to compensate the highly depleted areas by increasing surface water allowance.

An integrated programme should be formulated and implemented in depleted command areas for effective utilization of available water as well as developed infrastructure to recharge to groundwater.

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