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REVIEW ARTICLE

An overview of impact of subsurface drainage project studies on salinity management in developing countries

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Abstract Subsurface drainage has been used for more than a century to keep water table at a desired level of salinity and waterlogging control. This paper has been focused on the impact assessment of pilot studies in India and some other countries from 1969 to 2014. This review article may prove quite useful in deciding the installation of subsurface drainage project depending on main design parameters, such as drain depth and drain spacing, installation area and type of used outlet. A number of pilot studies have been taken up in past to solve the problems of soil salinity and waterlogging in India. The general guidelines that arise on the behalf of this review paper are to adapt drain depth >1.2 m and spacing depending on soil texture classification, i.e., 100–150 m for light-textured soils, 50–100 m for medium-textured soils and 30–50 m heavy-textured soils, for better result obtained from the problem areas in Indian soil and climatic conditions. An attempt has been made in the manner of literature survey to highlight the salient features of these studies, and it is hopeful to go a long way in selecting design parameters for subsurface drainage problems in the future with similar soil, water table and climatic conditions.

Keywords Subsurface drainage · Salinity · Waterlogging and groundwater table

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Introduction

Land and water are two basic natural resources. Due to rapid population growth and fast industrialization, these resources are facing immense pressure and are depleting day by day. According to the FAO land and plant nutrition management service (1994), over 6 % of the world's land is affected by either salinity or sodicity. Much of the world's land is not cultivated; however, a significant proportion of cultivated land is salt-affected, and of the current 230 million ha of irrigated land, 45 million ha is salt-affected (19.5 %), and of the 1500 million ha under dry land agriculture, 32 million ha is salt-affected to varying degrees, i.e., 2.1 % (Hefny et al. 2013). World's large irrigated regions with serious salinity problems are Yellow River Plain in China, San Joaquin Valley in California, KaraKum Canal project in Turkmenistan, Indus Plain in Pakistan, Tigris–Euphrates Plain in Iraq, Murray–Murrumbidgee Area in Australia and lower Nile Valley in Egypt, which need a serious attention of researchers (Ghassemi et al. 1995).

Subsurface drainage is considered as a most suitable approach for groundwater balance and land and water management practices containing the groundwater table at a suitable level (Luthin 1978; Gates and Grismer 1989). Agricultural subsurface drainage is a process of removal of excess groundwater from the crop root zone system which promotes safe environment for efficient crop growth and for better health in rural and urban areas. Subsurface drainage lowers the high water tables, and the main causes of the rise in water table are precipitation, excess irrigation, leaching water, seeps from higher land or irrigation canal and ditches and groundwater under artesian pressure. This technique has gained international acceptance. Subsurface agricultural drainage provides agronomical and environmental benefits in terms of improved crop yield, improved soil trafficability, field operations and reduction in sediment and phosphorus losses from agricultural fields (Kornecki et al. 2001).

Subsurface drainage has been found to be the only solution for providing land reclamation on a long-term basis when salts are present in the soil and groundwater. Subsurface drainage has been provided in 75–80 % of irrigated area in Egypt and 25–30 % irrigated area in western USA Goel and Tiwari (2013). Comprehensive reclamation programs involving provision of subsurface drainage in irrigated areas have been embarked in a big way in Pakistan over the past 50 years, while these started much earlier in India during late 1920s (Thatte and Kulkarni 2000), and FAO (1999) reported that India has 2.5 million ha waterlogged land and 3.1 million ha salinity-affected area, while this hazard on the state level in India is extended, i.e., Uttar Pradesh has salinity-affected area over 1 million hectares, 1 million hectares in Gujarat, 0.5 million ha in Punjab, 0.2 million ha in Haryana and a smaller area in Rajasthan, and significant less proportionate area in Tamil Nadu in the south is also affected. At the time of nineties, subsurface drainage installed <10 % of the total irrigated area Zimmer et al. (2002). But currently <0.02 % irrigated area in India is provided with subsurface drainage Tiwari (2011), and Maharashtra state has minimum salt-affected area to the extent of 0.6 M ha (Sethi et al. 2010).Still India is facing varying degree of salinity problems such as saline soil, costal saline and alkalinity (Patel et al. 2002; Mandal and Sharma 2011).

Some past review papers and past remarkable studies on subsurface drainage and salinity management were discussed in this session. The purpose of this literature survey is that the findings and recommendations of these studies would be useful to take as guidelines to plan a new subsurface drainage system in an efficient, effective, economic and ecofriendly manner for future in India and other countries.

Gupta (2002, 2003) has summarized past 100-year Indian efforts to control salinity and waterlogging problems, which were conducted under the supervision of Central Soil Salinity Research Institute (CSSRI) from 1972 to 2002. He has covered several pre- and post-independence pilot studies and their salient findings from 1873 to 1975. He has provided general drainage design guidelines and operationalizes the subsurface drainage system for Indian conditions.

Kaledhonkar et al. (2009) have summarized preliminary studies conducted in India from 1980 to 2008. He has been enlightening on the 18 Haryana, 3 Gujarat, 2 Maharashtra, 2 Andhra Pradesh, 1 Karnataka and 1 Rajasthan pilot studies of their saline areas in the listed states, and he made efforts to focus the subsurface drainage operational and subsurface drainage effluent management problems. They discussed the drainage design parameters, crop production, cropping intensity and cost investment for the subsurface drainage installations but did not considered the maintenance of SSD.

Several researchers have suggested different strategies for salinity management in developing countries from 1969 to 2014. Special issues in SSD are discussed/highlighted, and specific methodologies for design of SSD are summarized in this paper. In the end, some of the general guidelines have been proposed which can be kept in mind while designing any SSD project in future.

Subsurface drainage pilot or project studies

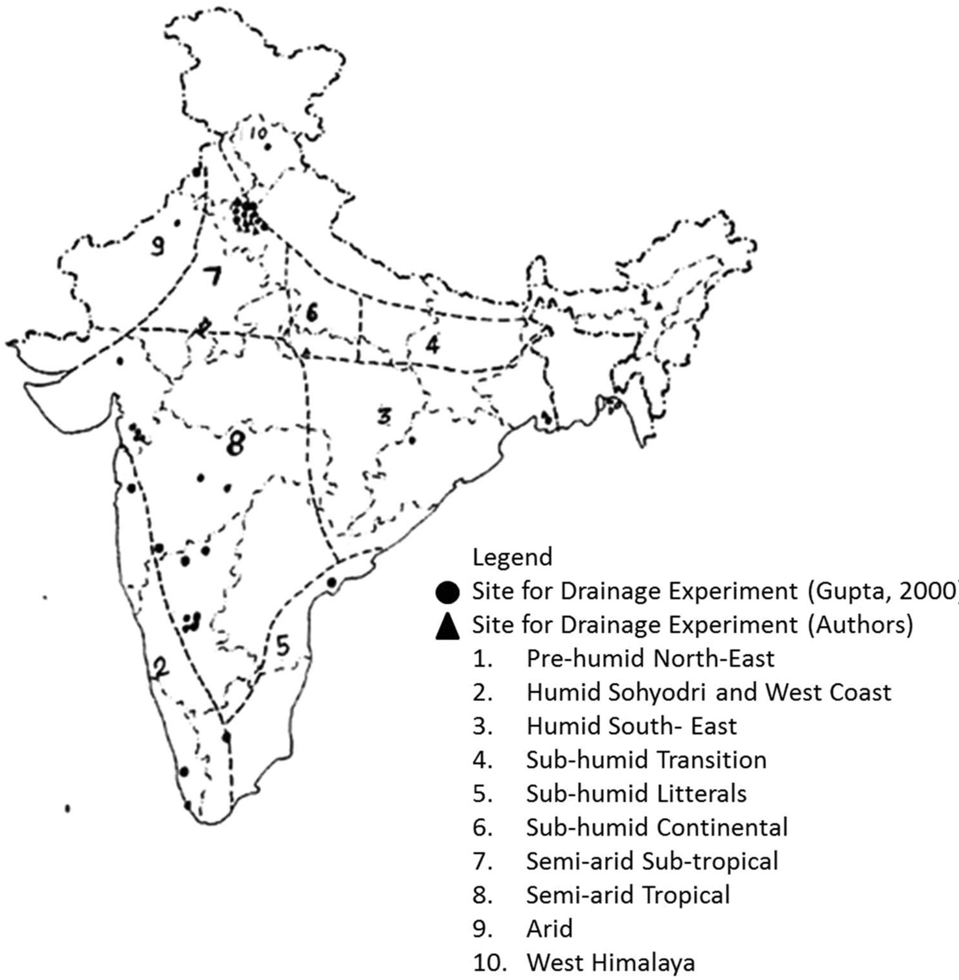
India

The requirement of salinity management was firstly reported by Punjab Govt. in 1865 to Governor General. Mr. Robertson and started India's first drainage project in 1873 to reclaim the land from waterlogging, and people cure from malaria disease. History of northwest India's salinity has to reclaim through subsurface drainage installation and keep functioning it till achieving the aim of installation (Hanumanthaiah and Satyanarayana 2003). But they always worried about drain discharge disposal. Till few years ago, the drain discharge was disposed in canals. And also they tried to reuse the saline drain water in crop production, but the problem in those days was the pumping out of large quantity of drain discharge. So nowadays, the drainage installation is costly and seen more problematic in disposal point of view. A number of pilot scales subsurface drainage projects undertaken by CSSRI Karnal (Haryana), India, during 1980s have slowly paved the way for communication of large-scale mechanically installed drainage projects in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka. India is divided into ten climatic zones which played very important role in SSD installation because any region is more affected by their weather conditions. On the basis of the climatic zones, experimental sites are through the India map (Fig. 1).

About 35,000 ha waterlogged saline soils have been reclaimed in these states with significant improvement in crop intensity, yield, land value and farmers income. India's major pilot studies literature survey has been discussed in Table 1. Here we are discussing the important factor of the drainage design criteria with their major outcomes. The following table (Table 1) have described about India's 56 successful pilot studies with their study area, installation year, operational duration, necessary drainage design parameters and their major conclusions.

On the basis of the Table 1, the pilot studies following guidelines are framed which would be helpful in drainage

Fig. 1 Climatic zone wise distribution of SSD studies in India



design subsurface drainage system in India. It is expected that these salient points would be useful in new wherein similar soil, water table and climatic conditions existing in India.

Basic guidelines for Indian subsurface drainage design

Although Drainage manual (1978) and Drainage design factors (1986) have recommended general guidelines for installation procedure and drainage design parameters for more effective performance yet on the basis of pilot studies undertaken in the past 50 years in India, few more guidelines have emerged which are mentioned below.

1. Before subjecting any drainage project into a problematic area, the primary data (technical, socioeconomic, geo-hydrological climate) and secondary (water quality) have to be collected, which are relevant to the particular area.
2. In past, cement concrete pipes were very popular in alkaline and saline areas because these pipes have not given any complaints up to 20 years in alkaline areas and 8 years in saline zones after installation. But nowadays PVC pipes are more popular than others due to its portability and light in weight.
3. Drainage depth is an issue of increase or decrease in cost of installation and also availability of machineries and labor. But it is depending on position of groundwater table, soil type and hydraulic characteristics. For agricultural drainage, recommended depth of the lateral is >1.2 m because agricultural activities may damage the laterals.
4. Drain spacing is classified on the basis of the texture of the soil. The lateral spacing, size and grade (in %) for light-textured soils are ranging between 100 and 150 m, 100 mm and 0.10 %, respectively, 50 and 100 m, 125 mm and 0.075 % for medium-textured soil and 30 and 50 m, 150 mm and 0.05 % for heavy-textured soils.
5. On the basis of climatic conditions, drainage coefficient has an optimum value which lies between 1 and 3 mm/day (i.e., arid region is a 1 mm/day, semiarid region is a 2 mm/day, and subhumid region is 3 mm/day).

Table 1 Pilot studies on subsurface drainage in India

S.no.	References	Study area description for SSD Installation		Drainage design parameters				Major conclusion
		Place and area (ha)	Year of installation	Drain depth (m)	Drain spacing (m)	Type of drain	Type of outlet and envelope material	
Andhra Pradesh								
1	Channabasiah (1972)	Siruguppa	1972	1.2	12	Open drain	Gravity	Significant increase in crop yield is observed
2	Devadattam and Chandra (1995)	Machilipatnam	1995	–	–	Tile drain	–	Increased rice crop yield
3	Joint completion report on IDNP (2007)	Nagarjuna Sagar Right Command and Krishna Western Delta	–	1 1.0–1.2	60 75	Pipe drain Open drain	Pumped Geo-textile	Paddy crop yields have increased around 50 % in 2-year duration
4	Srinivasulu et al. (2005)	Konanki village in Prakasam district (21.63 ha)	1998–1999	0.9 and 1.1, 1	100 30, 60	Open Pipe Pipe	Gravity Geo-textile Nylon mesh	Late sowing kharif crop rice yield increase by 51 %
5	Ritzema et al. (2008)	Konanki and Uppugunduru (8 and 5 ha)	1999	0.90–1.75	45–150	Open drain Pipe drains	Pumped Geo-textile Nylon mesh	Water table has controlled and cropping intensity increased
Assam								
6	Bhattacharya et al. (1996)	Mornai	1996	–	–	Tile drain	–	Controlled water table and increased yield of tea leaves are observed
Gujarat								
7	Michael and Ojha (2013)	Saurashtra (22 km)	1972	1.2–1.8	–	Open drains	–	Land has reclaimed from salinity and waterlogging problems
8	Anonymous (1988)	Bidaj	1981	–	–	Open drains	–	Controlled salinity and waterlogging.
9	Ritzema (2009)	Segwa, Surat (5.6 ha, 2.6 ha, 5.7 ha and 4.6 ha)	1998–1999	0.9 1.0–1.2 1.2 1.2	45 30 45 60	Singular and Composite open pipe drains	Gravity	Water quality (EC reduced from 18.2 to 1.4 dS/m during 2001) has improved after one year and has used in irrigation
10		Sisodra, Surat (4.2 ha, 5.4 ha, 2 ha and 14 ha	2000	0.9 0.9 0.7 0.8	30 60 30 60	Singular and open pipe drains	Gravity	Cropping intensity has increased to 102 % after SSD installation
11	Kaledhonkar et al. (2009)	DabuoKheda (50 ha)	1987–1988	–	–	–	–	Water table has controlled, and this has given positive effect on crop production.
12		Muraj Kheda (52 ha)	1990–1991	–	–	–	–	Water table has controlled
Haryana								

Table 1 continued

S.no.	References	Study area description for SSD Installation		Drainage design parameters				Major conclusion
		Place and area (ha)	Year of installation	Drain depth (m)	Drain spacing (m)	Type of drain	Type of outlet and envelope material	
13	Jaiswal and Dhruvanarayana (1972)	Karnal, Haryana	1972	1.5	10–30	Tile and open drains	Gravity Pumped	Open drain has not been found suitable in alkaline soils
14	Kaledhonkar et al. (2009), Anonymous (1988)	Kailana khas (1.6 ha)	1980–1982	–	–	Open and Tile drains	Gravity	Groundwater table has been controlled
15	Rao et al. (1986), Kamra et al. (1991), Kaledonkar et al. (1998), Gupta (2002)	Sampla, Rohtak (1 ha, 10 ha, 27 ha, 13 ha)	1980–1981 1983–1984 1986–1987 1991–1992	1.5 1.5 1.75	20 50 25, 50, 75	Open drains Tile drains	Pumped and gravel for deep drain system Synthetic for shallow drain system	Wheat and barley crops yield was obtained 2.5–4.9 (t/ha) and 2.1–4.2(t/ha) at the zero production area Cropping intensity has been increased up to 200 % after drainage installation
16	Hirekhanet al. (2007), Pali et al. (2014)	Mudlana, Sonepat (50 ha)	1984–1985	1.75 and 1.6	50, 67, and 84	PVC corrugated pipes	Pumped	Salinity has been controlled
17	Kelleners et al. (2000)	CIRB, HAU Hisar (75 ha)	1990–1991	1.5	24	Tile drain	Pumped	Water table has controlled and crop yield increased
18	Kaledhonkar et al. (2009)	HLRDC farm, Hisar	1989–1990	–	–	Tile drain	Pumped	Groundwater table has controlled and increased crop yield
19		Ujana, Sonepat (32 ha)	1986–1987	–	–	Tile drain	Pumped	
20		Bhan Brahmana (105 ha)	1988–1990	–	–	Tile drain	Pumped	
21		Kolekhan, Jind (41 ha)	1989–1990	–	–	Tile drain	Pumped	
22		Ishapur Kher (58 ha)	1989–1990	1.0–1.2	–	Tile drain	Pumped	
23		Rori, Sirsa (1500 ha)	2004–2005	–	–	Poly-pipes	Pumped	
24	Joint Completion Report on IDNP (2007)	Gohana (1236 ha)	1979–1999	1.6	60–67	PVC corrugated pipes	Pumped Synthetic	Salinity has decreased 35 % from the year of installation to 2000
25	Lal (2011)	Jhajjar (Beri, 800 ha)	2004–2005	1.75	60–67	Poly-pipes	Pumped	Land has been reclaimed from salinity hazard
26		Dadri, Bibhani (800 ha)	2004–2005	–	–	Poly-pipes	Pumped	Agricultural land removes salinity at a desired level
27		Kalyant (1000 ha)	2004–2005	–	–	Poly-pipes	Pumped	Cropping intensity has increased
28		Sonipat (1500 ha)	2004–2005	–	–	Poly-pipes	Pumped	Water table has controlled
Karnataka								
29	Joint Completion Report on IDNP (2007)	Islampur, Karnataka (Upper Krishna Canal Command, 29.3 ha, 14.4 ha)	1998–1999 1998–1999-	1.0–1.1 1.0–1.1	50 50	PVC perforated corrugated Pipe Open Drain	Pumped Geo-textile	Cropping intensities have increased 27, 35 and 100 % in first three years
30				1.1–1.2 1.1–1.2	50 30	Pipe drain Pipe drain	Pumped	Cropping intensities have increased 114 and 156 % in first two years
31	Datta et al. (2004)	Mudhol Taluk Karnataka Bagal kot (19.35 ha)	1995–1996	–	1	–	Gravity	Water logged area has reclaimed

Table 1 continued

S.no.	References	Study area description for SSD Installation		Drainage design parameters				Major conclusion
		Place and area (ha)	Year of installation	Drain depth (m)	Drain spacing (m)	Type of drain	Type of outlet and envelope material	
32	Satyanarayana et al. (2002) Srinivasulu et al. (2014)	Uppugunduru	1999	0.85–1.1	50	Open	Pumped	Water table has controlled and cropping intensities increased to 170 % after drainage installation
		In Krishna Western Delta(7 and 5 ha)			30	Pipe	Geo-textile	
					45	Pipe	Nylon mesh	
					60	Pipe		
Kerala								
33	Mathew et al. (1993)	karumady	1993	–	–	Tile drain	–	Increased rice yield
Madhya Pradesh								
34	Yadav (1975), Anonymous (1988)	IARI, New Delhi	1975	1.0	32	Open drains	Gravity	Significant increase in sorghum and wheat yield
35	Yadav (1975), Anonymous (1988)	Indore, M.P.	1975	0.6–0.9	6.5–40	Tile drains	Gravity	Significant increase in crop yield and coarse sand filters are not suitable for alkaline vertisols
36	Sharma et al. (1995)	Barna, M.P.	1995	–	–	Open drain	–	Increased crop yield
37	Ramana et al. (2009)	CIAE Bhopal (M.P.)	–	0.60	2, 4 and 6	Tile drain and mole drain	Gravity	Water table has controlled
Maharashtra								
38	Gupta (2002), Kaledhonkar et al. (2009)	Manjri	1920	1.5	–	combination of open and tile drains	Gravity	Crop yield has increased
39	Anonymous (1988)	Manjri	1941	–	–	Tile drains and open drain	Gravity	Crop yield has increased
40		Parbhani	1982			Tile drain	Gravity	Increased net profit
41	Kamble et al. (2006)	Dhudgan Sangli (1100 ha)	–	2.5		Corrugated perforated PVC pipes	Gravity	Water table has controlled
42	Kaledhonkar et al. (2009)	Kasabe Digraj Sangli (1065 ha)	2004–2006	2.5	10.75	Tile drains	Gravity	Water table has controlled
43	Kolekar et al. (2014)	College of Agril Engg and Tech., Parbhani	2006–2008	2, 4 and 6	–	Mole drain	–	The total yield of groundnut has highest in 4 m mole spacing, i.e., 69.20 %
Punjab								
44	Gupta (2002)Kaledhonkar et al. (2009)	Amritsar	1873	–	–	Stone, tile drains and 16-tube well (0.0425 m^3/sec)	Gravity	Malaria disease has mitigated and land free from waterlogging problem
45		Chakanwal	1920	0.9	33–66	Open drain	Gravity	This has played a vital role in crop production
46	Anonymous (1988)	Ludhiana	1967	–	–	Tile drains and open drain	Gravity	Maize yield increased

Table 1 continued

S.no.	References	Study area description for SSD Installation		Drainage design parameters				Major conclusion
		Place and area (ha)	Year of installation	Drain depth (m)	Drain spacing (m)	Type of drain	Type of outlet and envelope material	
47	Michael and Ojha (2013)	Ranbirpura, Patiala (800 h)	1959–1960, 1971	–	–	Open drain	–	This area has significantly free from salinity
48	Michael (1967), Michael and Ojha (2013)	Ludhiana	1966	1.2	–	Interceptor and combination of open and tile drains	Pumped	System was not much effective in rabi season
49	Shakya et al. (1995)	Golewala	1995	–	–	Multiple well one point system	Pumped	Permitted conjunctive use of groundwater
Rajasthan								
50	Lovas (1972), Anonymous (1988)	Digod	1972	0.6–1.0 1.0–1.3	2–2.5 8–12 15–20	Mole, plastic asbestos pipes	Gravity	Mole drains have found to be cheaper and less time-consuming
51	Datta et al. (2004)	Chambal command area RAJAD (1420 ha, 12580 ha)	1992–1993 1993–1997	1–1.2	30, 60	Tile and open drains	Gravity	Cropping intensity has increased
52	Anonymous (1995)	Kota	1995	–	–	Tile and open drains	Gravity	Project benefit cost ratio 2.5
53	Shekhawat (2007)	Lakhuwali (15 ha, 60 ha)	2000 2001	1.2	100, 150, 200	Pipe Drain	Pumped 300–350 Microns geo-textile nonwoven	Kharif (paddy, cotton,) and Rabi (wheat barley, mustard) crops has obtained just double yield and cropping intensity has increased 160 %
Uttar Pradesh								
54	Chauhan and Ram (1972)	Pant Nagar, U.P.	1972	1.0	15–35	Tile drains	Gravity	More water storage has taken place in the profile and less runoff from draining lands
West Bengal								
55	Maity et al. (1996)	Midnapur	1996	–	–	Open drain	–	Increase in observed crop yield
56	Bhattacharya (1999)	Dankuni Basin	1999	–	–	Raised bed pond	–	Salvaged waterlogged land for agriculture activities

Table 2 Major four pilot studies of Pakistan

S. no.	References	Site information	Main design parameters						Shortcomings
			Drain depth (m)	Drain spacing (m)	Design discharge (mm/day)	Design $D_{W.T.}$ (m)	Type of drainage	Outlet and sump	
1	Ghumman et al. (2012)	Khushab SCARP, Pakistan (42,000,000 ha)	1.68–1.98, 2.1	150–300	1.8	1.2	Pipe drainage	Pumped	In Khushab, the water salinity measured in terms of dS/m was reduced by 33 %, respectively, in 12 years
2		FDP (Fourth Drainage Project, Faisalabad), Pakistan (30,351 ha)	1.68–1.98	500–600	2.44	1.2	Pipe drainage	Pumped	In Faisalabad, the water salinity measured in terms of dS/m was reduced by 25 %, respectively, in 12 years
3	Azhar and Latif (2011), Ghumman et al. (2012)	Mardan SCARP Project (MSP) Pakistan (29,542 ha)	2.4	150–200	3	1.05	Pipe drainage	Pumped	Increase in rice, sugarcane, kharif fodder, wheat, sugar beet and tobacco yield was 46, 49, 50, 56,43 and 23 %, respectively
4		Mirpukhas Tile Drainage Project Pakistan (24,281 ha)	1.8–2.4	–	0.95		Pipe drainage	Pumped	Crop yield had increased by the use of saline drain water
5	Ritzema (2007)	East Khaipur Tile Drainage	1.95	–	2.5–3.5	1.0	Pipe drain	Pumped	Crop yield had increased
6	Sarwar and Muhammad (2008)	Swabi SCARP	1.8–2	100–150	2	1.0	Pipe Drain	Pumped	Yields of sugarcane, rice and wheat were increased by 16, 24 and 37 %, respectively
7	Asian Development Bank (1984)	Chashma Command Area Development (18160 ha)	2.10 1.8–2.7	–	1.2–2.6	1.4	Interceptor drain, PVC pipe drain	Pumped	Cropping intensities increased 105 to 135 % after installation of SSD
8	Ritzema (2007)	DC Khan SCARP	–	–	1.88	–	Pipe drain	Pumped	Crop yield has increased and water table is controlled
9	Ritzema (2007)	Fordwah Eastern Sadiqia (South)	2.1		1.5	1.2	Pipe drain	Pumped	Crop yield has increased

Table 3 Pilot studies on desalinization and waterlogging

S. no.	References	Location states and countries	Spacing(m) and	depth (m)	Type of drains and	type of outlet	Major conclusions
1	Kale 2011	Konya–Cumra Plain, Turkey	–	–	–	Pumped	Water table, soil salinity have been controlled, and wheat crop yield also increased
2.	Ozturk (2004)	Anatolia, Turkey	21.3	1.8–2.0	Tile drains	Gravity	Crop yield increased, and water table has been controlled
3.	El-Mowelhi et al. (1988)	Nile Delta Egypt	20, 75	1.5	Tile drains	Gravity	Crop yield increased

6. Continuous movement of water in the pipe and aquifer system collects sediment in the pipes which may affect the performance of the drainage system. For resolving the problem, the provision of filters and envelopes on the drain pipes has to be adopted. Filter/envelope material is used to filter that surrounds drain pipe, and these are commonly used along with drain pipes (geotextile, polypropylene, coconut fiber, polystyrene and foam plastic). The traditional filter material is a combination of gravel and coarse sand.
7. Normally the drain effluent is disposed in the canal, salt-making ponds, fishpond, or it can be reused in crop production. The several methods have been suggested by researchers for effluent reuse in irrigation such as blending and mixing.

Subsurface drainage pilot studies in Pakistan

As a consequence, waterlogging and salinity now are serious threats to irrigated agriculture of the 16.7 million hectare in the Indus Basin; about 2 million hectare is waterlogged, and 6 million hectare is salt-affected (Nijland et al. 2005).

Pakistan made an effort for salinity control by starting a series of salinity control and reclamation projects in 1959, and results show a very good agreement to reduce salinity level in the surface and soil profile salinity. The salinity in percentage has been compared for 17-year variation (between the initial salinity year 1960 and 1977–1979) after installation of drainage, and this is also indicated that the salt-free areas increased up to 20 % in surface and profile salinity from past decades (Bhutta 2007).

The subsurface drainage installations in Pakistan are still <1 % of the total cultivable commanded areas so it needs to be increased (Ghumman et al. 2012; Azhar et al. 2004). Bhutta (2007) has discussed salient findings of drainage research and its benefits in Pakistan. Pakistan has world's largest irrigation system, namely the Indus Basin Irrigation System that commands about 14.2 M ha canal irrigated area (Niazi 2008). Due to poor maintenance and neglecting behavior of academician of Pakistan, most of the parts of canal are still unlined and result in the basic cause of waterlogging problem, which directly covered major part of agricultural lands of Pakistan. Niazi (2008) and Ghumman et al. (2010) reported that Government of Pakistan has made effort to save major fertile land of agriculture by the installation of major subsurface drainage projects from past few decades. Various methodologies have been used to protect agricultural lands of Pakistan from the salinity, but most of the subsurface drainage project had not proved informative and beneficial to solve the problem (Smedema 1990; Sarwar 2000; Kahlown and Khan 2004). So many approaches like surface drainage, subsurface pipe drainage and tube wells had been installed for reclamations of fertile lands of Pakistan, but subsurface pipe drainage was proved more beneficial than other two methods (Azhar et al. 2010). Four decades ago, Pakistan government was more concerned about the protection of the productive agricultural lands, and they passed eight subsurface pipe drain projects, but Sarwar and Feddes (2000) and Azhar et al. (2004) have reported that the installed drainage projects had not proved beneficial as per the expectation because these projects have not been technically sound and designed in that particular decade. After that Pakistan's irrigation and drainage engineers and scientists continuously worked on the drainage design parameters such as drainage coefficient, drain spacing Naz et al.2009) and drain depth. Kahlown et al. (2007) and Azhar and Latif (2011)have been worked on three experimental sites NIA, Bughio and Nawazabad farms in Pakistan in order to find the drainage coefficient for the efficient performance of futuristic projects and problems. History of Pakistan's irrigation and drainage researches are mainly explained by existence of nine different subsurface drainage projects (Azhar et al. 2005) as presented in Table 2.

Pakistan drainage design guideline

In Pakistan, in drained areas where a deep water table is maintained, farmers sometimes complain about the increased need of irrigation water (Qureshi et al. 1997). A shallow water table, especially in the fine soils of the Indus plains, is capable of water delivery to the crops through capillary rise. In areas with an 'acceptable' groundwater quality, there is no need to maintain a deep water table. The following guideline arises from the studies of the different research works. On the bases of the pilot studies, following steps are recommended.

1. In Pakistan, drainage design depth of the subsurface drainage systems should be in between 1.8 and 2.4 m while collector depth >3 m.
2. SSD drain discharge has to be designed as 0.95–3.5 mm/day.
3. PVC pipes are generally popular in field drains with fixed dimensions, i.e., diameters 100–200 mm and length up to 800 m.
4. In collector drains, PVC and PE pipes are used with fixed dimensions of 200–380 mm in diameter and length >4 km.
5. Gravel filters are more popular in Pakistan subsurface drainage installation.

© Iraq and Egypt

In Iraq, for example, more than 50 % of the lower Rafidain Plains faces a stern salinity and waterlogging problems (El-Hinnawi 1993). Similarly, salinity and waterlogging have been an inevitable problem in Egypt. These problems have existed during the pre- and post-Aswan High Dam periods (Ritzema 2009; IPTRID Secretariat 2007). To overcome this twin problem, subsurface drainage projects were commissioned in 1942. About 55 % of agricultural land was reported as saline in Iran (FAO 1994). Waterlogging and drainage problems occur in the central and southern parts of the Saudi Arabia. In some projects, like Al-Hassa irrigation project, the agricultural drainage water is mixed with fresh groundwater and reused for irrigation. So, due to the poor quality of irrigation water, soil salinity problem is increasing (AQUASTAT 2008). Multi-level subsurface drainage has also proved beneficial (Hornbuckle et al. 2012). Hirekhan et al. (2007) have suggested that field observation must be taken before and after the installations of SSD in a semiarid climate area and have stressed on rigorous analysis before adopting a subsurface drainage technique. Chahar and Vadodaria (2010) and Chahar and Vadodaria (2012) investigated the optimal spacing in an array of fully penetrating ditches for subsurface drainage. They developed an explicit equation for computing the optimal spacing between the ditches. Eldeiry and Garcia (2010) have compared ordinary kriging, regression kriging and co-kriging techniques to estimate the soil salinity using various images. The best combinations have evaluated to estimate soil salinity with different crop types. Gammal El and Ali (2010) reported that subsurface drainage water has proved very beneficial for crop production in Egypt. Salinity and waterlogging problems affected countries are trying to reclaim their waste land, which are severely affected from these hazardous reasons presented in Table 3.

Conclusions

This paper briefly discussed the old to current state of art in subsurface drainage system, positive effects of drainage on crop production and also what the future hold for this technical approach. Pilot studies reviewed subsurface drainage investigations from 1969 to 2014 (India and abroad) with their outcomes. This study is to suggest the numeric value of drain depth which is kept greater than 1.2 m, i.e., >1.2–1.8 m and drain spacing depending on the soil texture classification, i.e., 100–150 m for light-textured soils, 50–100 m for medium-textured soils and 30–50 m for heavy-textured soils for Indian subsurface drainage installation in the problem area, and Pakistan subsurface drainage project studies show drain depth kept more than 1.8 m. With the help of this paper, researchers will be able to decide the drain depth, spacing, types of subsurface drainage and type of outlets.

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