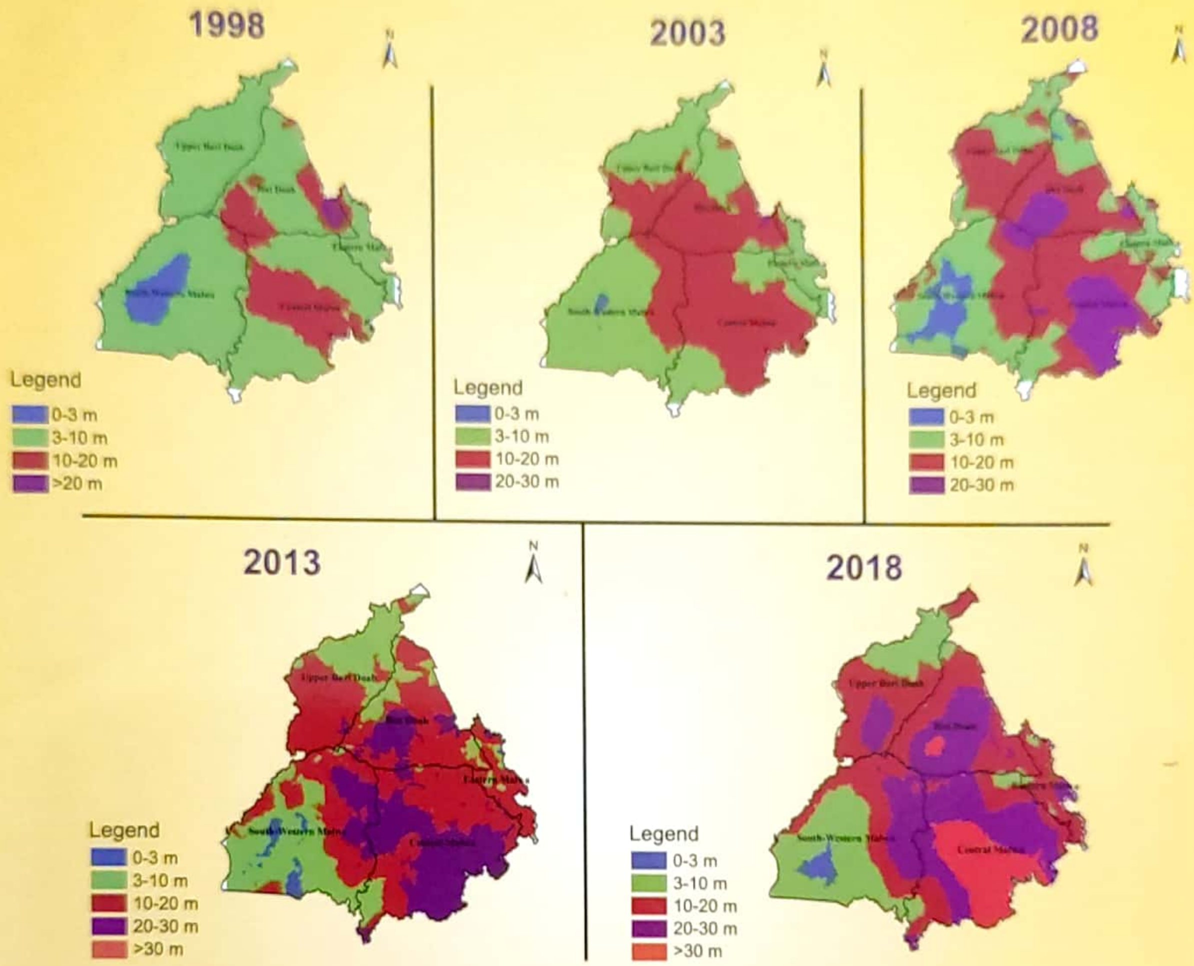
Groundwater Depletion in Punjab



PUNJAB AGRICULTURAL UNIVERSITY
LUDHIANA

GROUNDWATER DEPLETION IN PUNJAB

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PREFACE

Water is one of the most fundamental needs to sustain life. Punjab is one of the most developed states of India where more than 99 per cent area is irrigated through canals and tubewells, and productivity of major cereal crops like rice and wheat is at the highest level. Agriculture in the state is therefore heavily dependent on large amount of water. The advent and rapid spread of energized pumping technologies in Punjab has enabled speedy groundwater development, and emergence of land use and cropping systems dependent on its reliability.

The present publication provides long term groundwater behaviour of the state. The change maps derived in the bulletin help to identify regions experiencing sharpest decline of groundwater levels and should be taken on priority basis for management of groundwater resources. The water table behaviour is classified as ≤3 m, 3-10 m, 10-20 m, 20-30 m and more than > 30 m, which reflects depth of groundwater in time and space. The area under water table depth ≤3m is either waterlogged or prone to waterlogging.

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AUTHORS

Groundwater Depletion in Punjab

Punjab, having a geographical area of about 50,362 sq km, is divided into 22 districts and 145 blocks; it is predominantly an agrarian state (Figure 1). It is one of the most developed states of India where more than 99 per cent area is irrigated through canals and tubewells, and productivity of major cereal crops like rice and wheat is at the highest level. Agriculture in the state is therefore heavily dependent on large amount of water. The advent and rapid spread of energized pumping technologies in Punjab has enabled speedy groundwater development, and emergence of land use and cropping systems dependent on its reliability.

Punjab is a flat alluvial plain except a thin mountainous belt along the North-Eastern border and stable sand dunes are seen dotting the landscape in the South-Western parts. Slope of the plain is towards South and South-West which seldom exceeds 0.4 m/km.

There are three perennial rivers, namely, Sutlej, Beas and Ravi; and one non-perennial river Ghaggar in the state. These rivers feed a vast network of canal system and even provide water to Haryana, Rajasthan, and Jammu and Kashmir.

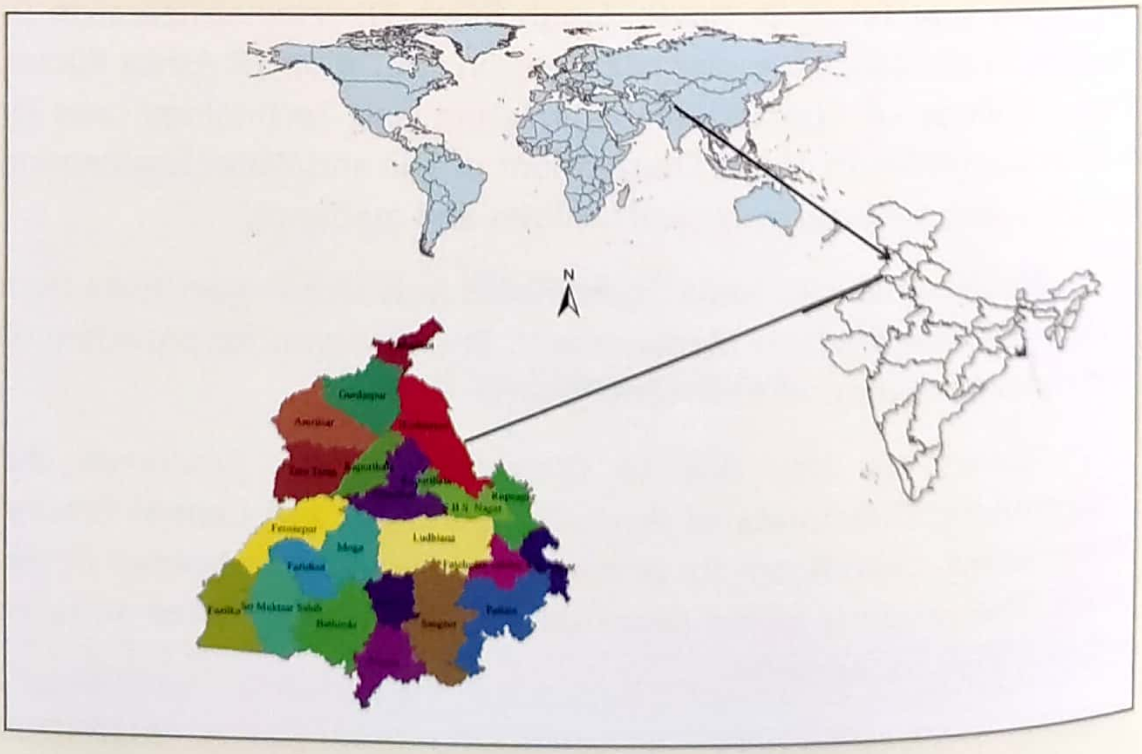


Figure 1: Location map of Punjab in India

Alluvial deposits in the state comprise sand, silt and clay often mixed with *kankar*. Sandy zones of varying grade constitute a vast ground cover reservoir. The alluvial plain towards the hills is bordered by the piedmont deposits comprising *Kandi* and Sirowal. The saturated sand, gravel or boulder beds constitute the aquifers.

Climate of the state is semi-humid to semi-arid in the North, arid in the South and South-West, and semi-arid in the remaining part of the state. Punjab experiences four seasons in the year, namely, winters from November to March, summers from April to June, South-West monsoon season from last week of June to mid of September and post-monsoon season from September to beginning of November.

There are two periods of rainfall in the state. South-West monsoon, the principle source of groundwater, sets in the last week of June and withdraws towards the end of September, and constitutes about 80 per cent of the annual average rainfall. Another period of rainfall is winter rain from December to March; it is about 20 per cent of the total rainfall which is mostly absorbed into the soil. However, the rainfall distribution in Punjab is erratic both in time and space. The annual rainfall in the state varies from about 1,000 mm in the North-East to less than 300 mm in the South-West. Areas to the North of Gurdaspur and near the Shivalik Hills receive maximum amount of rainfall, while the areas situated in the South-Western side of Punjab (Fazilka) receive minimum amount of rainfall. In the central part of the state, average long-term rainfall varies from 400 to 600 mm. The highest and the lowest annual average rainfall in the state for the year 2016 were recorded in Pathankot and Fazilka districts with 1,110 mm and 82 mm, respectively.

So, keeping in view wide range of agro-climatic conditions of the state, it is imperative to study the water resources especially when groundwater depletion is a major concern for sustainability of agriculture. About 85 per cent of the state's area is cultivated with cropping intensity of more than 204 per cent. In fact, 71.3 per cent area is irrigated by groundwater and 28.7 per cent area is irrigated by canal network. The canal network and topography map is shown in Figure 2.

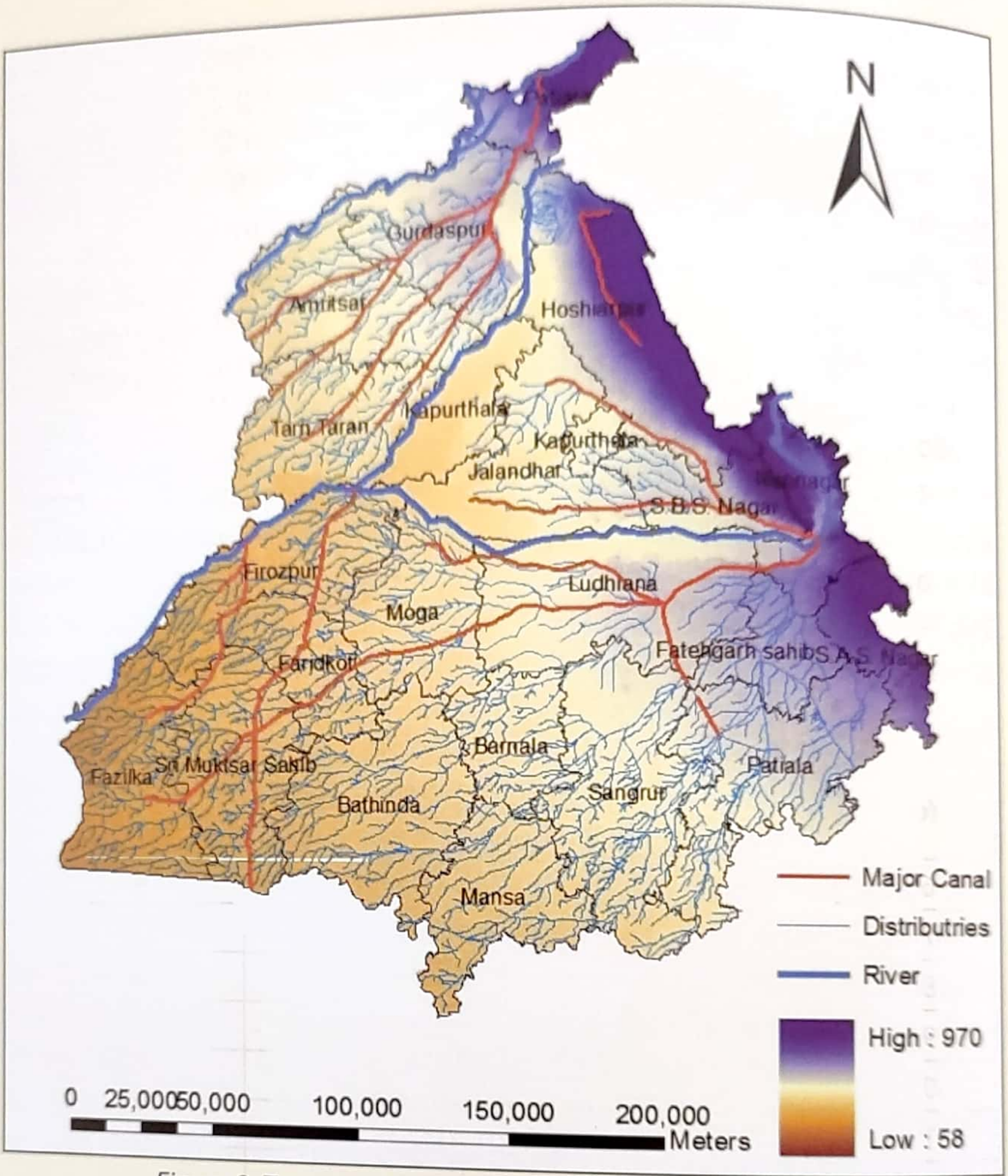


Figure 2: Topography, river and canal network in Punjab

Canal irrigation system in the state comprises Sirhind Canal, Bist Doab Canal, Bhakra Main Line (BML) Canal, Upper Bari Doab Canal, Kashmir Canal, Ferozepur Feeder/Sirhind Feeder, Eastern Canal, Makhu Canal, Shahnehar Canal and *Kandi* Canal System. It consists of 14,482 km channels in the shape of main/branch canals, distributaries and minors, out of which, 615 km length of channel was originally lined (http://www.pbirrigation.gov.in/OldVersion/lining admn.html accessed on dated February 10, 2016). The canal network is strong in South-West Punjab, medium in Central Punjab and weak in North-Eastern Punjab (Figure 2).

The share of area irrigated by canals decreased from 1.18 Mha (58.4%) during 1960-61 to 1.13 Mha (27.5%) during 2012-13 and the share of area irrigated by tubewells increased from 0.83 Mha (41.1%) during 1960-61 to 2.91 Mha (71.3%) during 2018-19 (Table 1). As per the perusal of Table 1, the area irrigated by groundwater increased drastically (almost double) during 1960-61 to 1970-71. Although area under canal irrigation also increased marginally, yet its percentage area decreased by 13.8 per cent. The area under irrigation increased in both the systems gradually between 1970-71 to 1990-91 with the predominance of groundwater irrigated area. But there was a big jump in the dependency of groundwater for irrigation between 1990-91 to 2000-01. In the next decade i.e. 2000-01 to 2010-11, there was a marginal increase in canal irrigated area and subsequently slight change during 2017-18. The canal irrigated area was 27.4 and 28.7 per cent during 2010-11 and 2017-18, respectively.

Table1: Area irrigated (Mha) by different sources in Punjab

Year	Canal		Groundwater (well and tubewell)	
	Area (Mha)	Area (%)	Area (Mha)	Area (%)
1960-61	1.18	58.4	0.83	41.1
1970-71	1.29	44.6	1.59	55.0
1980-81	1.43	42.3	1.94	57.3
1990-91	1.67	42.7	2.23	57.1
2000-01	0.96	23.8	3.07	76.1
2010-11	1.12	27.4	2.95	72.6
2017-18	1.17	28.7	2.91	71.3

*Numerals in parenthesis indicate percentages
Source: Statistical Abstracts of Punjab (2008 & 2018)

In the last six decades, the canal irrigated area decreased from 58.4 to 28 per cent, whereas, tubewell irrigated area increased from 41.1 to 71.3 per cent. Moreover, net irrigated area increased from 54 to 99.2 per cent. So, there is a lot of stress on water resources and groundwater in particular. This is evident from Table 2 and Figures 3 and 4. The number of over-exploited blocks jumped from 53 to 109 from 1984 to 2017, whereas, the number of safe blocks slipped from 36 to 22 only. The blocks are classified as over-exploited, critical, semi-critical and safe blocks where the groundwater extraction is more than 100, 90-100, 70-90 and <70 per cent, respectively of annual extractable groundwater resources. If 50 per cent or more area of the block under water table depth is less than 5 m, then that block is considered to be safe even if groundwater withdrawal is more than 70 per cent. The perusal of Table 3 reveals that in many districts, all the blocks are over-exploited; these districts are Amritsar, Tarn Taran, Ferozepur, Faridkot, Ludhiana, Fatehgarh Sahib, Barnala, Patiala, Kapurthala, Moga, Jalandhar and Sangrur. Sri Muktsar Sahib is the only district in Punjab in which all the blocks are in safe category; rest of the blocks in different districts show mixed trend. In the state; Fazilka, Dina Nagar, Gidderbaha, Bamyal and Narot Jaimal Singh have groundwater withdrawal of more than 100 per cent but 50 per cent or more of the block area is under water table depth less than 5 m; so their level in whole of the block is less than 5 m which is considered under safe category.

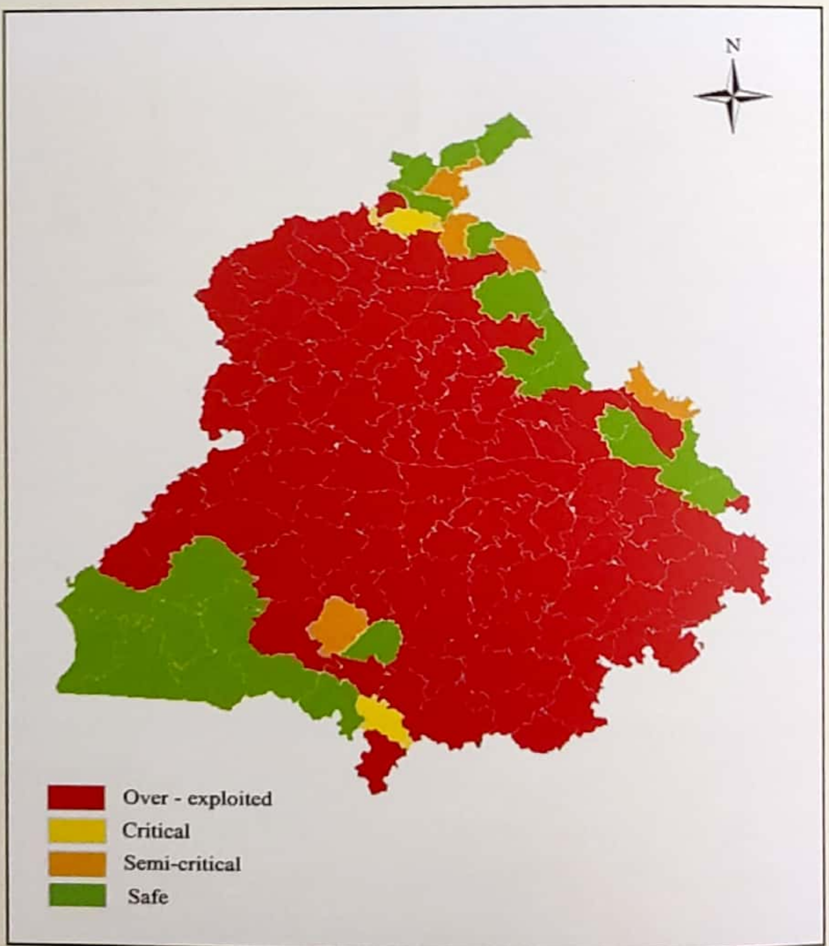


Figure 3: Categorisation of different blocks in Punjab map

Table 2: Categorisation of blocks under different years

Year / Category	1984	1986	1989	1992	1999	2004	2009	2011	2013	2017
Over-exploited	53	55	62	63	73	103	110	110	105	109
Critical	7	9	7	7	11	5	3	4	4	2
Semi-critical	22	18	20	15	16	4	2	2	3	5
Safe	36	36	29	33	38	25	23	22	26	22
Total	**118**	**118**	**118**	**118**	**138**	**137**	**138**	**138**	**138**	**138**

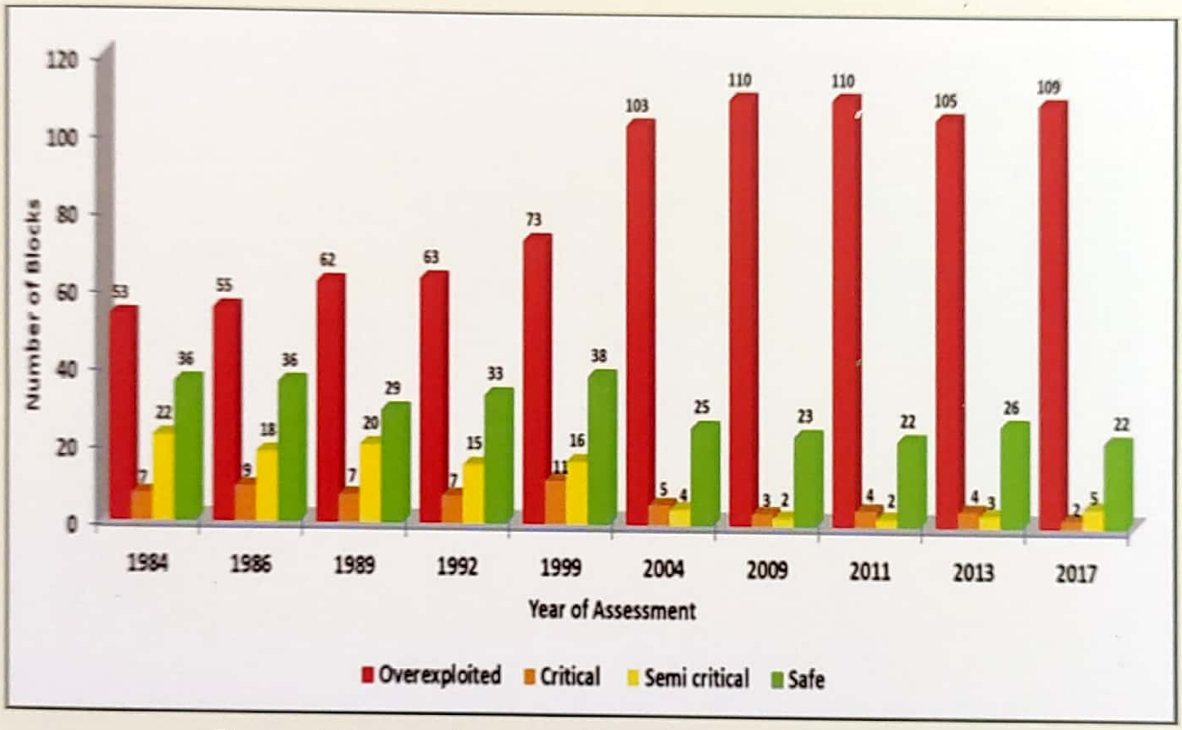


Figure 4: Categorisation of blocks between 1984-2017

Table 3: Groundwater extraction (%) and classification of different blocks in Punjab

District	Block	Groundwater extraction (%)	Category
Pathankot	Bamyal	105	Safe
	Dhar Kalan	24	Safe
	Pathankot	81	Semi-critical
	Narot Jaimal Singh	107	Safe

Gurdaspur	Batala	171	Over-exploited
	Dina Nagar	101	Safe
	Fatehgarh Churian	144	Over-exploited
	Gurdaspur	93	Critical
	Kahnuwan	137	Over-exploited
	Kalanaur	141	Over-exploited
	Qadian	143	Over-exploited
	Sri Hargobindpur	129	Over-exploited
	Dera Baba Nanak	151	Over-exploited
	Dhaliwal	130	Over-exploited
Amritsar	Ajnala	178	Over-exploited
	Chogawan	133	Over-exploited
	Harsha China	124	Over-exploited
	Jandiala	196	Over-exploited
	Majitha	120	Over-exploited
	Rayya	168	Over-exploited
	Tarsika	174	Over-exploited
	Verka	123	Over-exploited
Tarn Taran	Bhikhiwind	139	Over-exploited
	Chola Sahib	141	Over-exploited
	Gandiwind	134	Over-exploited
	Khadur Sahib	164	Over-exploited
	Naushehra Panuan	177	Over-exploited
	Patti	177	Over-exploited
	Tarn Taran	147	Over-exploited
	Valtoha	163	Over-exploited
Hoshiarpur	Hoshiarpur-2	68	Safe
	Bhunga	70	Safe
	Dasuya	123	Over-exploited
	Garhsahnkar	131	Over-exploited
	Hazipur	69	Safe
	Hoshiarpur-1	147	Over-exploited

Hoshiarpur	Mahilpur	70	Safe
	Mukerian	86	Semi-critical
	Talwara	81	Semi-critical
	Tanda	183	Over-exploited
Kapurthala	Nadala	198	Over-exploited
	Dhilwan	217	Over-exploited
	Kapurthala	201	Over-exploited
	Phagwara	281	Over-exploited
	Sultanpur Lodhi	223	Over-exploited
Jalandhar	Adampur	190	Over-exploited
	Bhogpur	279	Over-exploited
	Rurka Kalan	211	Over-exploited
	Jalandhar-east	316	Over-exploited
	Jalandhar-west	213	Over-exploited
	Lohian	266	Over-exploited
	Nakodar	277	Over-exploited
	Nur Mahal	218	Over-exploited
	Phillaur	206	Over-exploited
	Shahkot	266	Over-exploited
Nawanshaher	Aur	177	Over-exploited
	Balachaur	63	Safe
	Banga	150	Over-exploited
	Nawanshaher	108	Over-exploited
	Saroya	66	Safe
Ludhiana	Dehlon	208	Over-exploited
	Doraha	121	Over-exploited
	Jagraon	156	Over-exploited
	Khanna	251	Over-exploited
	Ludhiana	275	Over-exploited
	Machhiwara	119	Over-exploited
	Mangat	174	Over-exploited
	Pakhowal	210	Over-exploited
	Raikot	256	Over-exploited

Ludhiana	Samrala	225	Over-exploited
	Sidhwan Bet	185	Over-exploited
	Sudhar	163	Over-exploited
Barnala	Barnala	255	Over-exploited
	Mahal Kalan	177	Over-exploited
	Sehna	185	Over-exploited
Sangrur	Ahmedgarh	275	Over-exploited
	Andana	271	Over-exploited
	Bhiwanigarh	251	Over-exploited
	Dhuri	320	Over-exploited
	Lehraghaga	222	Over-exploited
	Malerkotla	198	Over-exploited
	Sangrur	285	Over-exploited
	Sherpur	254	Over-exploited
	Sunam	299	Over-exploited
Patiala	Bhuner Heri	231	Over-exploited
	Ghanaur	160	Over-exploited
	Nabha	160	Over-exploited
	Patiala	228	Over-exploited
	Rajpura	211	Over-exploited
	Samana	284	Over-exploited
	Sanaur	250	Over-exploited
	Patran	368	Over-exploited
Fatehgarh Sahib	Khera	210	Over-exploited
	Sirhind	213	Over-exploited
	Amloh	206	Over-exploited
	Bassi Pathana	207	Over-exploited
	Khamanon	199	Over-exploited
Ropar	Anandpur Sahib	80	Semi-critical
	Chamkaur Sahib	212	Over-exploited
	Morinda	178	Over-exploited
	Nurpur Bedi	109	Over-exploited
	Ropar	47	Safe

Mohali	Dera Bassi	147	Over-exploited
	Kharar	119	Over-exploited
	Sialba Majri	58	Safe
Ferozepur	Ferozepur	132	Over-exploited
	Ghall Khurd	198	Over-exploited
	Guru Har Sahai	117	Over-exploited
	Makhu	149	Over-exploited
	Mamdot	154	Over-exploited
	Zira	259	Over-exploited
Moga	Bagha Purana	178	Over-exploited
	Dharamkot (Kot Isa Khan)	211	Over-exploited
	Moga-1	283	Over-exploited
	Moga-2	286	Over-exploited
	Nihal Singh Wala	277	Over-exploited
Faridkot	Faridkot	169	Over-exploited
	KotKapura	165	Over-exploited
Sri Muktsar Sahib	Gidderbaha (Kot Bhai)	105	Safe
	Lambi	45	Safe
	Malout	64	Safe
	Muktsar	85	Safe
Fazilka	Abohar	38	Safe
	Fazilka	155	Safe
	Jalalabad	150	Over-exploited
	Khuyian Sarwar	56	Safe
Bathinda	Phul	184	Over-exploited
	Nathana	73	Semi-critical
	Maur	127	Over-exploited
	Bathinda	103	Over-exploited
	Talwandi Saboo	65	Safe
	Sangat	67	Safe
	Rampura	69	Safe

Mansa	Bhikhi	125	Over-exploited
	Budhlada	188	Over-exploited
	Jhunir	99	Critical
	Mansa	123	Over-exploited
	Sardulgarh	193	Over-exploited
	Talwandi Saboo	65	Safe
	Sangat	67	Safe
	Rampura	69	Safe

From the presented facts, it is clearly evident that the water table is declining in almost the entire state. There is a need to study the water table behaviour in time and space. For this purpose, the pre-monsoon (June) data on groundwater levels was procured from Water Resources and Environment Directorate, Punjab; and Directorate of Agriculture and Central Ground Water Board (CGWB) to study groundwater behaviour in Punjab for a period of 20 years (1998-2018). The pre-monsoon levels are considered to be more stable than post-monsoon as the effect of rainfall diminishes during this period.

The Geographical Information System (GIS) is one of the important tools for integrating and analyzing spatial information from different sources or disciplines. The groundwater maps were prepared for different years from the observation well/piezometer data. The groundwater maps were classified and then analyzed for 0-3 m, 3-10 m, 10-20 m, 20-30 m and beyond 30 m. Classification was done based on the fact that the areas with water table depth between 0-3 m are prone to waterlogging or waterlogged, water table depth between 3-10 m is suitable for installation of centrifugal pump (which is economical and efficient pump for groundwater abstraction), water table beyond 10 m depth is critical limit for shifting from centrifugal to submersible pump, beyond 20 m water table is deep and beyond 30 m water table is very deep. These maps were useful to visualize groundwater behaviour and determine areas of greatest changes in storage in the regional systems. Finally, the changes in water table were analyzed district wise from these maps.

The average water table depth of Punjab state was 6.8 m in 1998 and 17.6 m in 2018, thus, indicating an average annual fall of 53.6 cm/

year. The reclassified water table maps are shown in Figures 6 to 11. Based on Figures 6 to 11, the analysis of area under different water table depths was computed and the groundwater scenario is presented in Table 5. A perusal of these indicates that during a span of 20 years, the area susceptible to waterlogging or waterlogged reduced from 355.6 '000 ha to 74.5 '000 ha i.e. net decrease by 281.1 '000 ha, but it is also evident from the figures and Table 5 that the area under water table depth < 3 m has a fluctuating trend. The waterlogged area in the state was less than 150'000 ha in 2003, 2004, 2005, 2013 and 2018, whereas, it was maximum in 2011 with 471.4'000 ha. The area under water table depth of 3-10 m reduced from 3,434.6 to 1,08,808 '000 ha and the area under water table depth of 10-20 m increased from 1,230.2 to 1,819.8 '000 ha, indicating a fall of groundwater beyond critical limit of 10 m, which occurred mostly in areas that were earlier under the safe limit i.e. 3-10 m. The area under 20-30 m saw a jump from 9.6 to 1,506.8 '000 ha during the study period. In 1998, there was no area beyond groundwater depth of 30 m but it had shown its presence in 2009 in 0.6'000 ha and further increase to 540.6 '000 ha.

District wise analysis was also carried out to identify the worst affected and least affected districts and the results are presented in Table 4. The analysis revealed that the mean water table depth of 10 m or greater was observed in only two districts *viz.* Jalandhar and Sangrur in 1998 and all other districts were in the safe limit (<10 m). However, in 2018, except for four districts *viz.* Faridkot, Ferozepur, Gurdaspur and Muktsar, all other districts showed water table depth of more than 10 m. The district Muktsar is situated in the command area of Indira Gandhi Canal and farmers are using canal water rather than groundwater for irrigation as groundwater quality is brackish in this area. The district Gurdaspur is characterized by high rainfall and undulating topography due to which water table behaviour is erratic; this makes exploitation of groundwater uneconomical for the individual farmer.

Worst affected districts were also identified which comprise Sangrur, Barnala and Patiala having an annual fall rate of 106.5, 103.3 and 100.2 cm, respectively. In SAS Nagar, Fatehgarh Sahib, Jalandhar, Tarn Taran and Ludhiana, the water table is falling annually at the rate of 59.8, 70.4, 68.4, 56.7 and 56.1 cm, respectively. In general, all the districts lying in center of the state are experiencing declining water table at higher rate as compared to districts in the North-East and South-West. The districts lying in the South-West Punjab are experiencing comparatively least water table declining rate due to their poor quality.

Further, depending on the availability of surface water resources (river or canal water) and water table behaviour, the state can be divided into five zones, namely, Bist Doab, Eastern Malwa, Central Malwa, South-Western Malwa and Upper Bari Doab (as shown in Figure 5).

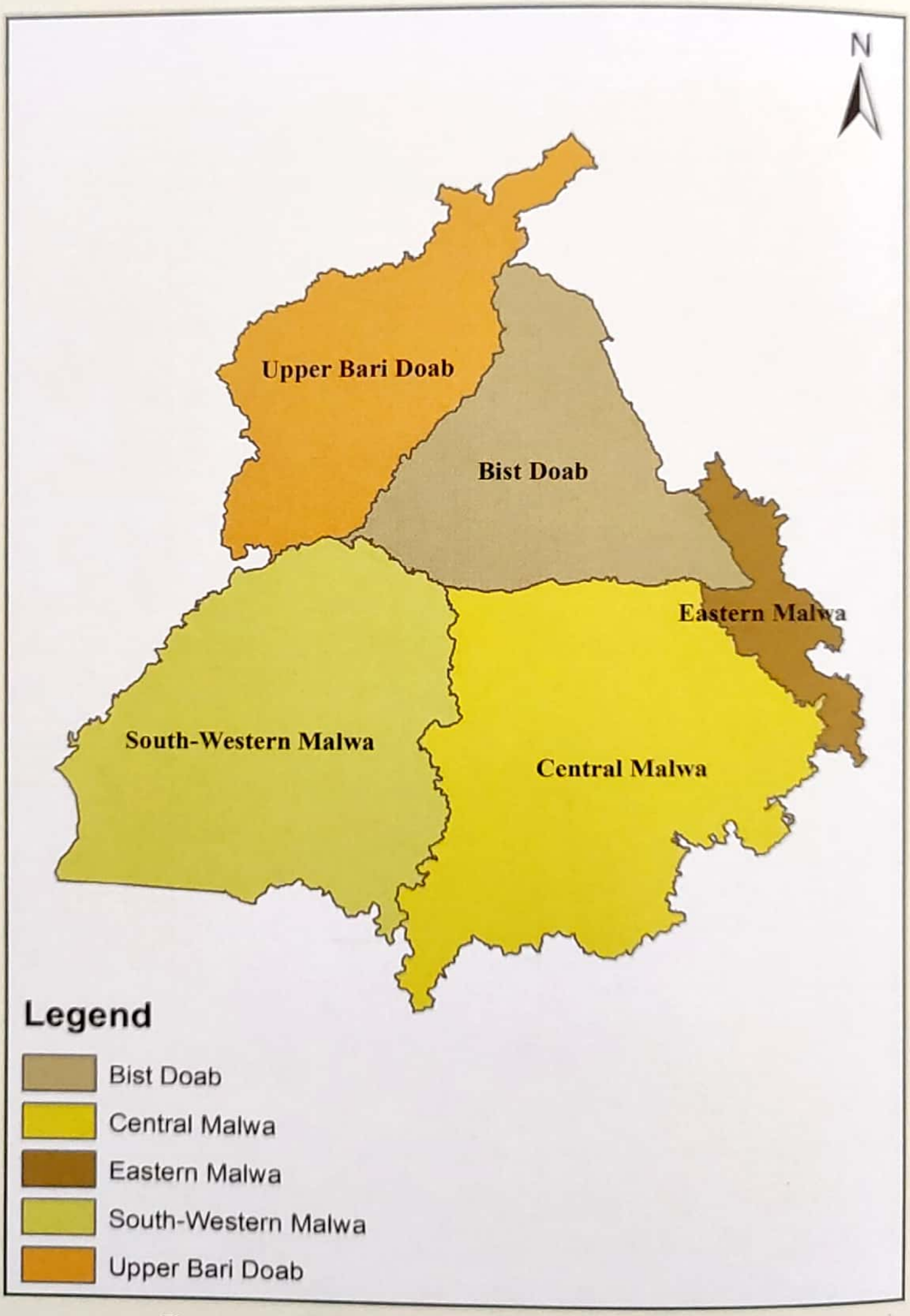


Figure 5: Demarcation of five zones in Punjab

Table 4: Mean water table depth (m) and average annual rise/fall (m/year) of different districts during 1998-2018

District	Mean water table depth (m)																					Average fall rate (cm/ year)
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Amritsar	6.4	6.9	7.8	8.4	8.9	9.5	9.6	10.1	10.6	10.7	10.8	10.4	12.7	13.1	11.3	13.1	13.4	13.9	13.9	14.6	15.0	42.9
Barnala	9	8.9	9.5	10.7	11.8	12.7	13.4	14.3	14.8	16	17.1	18	18.9	19.4	19.6	23	25.1	26.5	27.8	28.5	29.7	103.3
Bathinda	7.7	7.3	7.7	8.2	8.9	9.5	9.3	10	10.1	10.5	10.9	11.2	11.3	11.4	11.7	12.9	12.7	13.4	13.8	14.3	14.8	35.6
Faridkot	3.9	3.8	4.5	4.9	5.4	5.7	6	6.3	6.2	6.2	6.2	6.4	7	7.2	7.6	7.8	8	7.9	7.6	8.2	9.6	28.5
Fatehgarh Sahib	7.4	7	7.5	8.2	8.7	9.6	10.1	10.8	11.5	12.4	13.1	12.7	17.2	17	16.8	18.1	19.2	20.3	20.7	22.0	21.5	70.4
Ferozepur	5.4	5.1	5.5	5.9	6.5	7	7.1	7.5	7.5	7.3	7.1	7.1	5.2	4.8	8.6	9.4	8.2	8.3	7.5	8.5	9.3	19.3
Gurdaspur	7.1	7.6	7.9	8.3	8.4	8.8	8.5	8.8	9.2	8.8	8.9	8.3	9.2	9.3	9.1	8.2	7	6.7	8.3	8.8	8.6	7.3
Hoshiarpur	6.2	6	6.2	6.6	7	7.8	8.1	9.1	9.8	9.9	10.8	10.2	12.6	12.7	10.3	13.8	14.1	14.5	17.5	13.5	18.1	59.5
Jalandhar	10.6	10.7	11.6	13	13.8	14.7	15.8	16.9	17.4	17.7	17.7	17.1	18.3	18.1	18.7	20	20.5	20.9	20.9	22.7	24.3	68.4
Kapurthala	9.5	10	10.5	11.7	12.5	13.4	14.5	15.5	15.9	15.9	16.1	15.7	13	14.5	14.6	14.4	14.2	14.8	15.3	16.5	18.9	47.2
Ludhiana	9.4	9.1	9.2	10.3	10.9	11.8	12.4	12.9	13.9	14.6	14.9	14.9	16.8	16.6	14.8	15.2	16.6	17.8	18.3	18.7	20.6	56.1
Mansa	4.8	4.5	5.6	5.9	6.5	7.4	7	7.9	8.5	8.6	9.1	9.2	9.7	9.7	9.6	9.9	11.2	11.9	14.3	13.5	16.3	57.3
Moga	7.2	7.6	8.4	9.5	10.9	11.9	12.8	13.8	14	15.1	15.6	16.1	17.4	17.7	19.3	21.6	21.3	21.8	22.6	23.8	21.8	73.1
SBS Nagar	8.1	7.3	8.2	8.8	9.1	10	10.6	11.1	11.8	12.3	13.2	12.9	15.1	14.2	11.9	12.4	14.8	14.4	16.4	16.9	16.1	40.2
Patiala	9.2	8.9	11	10.7	11.4	12.7	13.4	14.1	14.8	15.7	16.7	16.5	17.1	16.7	21.2	22	23.2	24.3	27.7	28.3	29.2	100.2
Rupnagar	4.6	4.7	5.3	5.5	5.9	6.5	6.6	6.7	6.9	7.4	7.4	7.4	9.1	8.2	6.9	7	9.4	11.3	11.6	12.3	13.1	42.5
Sangrur	11.1	10.9	12	13.1	14.2	15.3	16.2	17.4	18.5	19.6	20.9	21.6	20.9	20.9	21.9	24.6	26.4	27.5	29.7	31.7	32.4	106.5
Muktsar	3.7	3.4	3.5	3.5	3.6	3.9	3.7	3.9	3.5	3.3	2.9	2.8	3.2	2.9	3.6	4.2	3.1	3.5	3.3	3.7	4.0	1.3
SAS Nagar	5.4	5.1	6.1	6.6	7.1	7.5	7	7	7.4	7.9	7.8	7.2	9.8	8.8	10.7	14.5	15.1	17.3	21	20.7	17.4	59.8
Tarn Taran	7	6.9	7.8	8.5	9.4	10.6	11.3	12.1	12.2	11.9	12.1	11.9	11.5	12.1	14	14.4	14.8	15.3	16.7	18.5	18.3	56.7
Punjab	6.8	6.7	7.4	8.0	8.6	9.3	9.6	10.2	10.6	11.0	11.3	11.3	12.3	12.1	12.7	14.0	14.6	15.5	16.6	17.1	17.6	53.6

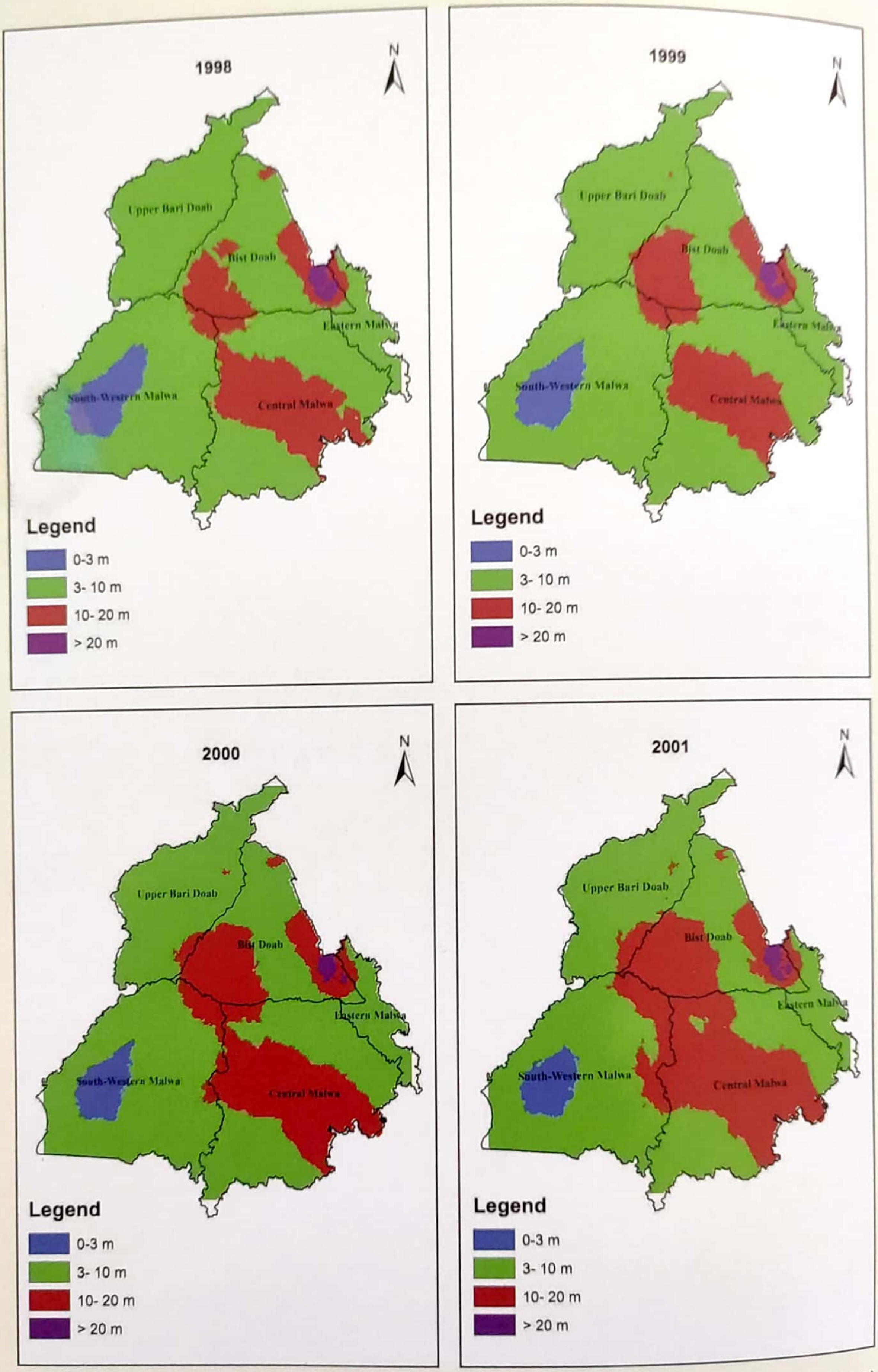


Figure 6: Water table behaviour of Punjab state for the study period (1998 to 2001)

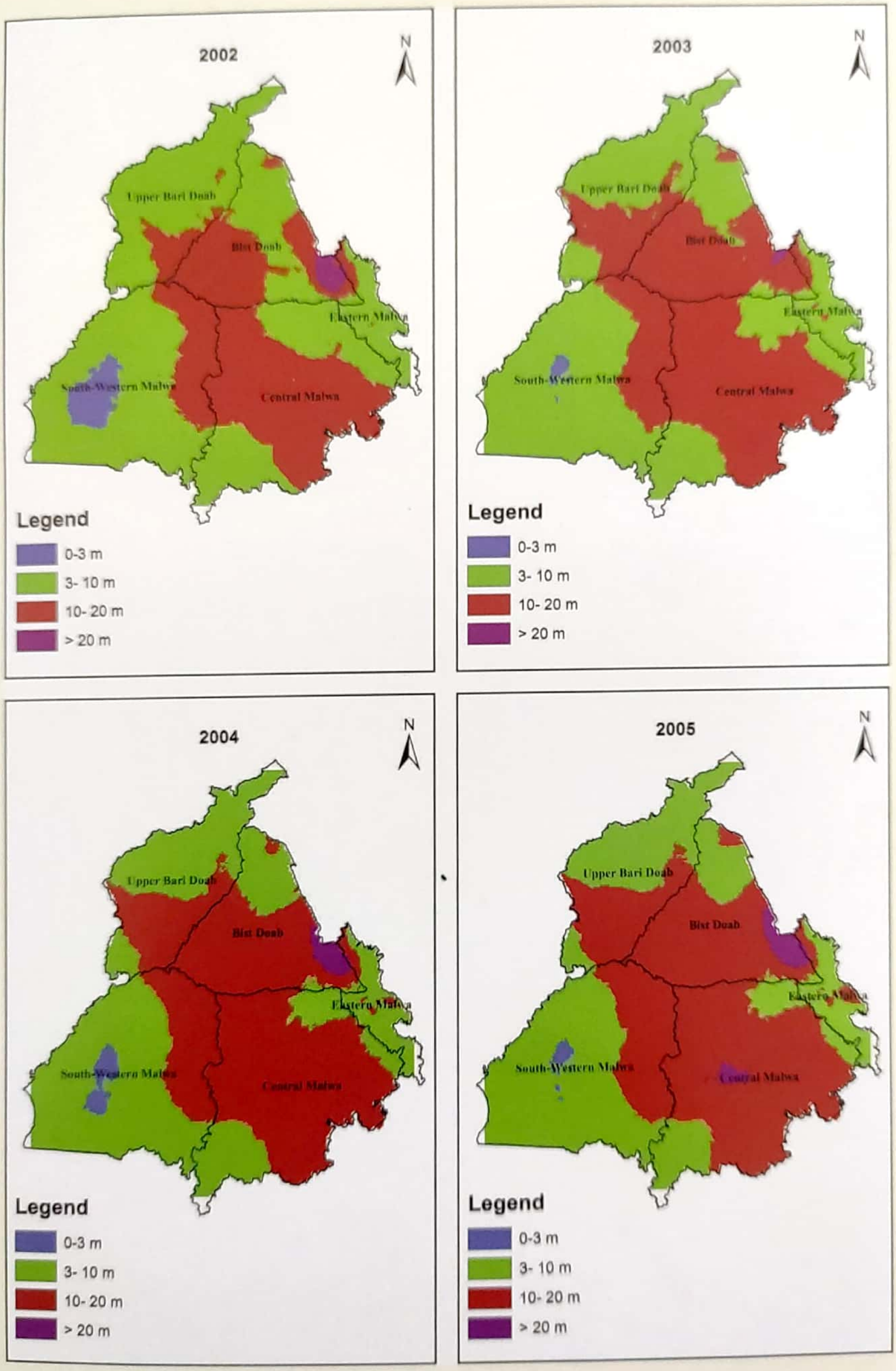


Figure 7: Water table behaviour of Punjab state for the study period (2002-05)

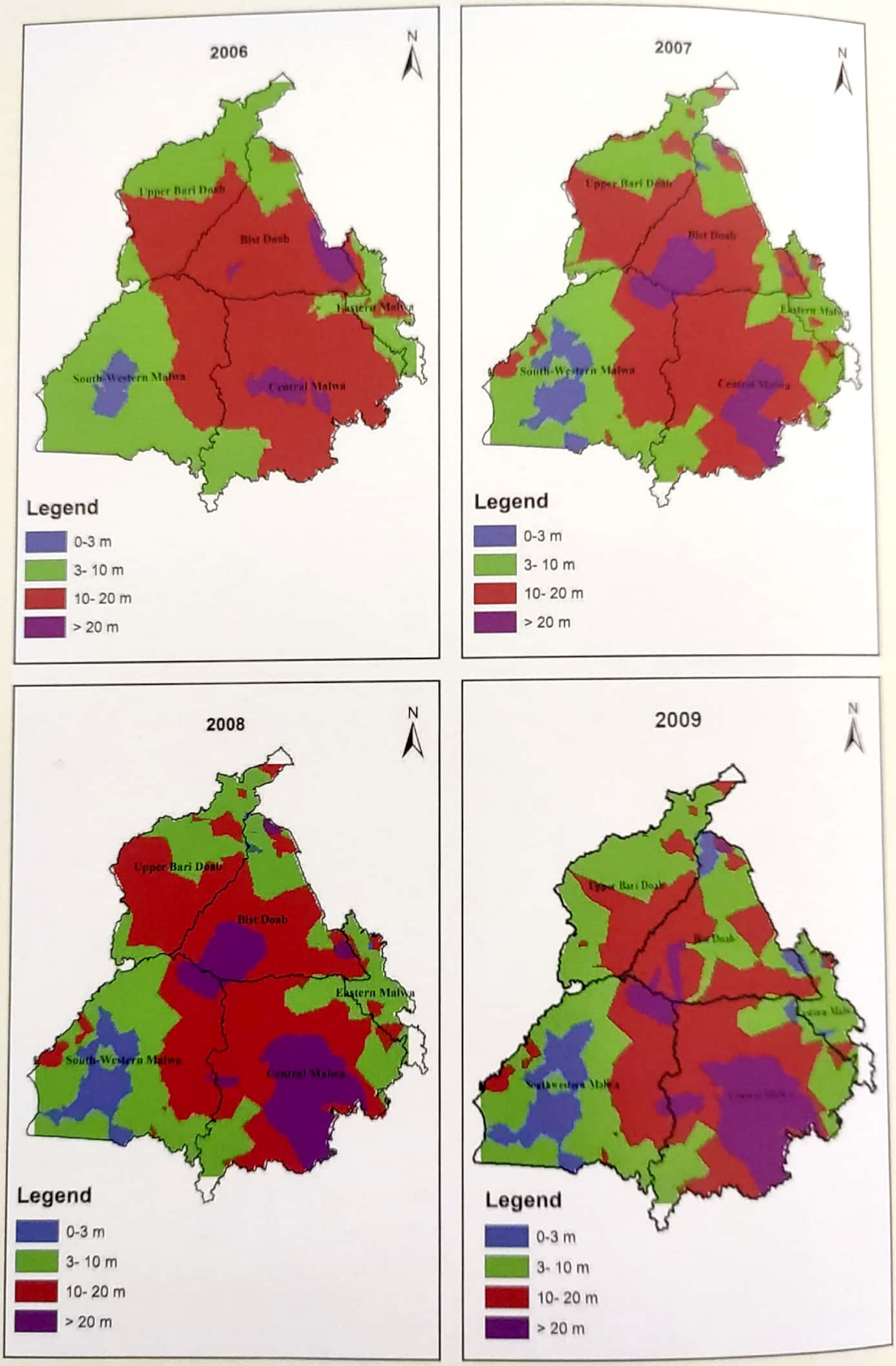


Figure 8: Water table behaviour of Punjab state for the study period (2006-09)

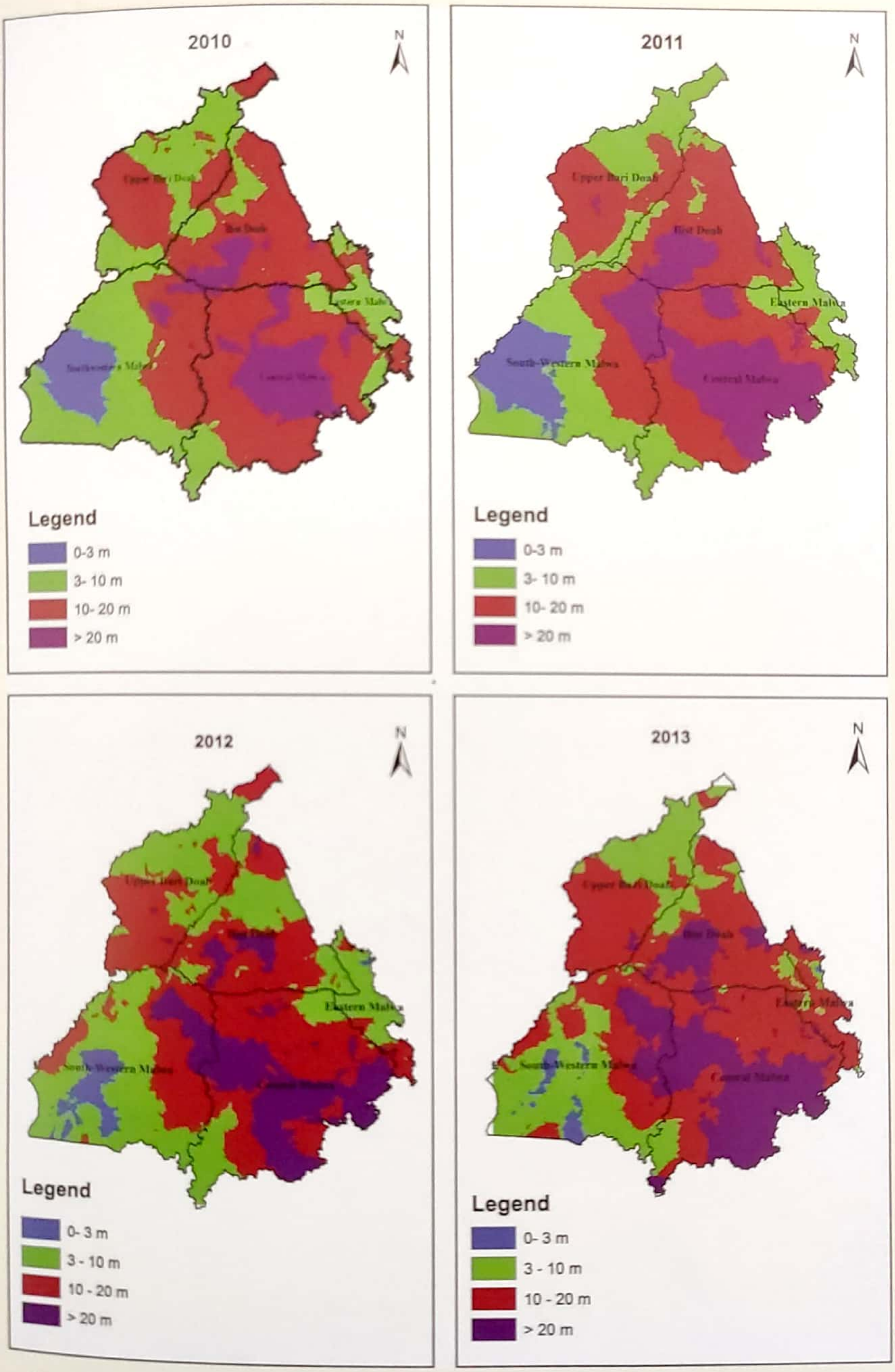


Figure 9: Water table behaviour of Punjab state for the study period (2010-13)

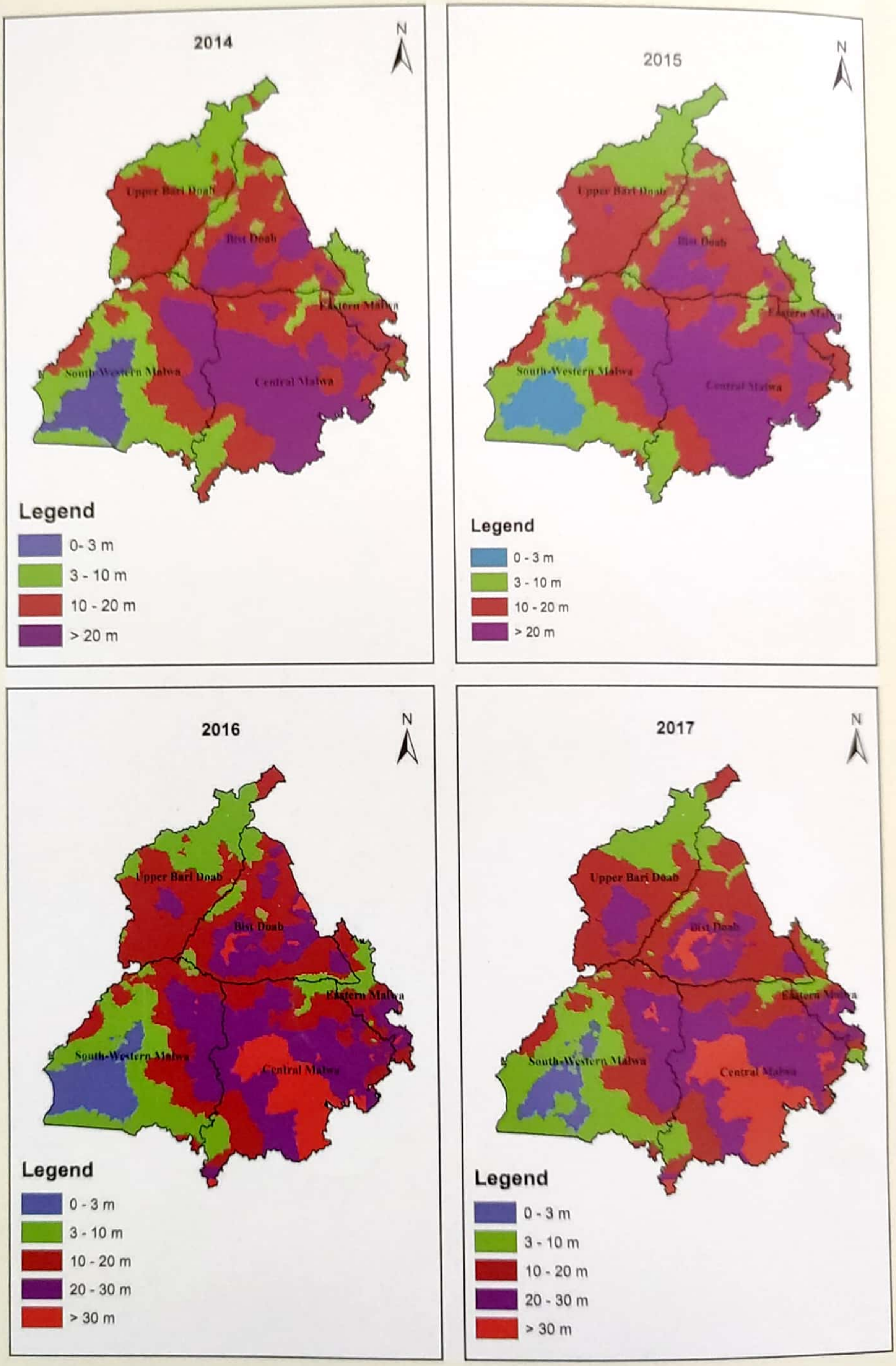


Figure 10: Water table behaviour of Punjab state for the study period (2014-17)

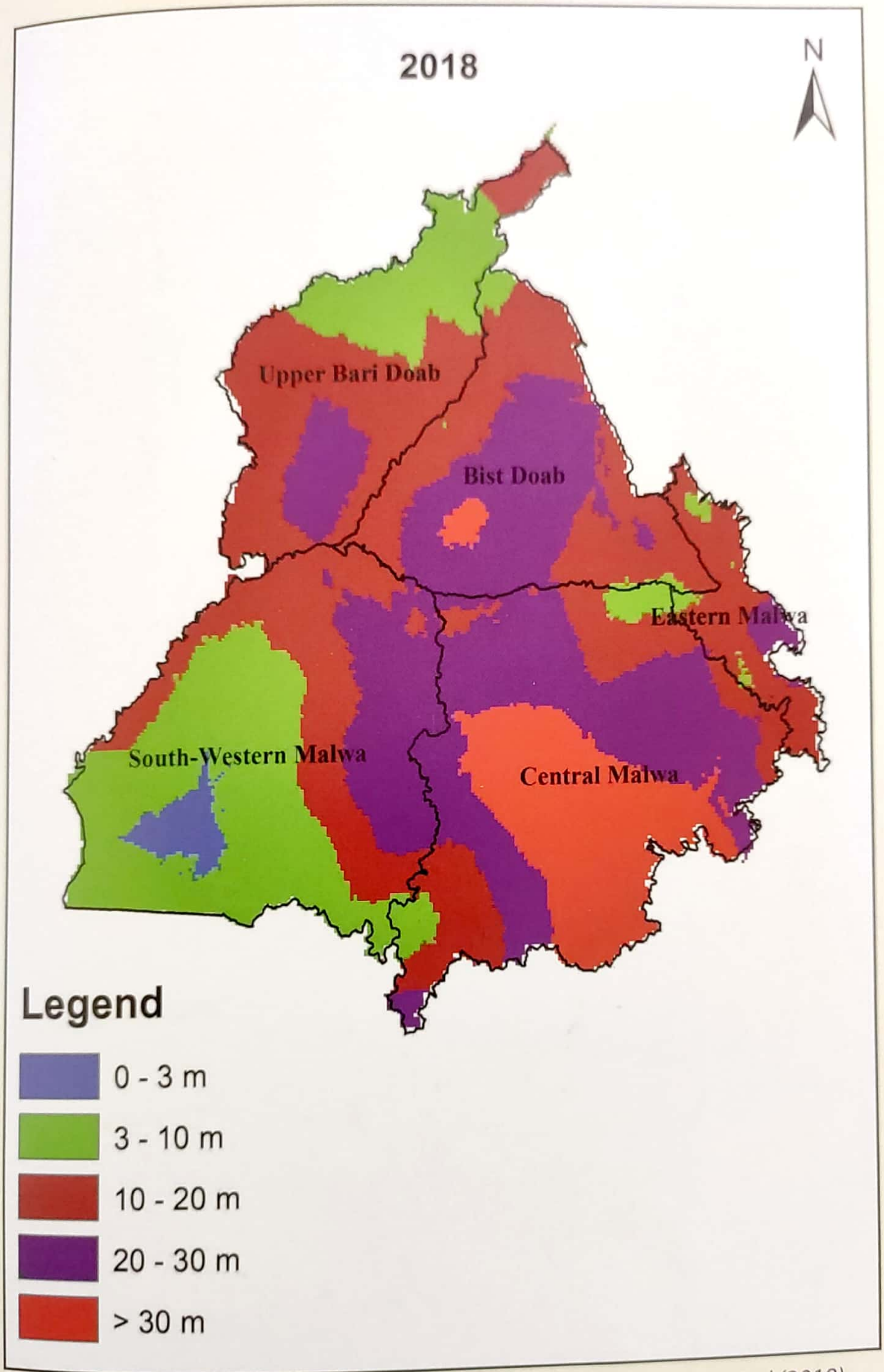


Figure 11: Water table behaviour of Punjab state for the study period (2018)

Table 5: Area ('000 ha) under different water table depths (m)

Year/Area	0-3 m	3-10 m	10-20 m	20-30 m	>30 m
1998	355.6	3,434.6	1,230.2	9.6	0.0
1999	338.9	3,571.7	1,109.5	9.9	0.0
2000	246.1	3,492.9	1,279.5	11.5	0.0
2001	218.2	3,216.5	1,585	10.3	0.0
2002	193.1	2,887.6	1,878.1	71.24	0.0
2003	132.8	2,635.3	2,150.7	111.3	0.0
2004	138.6	2,511.4	2,160.1	219.9	0.0
2005	122.9	2,292.5	2,334.4	280.2	0.0
2006	175.6	2,195.3	2,315.4	343.7	0.0
2007	230.7	2,055.1	2,328.4	415.8	0.0
2008	273.3	1,964.1	2,166.6	626.5	0.0
2009	265.7	2,039.4	2,031.8	693.1	0.0
2010	331.7	1,920.8	1,931.1	846.4	0.6
2011	471.4	1,809.5	1,870.3	869.4	9.4
2012	192.3	1,848.2	2,122	860.2	7.5
2013	133.1	1,449.3	2,359.5	1,043.1	45.5
2014	257.5	1,300.6	2,190.4	1,216.4	65.5
2015	224.7	1,188.1	2,185.1	1,346.3	86.3
2016	304.1	1,143.4	1,845.0	1,332.3	405.7
2017	181.1	1,178.1	1,862.7	1,298.1	510.4
2018	74.5	1,088.8	1,819.8	1,506.8	540.6

Bist Doab comprises Hoshiarpur, Kapurthala, Jalandhar and Shaheed Bhagat Singh (SBS) Nagar; Eastern Malwa comprises Rupnagar and Sahibzada Ajit Singh Nagar (SAS) Nagar; Central Malwa comprises Ludhiana, Barnala, Sangrur, Patiala and Fatehgarh Sahib; South-Western Malwa comprises Ferozepur, Moga, Faridkot, Sri Muktsar Sahib, Fazilka, Bathinda and Mansa; and Upper Bari Doab comprises Pathankot, Gurdaspur, Amritsar and Tarn Taran.

The analysis of all the maps, presented in the Figures 6 to 11 for the years 1998 to 2018, was made for all the regions and is shown in the Table 6 and Figures 12 to 17. The analysis has been discussed in the following sub-head:

Bist Doab: The perusal of Table 6 and Figures 12 to 16 reveals that in Bist Doab region, the area under water table depth less than 3 m remained zero during the study period (1998-2018) except in the years 2007 and 2009 with an area of 0.01 and 0.05 Mha, respectively. The area under water table depth 3-10 m decreased from the years 1998 to 2006 continuously from 0.56 to 0.15 Mha; then it fluctuated between the years 2007-12 with area ranging from 0.14 Mha to 0.32 Mha; after that it again started decreasing till 2018 and it was 0.03 Mha only which is just negligible. The range of area between water table depths 3-10 m was 0.56 to 0.03 Mha. The area under water table depth 10-20 m increased from the years 1998 to 2003 from 0.30 Mha to 0.64 Mha; then it fluctuated between the years 2004-12 with area ranging from 0.42 to 0.66 Mha. The area under water table depth 20 -30 m fluctuated between the range 0.01 to 0.42 Mha. The area above 30 m depth remained zero till 2013, after that it increased steadily from 0.01 to 0.05 Mha till 2017 and it was 0.02 Mha in 2018. The perusal of Table 7 and Figure 17 reveals that mean water table depth of this region varied from 8.31 to 19.79 m with an average decline rate of 0.57 m annually.

Eastern Malwa: The perusal of Table 6 and Figures 12 to 16 reveals that in Eastern Malwa region, the area under water table depth less than 3 m remained zero during the study period (1998-2018) except in the year 2009 with an area of 0.01 Mha. So in this region, waterlogging problem is almost negligible. The area under water table depth 3-10 m remained constant from 1998 to 2003 i.e. 0.20 Mha. In 2013, it decreased sharply to 0.03 Mha. After that from 2014-18, it reduced gently from 0.11 to 0.02

Mha except in 2017, when it increased marginally from 0.16 to 0.17 Mha as compared to the previous year i.e. 2016. The area under water table depth 10-20 m remained constant from the years 1998 to 2002 i.e. 0.02 Mha. Thereafter, it varied from marginally 0.03 to 0.09 Mha during the years 2003-12. During 2013-18, it fluctuated between 0.09 to 0.20 Mha. The area under water table depth 20-30 m remained zero during the years 1998-2014 except in the years 2006, 2013 and 2014 with an area of 0.01Mha. After 2014 i.e. from 2015-18, it fluctuated between 0.03 to 0.08 Mha. The area under water table depth more than 30 m remained zero during the study period 1998-2018 except in the year 2017 with an area of 0.01 Mha. The perusal of Table 7 and Figure 17 reveals that mean water table depth of this region varied from 4.89 to 16.21 m with an average decline rate of 0.51 m annually.

Central Malwa: The perusal of Table 6 and Figures 12 to 16 reveals that in Central Malwa region, the area under water table depth less than 3 m remained zero during the study period 1998-2018. So in this region, there is no waterlogging problem. The area under water table depth 3-10 m was 0.93 Mha in 1998; thereafter it decreased from 1.00 to 0.23 Mha during the period 1999 to 2006 but during the years 2007-13, this area fluctuated between 0.07 to 0.35 Mha. Also for water table depth 3-10 m during the years 2014 -18, the area under water table depth decreased gently from 0.13 to 0.06 Mha. The area under water table depth 10-20 m was 0.61 Mha in 1998; thereafter it increased from 0.54 to 1.23 Mha during the period of 1999 to 2005 but during the years 2006-18, the area decreased from 0.91 to 0.29 Mha except the year 2012. The area under water table depth 20-30 m remained zero during the years 1998-2004 but during the years 2005-09, it increased from 0.03 to 0.52 Mha; thereafter (2010 to 2018) this area fluctuated between 0.43 to 0.86 Mha. The area under water table depth more than 30 m remained zero during the study period 1998-2012, it was 0.15 Mha in 2013 and 0.11 Mha in 2014 and 2015; thereafter during 2016-18, it increased from 0.37 to 0.52 Mha. The perusal of Table 7 and Figure 17 reveals that mean water table depth of this region varied from 8.70 to 25.67 m with an average decline rate of 0.84 m annually. This region experienced maximum rate of declining groundwater and water table depths were also highest among all the five regions.

South-Western Malwa: The perusal of Table 6 and Figures 12 to 16 reveals that in South-Western Malwa region, the area under water table depth less than 3 m decreased from 0.24 to 0.02 Mha but remained fluctuating between 0.03 to 0.37 Mha during the rest of the period. The area under water table depth 3-10 m during the period 1998 to 2005 remained more than 1.00 Mha and fluctuated between 1.05 to 1.27 Mha; thereafter it remained less than 1.0 Mha and fluctuated between 0.56 to 0.97 Mha. The area under water table depth 10-20 m increased steadily from 0.04 to 0.48 Mha during 1998 to 2008 but it fluctuated between 0.37 to 0.51 Mha during rest of the period i.e 2009-18. The area under water table depth 20-30 m remained zero during the study period 1998-2006 and remained fluctuating between 0.01 to 0.07 Mha between 2007-10. It was 0.16 Mha in 2011; thereafter from 2012-18, it increased from 0.13 to 0.29 Mha. The area under water table depth more than 30 m remained zero during the study period 1998-2018. The perusal of Table 7 and Figure 17 reveals that mean water table depth of this region varied from 5.55 to 11.46 m with an average decline rate of 0.28 m annually. This region experienced minimum rate of declining groundwater and water table depths were also shallow among all the five regions.

Upper Bari Doab: The perusal of Table 6 and Figures 12 to 16 reveals that in Upper Bari Doab region, the area under water table depth less than 3 m remained zero during the study period 1998-2018. So in this region, there is no waterlogging problem like that in Central Malwa region. The area under water table depth 3-10 m during the period 1998 to 2006 decreased from 0.86 to 0.49 Mha; during 2007-09, it increased from 0.40 to 0.55 Mha; during 2010, 2011, 2012 and 2013, the area was 0.43, 0.42, 0.42 and 0.36 Mha respectively; whereas, during 2014-18, it again decreased from 0.37 to 0.25 Mha. The area under water table depth 10-20 m increased steadily from 0.00 to 0.46 Mha during 1998 to 2007 but it fluctuated between 0.31 to 0.52 Mha during rest of the period i.e. 2008-18. The area under water table depth 20-30 m remained zero during the study period 1998-2010 and in 2014, whereas, it remained 0.01 Mha during the years 2011-13 and 2015; thereafter in 2016, 2017 and 2018, it was 0.04, 0.12 and 0.11 Mha, respectively. So overall, the area under water table depth remained in narrow range in this region. The perusal of Table 7 and Figure 17 reveals that mean water table depth of this region varied from 6.87 to 13.35 m with an average decline rate of 0.32 m annually.

Table 6: Area (Mha) under different water table depths in different regions

Year	Region	0 - 3 m	3 - 10 m	10-20 m	20-30 m	> 30 m
1998	Bist Doab	0.00	0.56	0.30	0.04	0.00
	Central Malwa	0.00	0.93	0.61	0.00	0.00
	South-Western Malwa	0.24	1.24	0.04	0.00	0.00
	Eastern Malwa	0.00	0.20	0.02	0.00	0.00
	Upper Bari Doab	0.00	0.86	0.00	0.00	0.00
1999	Bist Doab	0.00	0.52	0.34	0.04	0.00
	Central Malwa	0.00	1.00	0.54	0.00	0.00
	South-Western Malwa	0.21	1.27	0.04	0.00	0.00
	Eastern Malwa	0.00	0.20	0.02	0.00	0.00
	Upper Bari Doab	0.00	0.86	0.01	0.00	0.00
2000	Bist Doab	0.00	0.46	0.41	0.03	0.00
	Central Malwa	0.00	0.82	0.71	0.00	0.00
	South-Western Malwa	0.17	1.25	0.10	0.00	0.00
	Eastern Malwa	0.00	0.20	0.02	0.00	0.00
	Upper Bari Doab	0.00	0.84	0.03	0.00	0.00
2001	Bist Doab	0.00	0.41	0.45	0.03	0.00
	Central Malwa	0.00	0.67	0.87	0.00	0.00
	South-Western Malwa	0.16	1.15	0.20	0.00	0.00
	Eastern Malwa	0.00	0.20	0.02	0.00	0.00
	Upper Bari Doab	0.00	0.80	0.06	0.00	0.00
2002	Bist Doab	0.00	0.38	0.47	0.04	0.00
	Central Malwa	0.00	0.57	0.97	0.00	0.00
	South-Western Malwa	0.14	1.07	0.30	0.00	0.00
	Eastern Malwa	0.00	0.20	0.02	0.00	0.00
	Upper Bari Doab	0.00	0.75	0.12	0.00	0.00

2003	Bist Doab	0.00	0.25	0.64	0.01	0.00
	Central Malwa	0.00	0.42	1.12	0.00	0.00
	South-Western Malwa	0.02	1.14	0.35	0.00	0.00
	Eastern Malwa	0.00	0.20	0.03	0.00	0.00
	Upper Bari Doab	0.00	0.58	0.28	0.00	0.00
2004	Bist Doab	0.00	0.22	0.63	0.05	0.00
	Central Malwa	0.00	0.35	1.19	0.00	0.00
	South-Western Malwa	0.07	1.06	0.38	0.00	0.00
	Eastern Malwa	0.00	0.19	0.03	0.00	0.00
	Upper Bari Doab	0.00	0.54	0.32	0.00	0.00
2005	Bist Doab	0.00	0.18	0.64	0.07	0.00
	Central Malwa	0.00	0.28	1.23	0.03	0.00
	South-Western Malwa	0.03	1.05	0.44	0.00	0.00
	Eastern Malwa	0.00	0.18	0.04	0.00	0.00
	Upper Bari Doab	0.00	0.52	0.35	0.00	0.00
2006	Bist Doab	0.00	0.15	0.66	0.08	0.00
	Central Malwa	0.00	0.23	1.21	0.10	0.00
	South-Western Malwa	0.11	0.97	0.44	0.00	0.00
	Eastern Malwa	0.00	0.15	0.06	0.01	0.00
	Upper Bari Doab	0.00	0.49	0.38	0.00	0.00
2007	Bist Doab	0.01	0.22	0.51	0.17	0.00
	Central Malwa	0.00	0.35	0.96	0.23	0.00
	South-Western Malwa	0.23	0.81	0.44	0.06	0.00
	Eastern Malwa	0.00	0.16	0.04	0.00	0.00
	Upper Bari Doab	0.00	0.40	0.46	0.00	0.00
2008	Bist Doab	0.00	0.18	0.60	0.11	0.00
	Central Malwa	0.00	0.23	0.90	0.40	0.00
	South-Western Malwa	0.24	0.77	0.48	0.01	0.00
	Eastern Malwa	0.00	0.18	0.06	0.00	0.00
	Upper Bari Doab	0.00	0.45	0.42	0.00	0.00

2009	Bist Doab	0.05	0.29	0.50	0.06	0.00
	Central Malwa	0.01	0.35	0.67	0.52	0.00
	South-Western Malwa	0.31	0.71	0.43	0.07	0.00
	Eastern Malwa	0.01	0.17	0.03	0.00	0.00
	Upper Bari Doab	0.00	0.55	0.31	0.00	0.00
2010	Bist Doab	0.00	0.14	0.63	0.11	0.00
	Central Malwa	0.00	0.20	0.91	0.43	0.00
	South-Western Malwa	0.29	0.74	0.42	0.04	0.00
	Eastern Malwa	0.00	0.15	0.09	0.00	0.00
	Upper Bari Doab	0.00	0.43	0.44	0.00	0.00
2011	Bist Doab	0.00	0.12	0.59	0.18	0.00
	Central Malwa	0.00	0.18	0.63	0.73	0.00
	South-Western Malwa	0.37	0.60	0.37	0.16	0.00
	Eastern Malwa	0.00	0.22	0.03	0.00	0.00
	Upper Bari Doab	0.00	0.42	0.44	0.01	0.00
2012	Bist Doab	0.00	0.32	0.47	0.09	0.00
	Central Malwa	0.00	0.21	0.71	0.62	0.00
	South-Western Malwa	0.17	0.76	0.44	0.13	0.00
	Eastern Malwa	0.00	0.17	0.07	0.00	0.00
	Upper Bari Doab	0.00	0.42	0.45	0.01	0.00
2013	Bist Doab	0.00	0.14	0.54	0.20	0.00
	Central Malwa	0.00	0.07	0.66	0.65	0.15
	South-Western Malwa	0.09	0.70	0.51	0.19	0.01
	Eastern Malwa	0.00	0.03	0.20	0.01	0.00
	Upper Bari Doab	0.00	0.36	0.49	0.01	0.00
2014	Bist Doab	0.00	0.15	0.50	0.23	0.01
	Central Malwa	0.00	0.13	0.57	0.72	0.11
	South-Western Malwa	0.29	0.56	0.45	0.20	0.00
	Eastern Malwa	0.00	0.11	0.13	0.01	0.00
	Upper Bari Doab	0.00	0.37	0.49	0.00	0.00

2015	Bist Doab	0.00	0.12	0.59	0.17	0.02
	Central Malwa	0.00	0.12	0.44	0.86	0.11
	South-Western Malwa	0.27	0.56	0.45	0.22	0.00
	Eastern Malwa	0.00	0.09	0.11	0.04	0.00
	Upper Bari Doab	0.00	0.37	0.49	0.01	0.00
2016	Bist Doab	0.00	0.12	0.45	0.30	0.03
	Central Malwa	0.00	0.10	0.38	0.68	0.37
	South-Western Malwa	0.31	0.56	0.38	0.25	0.00
	Eastern Malwa	0.00	0.06	0.12	0.07	0.00
	Upper Bari Doab	0.00	0.31	0.52	0.04	0.00
2017	Bist Doab	0.00	0.10	0.51	0.23	0.05
	Central Malwa	0.00	0.09	0.38	0.62	0.45
	South-Western Malwa	0.18	0.65	0.41	0.26	0.01
	Eastern Malwa	0.00	0.07	0.09	0.08	0.01
	Upper Bari Doab	0.00	0.27	0.48	0.12	0.00
2018	Bist Doab	0.00	0.03	0.42	0.42	0.02
	Central Malwa	0.00	0.06	0.29	0.67	0.52
	South-Western Malwa	0.08	0.73	0.42	0.29	0.00
	Eastern Malwa	0.00	0.02	0.18	0.03	0.00
	Upper Bari Doab	0.00	0.25	0.50	0.11	0.00

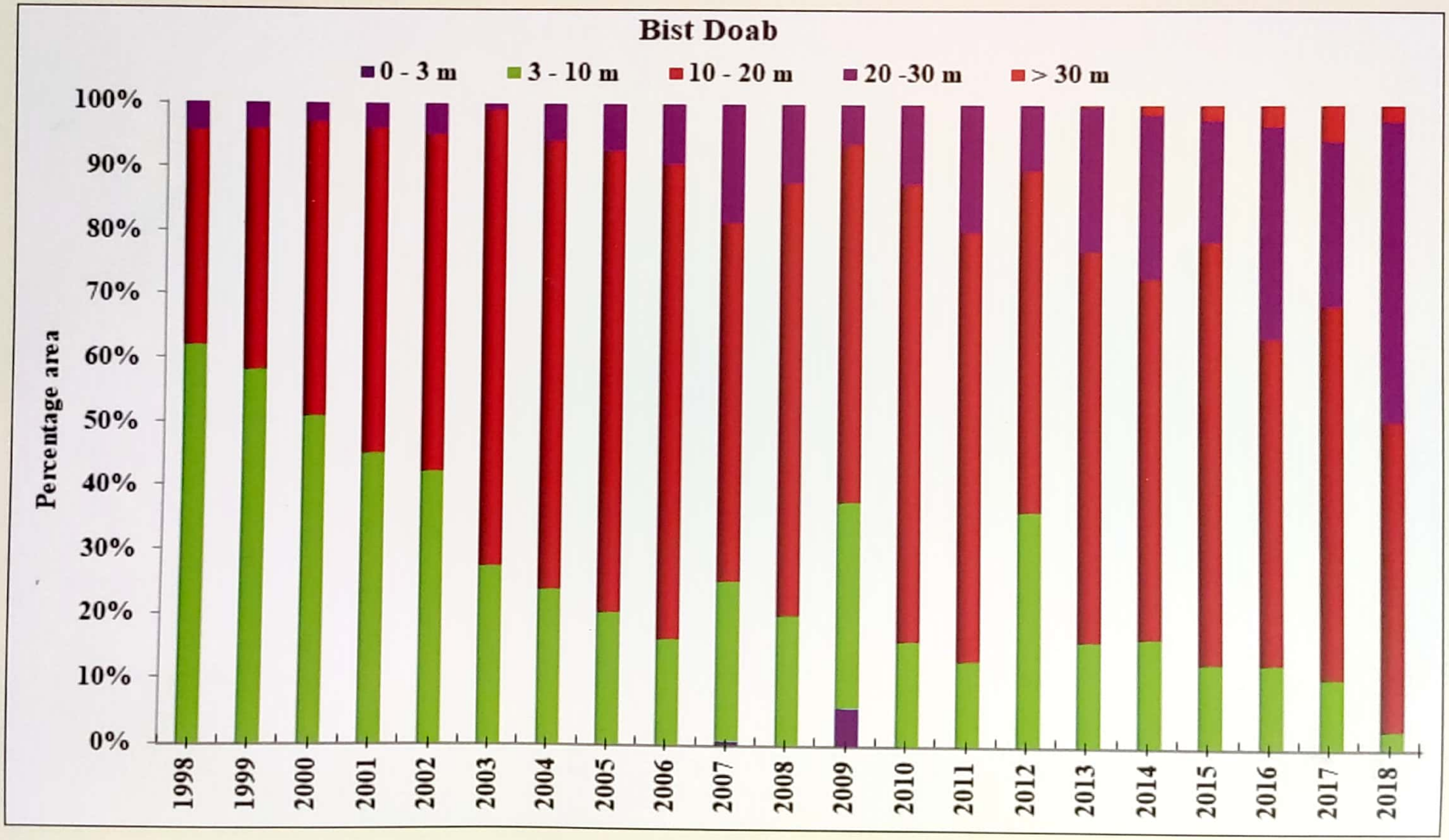


Figure 12: Percentage area under different water table depths in Bist Doab

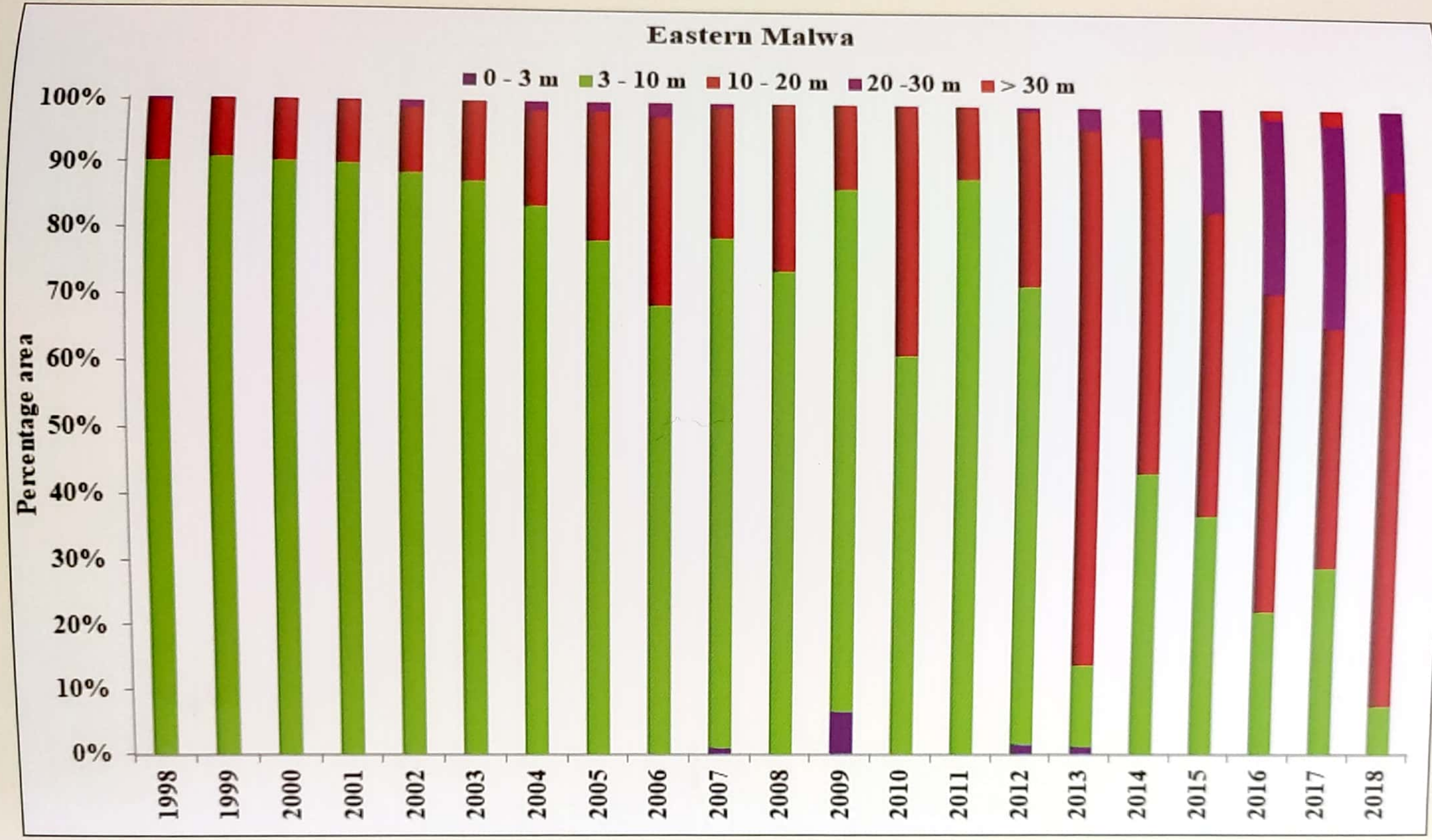


Figure 13: Percentage area under different water table depths in Eastern Malwa

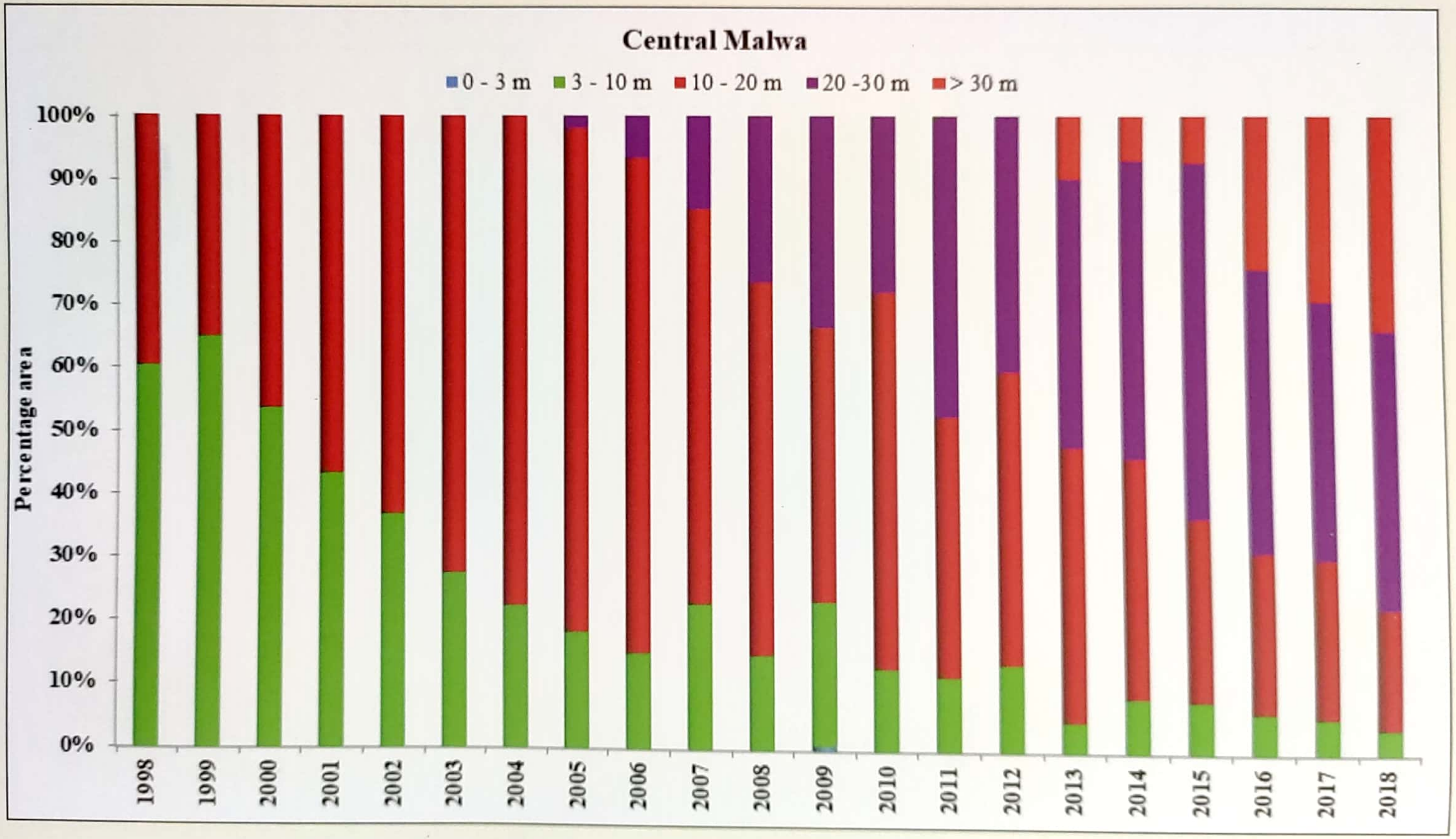


Figure 14: Percentage area under different water table depths in Central Malwa

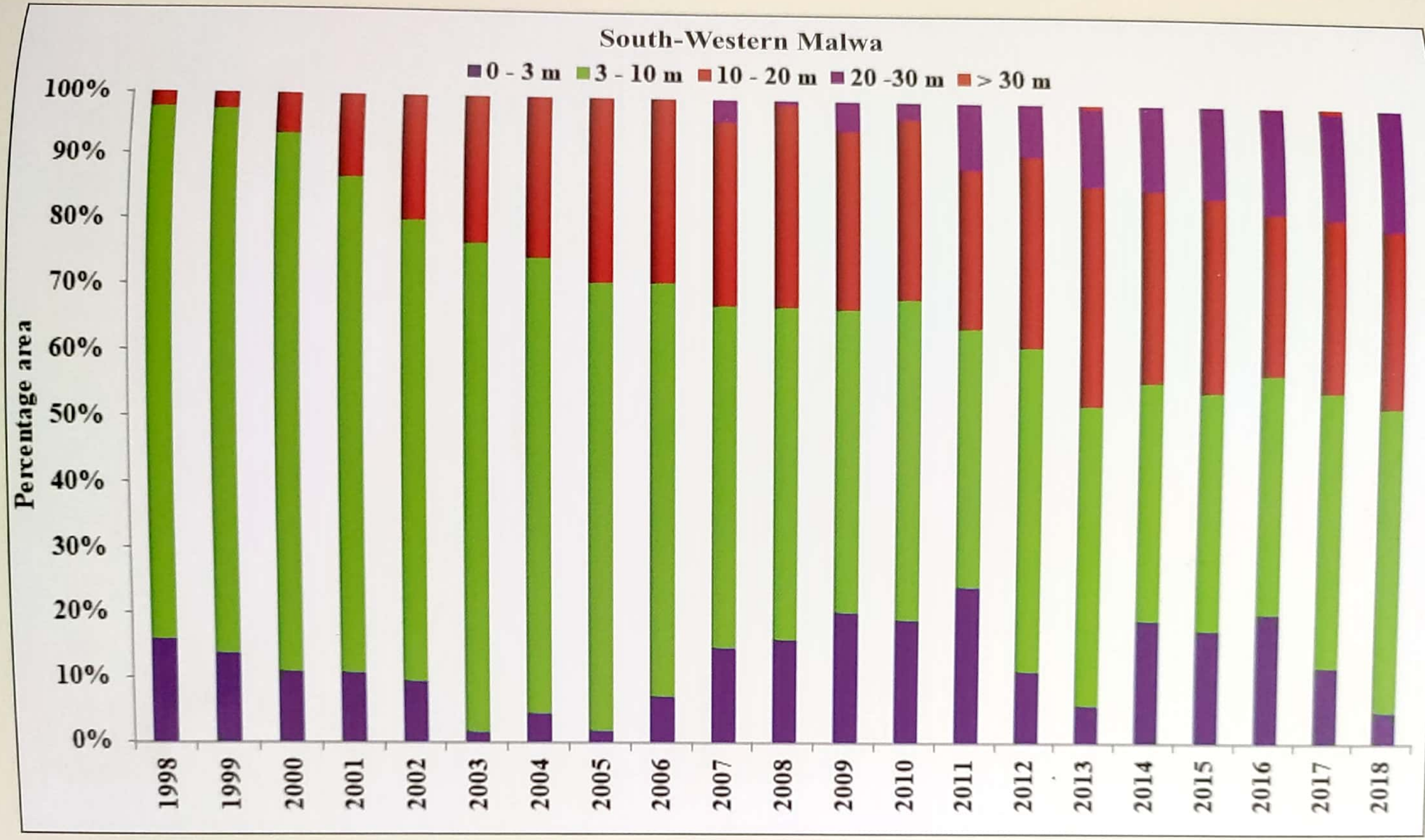


Figure 15: Percentage area under different water table depths in South-Western Malwa

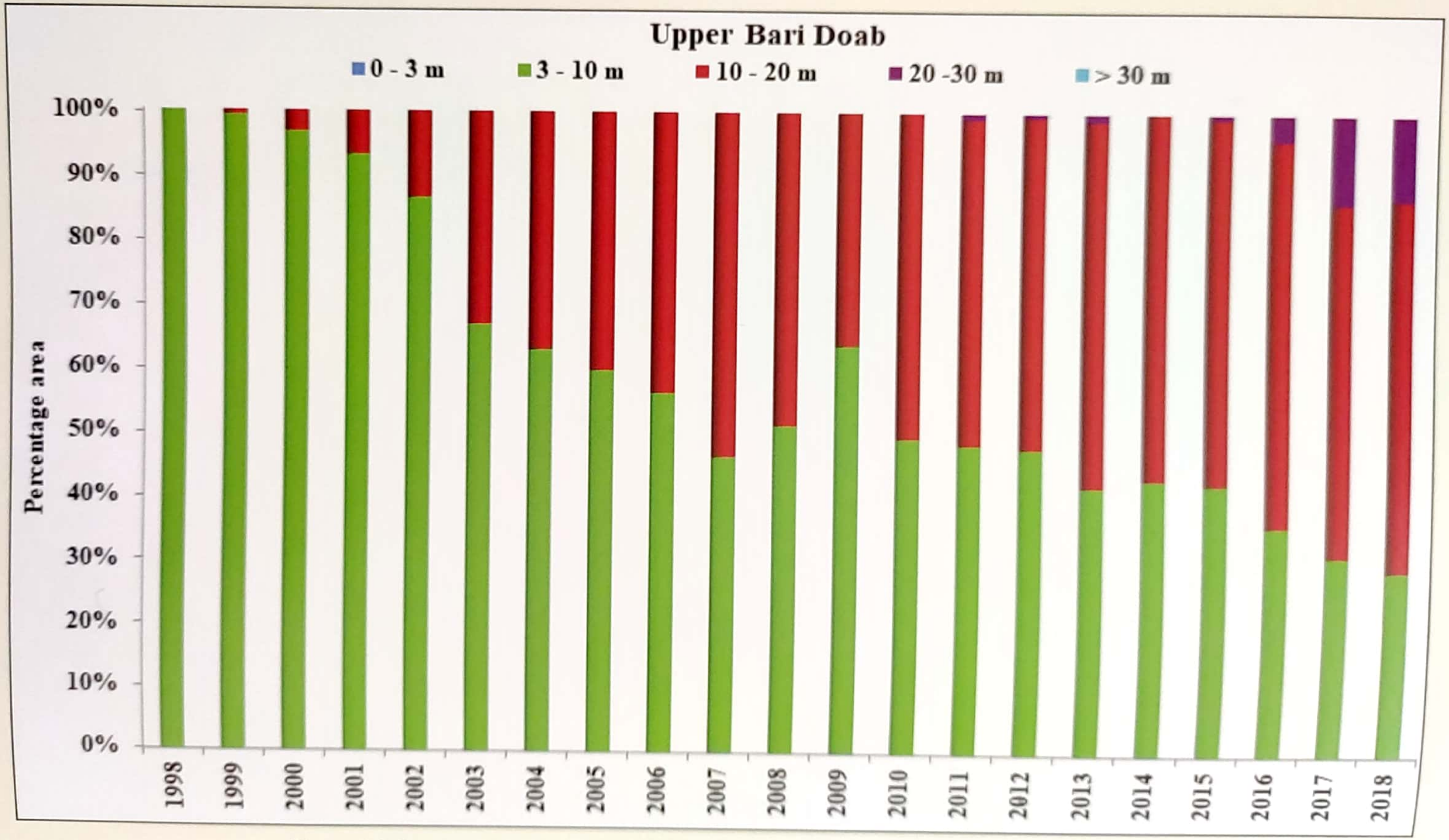


Figure 16: Percentage area under different water table depths in Upper Bari Doab

Table 7: Mean water table depth (m) in different regions from 1998-2018

Year	Mean water table depth (m)				
	Bist Doab	Eastern Malwa	Central Malwa	South-Western Malwa	Upper Bari Doab
1998	8.38	4.97	8.96	5.76	6.87
1999	8.31	4.89	8.70	5.55	7.19
2000	8.87	5.67	9.69	5.98	7.84
2001	9.75	6.01	10.36	6.44	8.39
2002	10.32	6.46	11.14	7.08	8.85
2003	11.18	6.96	12.18	7.62	9.55
2004	11.91	6.79	12.74	7.73	9.66
2005	12.87	6.84	13.56	8.24	10.17
2006	13.45	7.13	14.40	8.21	10.51
2007	13.65	7.63	15.22	8.36	10.28
2008	14.16	7.59	16.04	8.38	10.41
2009	13.64	7.31	16.24	8.52	9.99
2010	14.73	9.43	17.12	8.18	10.89
2011	14.85	8.48	17.02	8.07	11.23
2012	13.80	8.67	17.81	9.88	11.21
2013	15.53	10.48	19.18	10.90	11.47
2014	16.11	12.05	20.66	10.21	11.18
2015	16.43	14.09	21.76	10.54	11.35
2016	17.94	15.97	23.63	10.40	12.44
2017	17.28	16.21	24.38	11.15	13.39
2018	19.79	15.07	25.67	11.46	13.35
Average rise/fall (m/year)	**0.57**	**0.51**	**0.84**	**0.28**	**0.32**

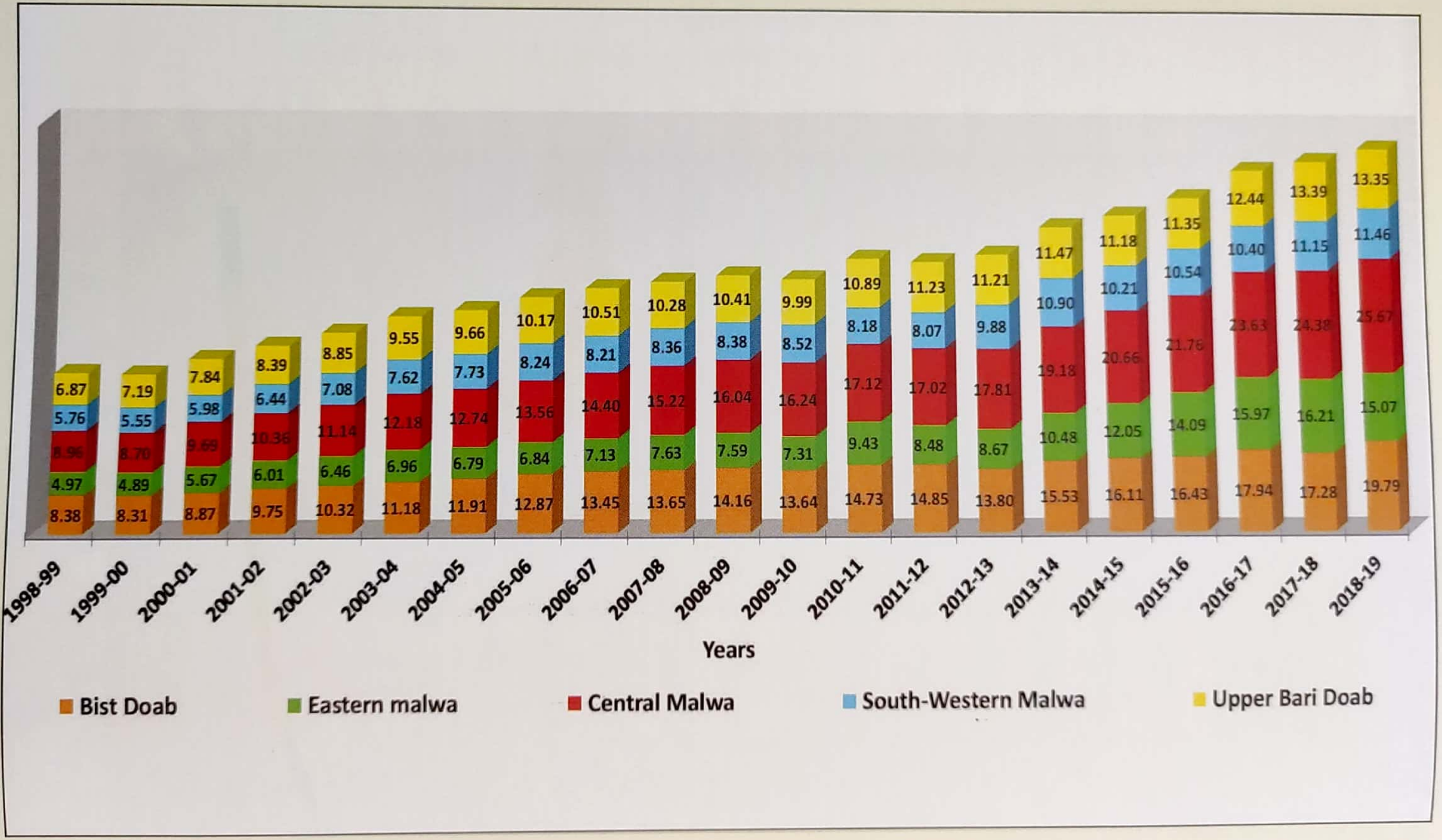
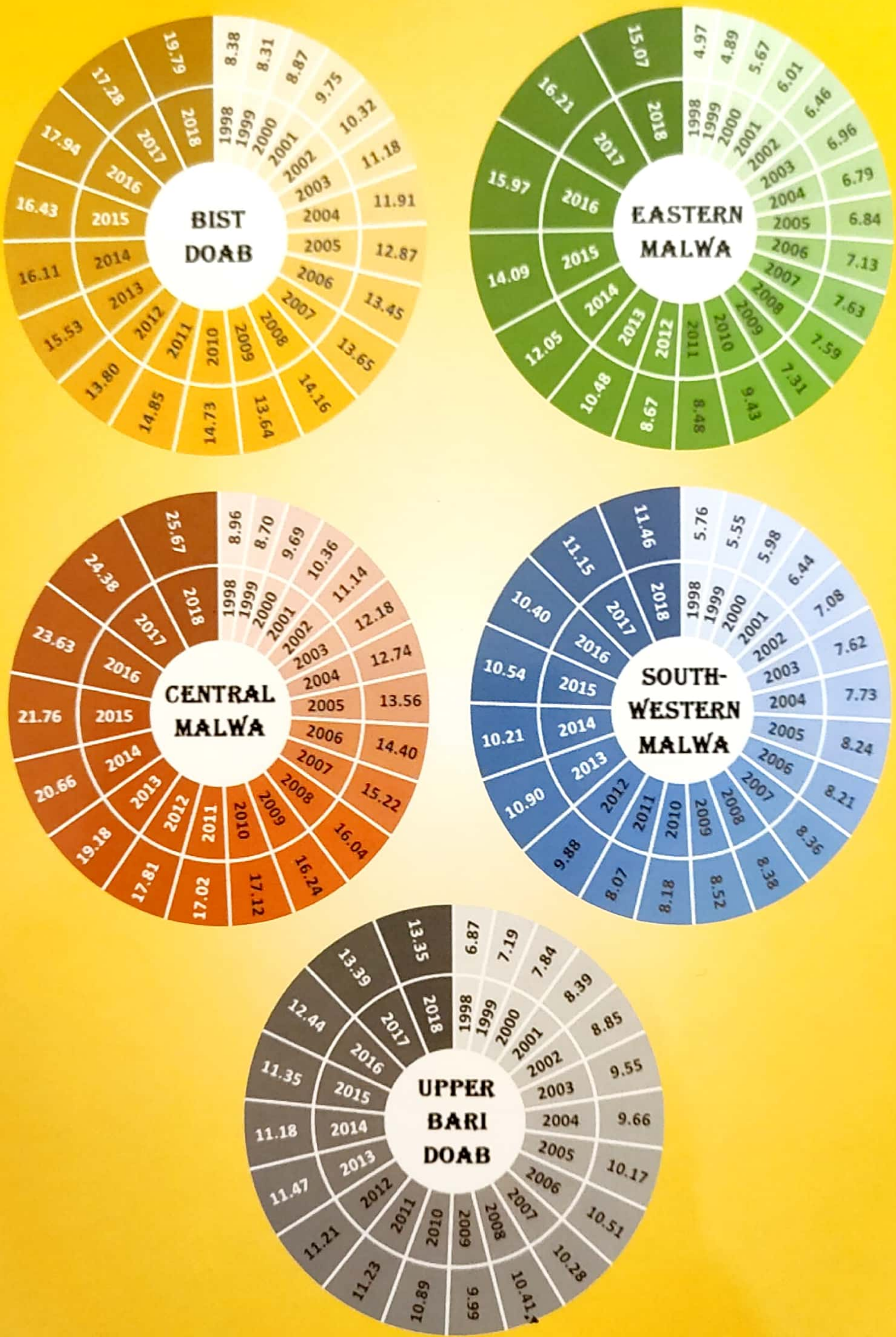


Figure 17: Region wise average water table depth (m) in Punjab

Figure 18 shows the variability of aquifer up to the depth of 300 m. This is as per the analysis made by the Central Groundwater Board along with other State government agencies in 2017. The perusal of Figure 18 reveals in-storage groundwater resources in aquifer I, II and III. In general, aquifer I has maximum storage in all the districts as compared to aquifer II and III, except Faridkot district that is too small in magnitude. Thorough analysis presented block wise, district wise, zone wise and for the overall state reveals that the first aquifer is depleted from bad to worst and the availability of water in subsequent aquifer is quite less; so the availability of groundwater up to 300 m or 1,000 feet is a question mark.



Region wise mean water table depth (m) in different years