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# Potential Agricultural Practices in Saline Waterlogged Areas of Haryana and their Impact on Socio-economic Conditions of Farmers – A Synthesis

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**Abstract**

Paradoxically, in India 147 million hectares (m ha) land is reported to be suffering from different processes of land degradation and about 14.3 and 8.6 m ha area suffers from waterlogging and permanent submergence, respectively. In the fast-developing state of Haryana having acute scarcity of cultivated lands, 0.45 m ha (around 10 percent of total geographical area) suffers from the problem of waterlogging and salinity which imposes, serious limitations for raising crops at least in eight south-western districts namely Rohtak, Jhajjar, Charkhi Dadri, Bhiwani, Hisar, Jind, Sirsa and Fatiabad, and adversely affects the cropping pattern and crop productivity resulting in huge socio-economic losses. In addition waterlogging got aggravated in late sixties and early seventies when the irrigated areas of these districts were brought under paddy cultivation which required excessive irrigation. To tackle these problems, some sub-surface drainage projects were undertaken by the institutes like Central Soil Salinity Research Institute, Karnal and Haryana Agriculture University Hisar in the form of Indo-Dutch collaborative projects. In addition to those many other research efforts were made by these institutes and several agricultural practices were developed. The present studies were undertaken to review the nature of problems being faced by the farmers, possible solutions based upon lessons-learnt from research and implementation experiences and also dovetailing the perceptions of the farmers as key players. Such an exercise may help to identify best agricultural practices, their need and scope of management of saline and waterlogged areas. The primary objectives of this study were comprehensive review of waterlogging and salinity problems in the state; critical analysis of the projects implemented showing the impacts on hydrology, salinity levels, crop production and productivity; identification of emerging best agricultural practices in terms of socio-economic implications; and farmers' perceptions about constraints, bottlenecks in implementation of subsurface drainage projects.

***Key words:*** Saline waterlogged areas, Subsurface drainage, Potential agricultural practices, Socio-economic impacts, Farmers perceptions, Implementation issues and concerns

## Introduction

The food security remains the primary concern of all the nations and the sustainable management of soil health and the water resources are the primary requirements for securing food, forage and fiber production. The decreasing per capita land holding with rise in population is a major concern impacting agricultural production and quite imperative that every piece of arable land must be put to productive use to meet the challenges of food security. In India, the per capita land availability decreased from 0.34 to 0.12 ha between 1961 and 2015 and on the other hand about 147 million-hectare (m ha) land is reported to be suffering from different processes of land degradation. Out of this, about 14.3 m ha area has been reported as waterlogged and 8.6 m ha being permanently submerged (Tewari *et al.,* 2010). The salt-affected soils of Haryana state as per IRS data of 2010-13 (Mandal, 2019), cover an area of 315617 ha (170563 ha alkali and 145054 ha saline) distributed in 18 districts.

In the fast-developing state of Haryana, 0.45 m ha area suffers from the problem of waterlogging and salinity and it has become one of the major constraints for raising crops in eight districts of the state namely Rohtak, Jhajjar, Charkhi Dadri, Bhiwani, Hisar, Jind, Sirsa and

Fatiabad. Waterlogging is adversely affecting the cropping pattern and crop productivity in irrigation command areas of these districts resulting in huge socio-economic losses. With continuous rising of water table in the affected areas, farmers lost their primary income source from agriculture as their lands have become unproductive due to waterlogging and salinity. As such, the overland topographic slope in the state is from north-east to south-west and the flood water moves towards these districts and accumulates in low lying areas. Historically, the problem of waterlogging became more apparent after 1861 as seepage from Western Yamuna Canal and its irrigation net-work started raising the level of groundwater. The problem further aggravated when this irrigated area was brought under paddy cultivation in late sixties and early seventies of nineteenth century. Excessive irrigation to raise paddy crop caused seepage to lower soil layers thus, raising the ground water table. With the rise of water within the capillary zone caused movement of salts on to the surface of soil which became the cause of soil salinity. Unfortunately, there is no system of natural drainage of accumulated water and there is impervious hard soil layer down below which inhibit the deep percolation of water accumulated in the root zone.

The state government, being quite concerned about this problem, operated several state and foreign-funded research-cum-development projects in selected pockets of the area. The ICAR-Central Soil Salinity Research Institute (CSSRI) Karnal and Haryana Agricultural University (HAU) Hisar also provided research and extension support for technology generation and replication but no comprehensive and holistic project was implemented, to tackle this gigantic problem, over the whole region. To increase the crop production and takeout the farmers from the web of poverty, there is an urgent need for developing a comprehensive project for the whole area. The formulation of such an ambitious project requires critical review of the problems, possible solutions based upon lessons-learnt from research and implementation experiences and also dovetailing the perceptions of the farmers as key players. Such an exercise may bring out the need and scope of the best, potential and successful agricultural practices for such salty and waterlogged saline areas. The present comprehensive study has been planned for this purpose and also to study the farmers' concerns and the impact of the studies already conducted on their socio-economic conditions.

## Materials and Methods

The published literature, on the extent and nature of problem of salinity and waterlogging in India in general and Haryana state in particular, has been critically reviewed. The review covers district-wise information on waterlogged and saline soils in Haryana, causes and effects of waterlogging and soil salinity on plant growth, environment, geohydrology, groundwater exploitation with rise and decline in water table, drainage basins, reclamation of saline and waterlogged soils, surface and subsurface drainage systems, and biodrainage and its advantages. Information has been compiled on the analysis of outcomes and lessons-learnt from previous projects with a comprehensive overview of Haryana Operational Pilot Project (HOPP) on sub-surface drainage operated at Gohana and Kalayat. Based on the implementation of HOPP project, several sustainability issues and technical and management concerns have been highlighted. The interaction with the farmers through group discussions, their perceptions about the problem and impacts on the livelihoods has been synthesized.

The NABARD mandated proforma has been used for collection of data at household, village and block level from both treated and untreated site areas. As per the preliminary information, the waterlogging and salinity problem is mainly concentrated in nine districts but Rohtak, Jhajjar, Bhiwani, Sonepat, Mohindergarh, Nuh and Jind are more seriously impacted. The sampling was made on randomly identified 10 farm families from each of 10 villages earmarked in each of two blocks from the selected five districts. The ten farm families covered small, medium and large families. As such, the total number of families and farmers covered were: 5 districts × 2 blocks × 10 villages × 10 families × 1 farmer from each family = 1000 farmers. The proforma was designed to collect data from the farmers of the waterlogged areas indicating the pre-project scenario such as nature of the problem, its impact on the rural life and livelihoods, loss in production and productivity, impacts on livestock and allied agriculture activities. The information was generated, on implementation of the drainage and salinity control projects, participation of rural communities in the planning and design of the projects and implementation problems and constraints; through these set of proforma and group discussions and consultation with stake holders. The data on post project impacts on groundwater, salinity control, crop production and productivity, and income generation were also generated. The data collection survey team composed of highly professional, well qualified and experienced 9 members. The most potential agricultural practices identified from the projects, based on the experience, survey, adaptation, socio-economic perspectives and farmers' perception; have been highlighted in the review.

## Results and Discussion

### General features of the study area

#### *Topography, location, physiography, geomorphology, climate and soils*

Haryana is essentially a plain area with ~94 percent area falling at < 300 meters above mean sea level. The plain area spreads between the hilly tract in the northeast and the sand dunes desert topography in the south and southwest. Whereas the Aravalis are situated in the southern part of the state. The geological set-up of the area comprises the sub-Himalayan system of rocks, mostly belonging to Siwalik Group which is exposed in the north-eastern extremity and adjoining parts. In the south and southwestern corner of Haryana bordering the state of Rajasthan, older rocks belonging to Delhi Sub-group are exposed. In between lays the vast stretch of Quaternary sediments of alluvial/aeolian origin.

The geomorphic setting of the state comprises of Himalayan topographic high in the north and Aravali Mountain in the south resulted in the development of a saucer type of topographic depression in the central part of the state. The state is characterized by a sub-tropical semi-arid climate with a relatively short but distinct monsoon season of about three months (July to September), receiving about 83% of the annual rainfall. Most of the remaining part of the year experiences a dry climate with high evaporation rates. The average annual rainfall varies from 800 mm in the north to 300 mm in the west. The maximum and minimum temperature of 41 and 5°C are recorded in the months of May-June and during December-January, respectively.

The state of Haryana having an area of 44000 km$^2$, lies in the north western part of India on the watershed between the Ganges and Indus River Basins. Nearly the whole state lies in the Indo-Gangetic plain and is an important food grain producer. About 80% area of the state is agricultural land (35000 km$^2$), of which some 24000 km$^2$ can barely be irrigated with the available water resources at present. The north-eastern part of the state is extensively underlain by fresh groundwater that is pumped for irrigation, resulting in certain trends of groundwater level decline. The remaining 28000 km$^2$ is underlain by brackish to very saline groundwater and mainly depends on canal water for irrigation. Losses through deep percolation in the conveyance system and in the fields, and the absence of pumping of saline groundwater resulted in a rapid rise of the water table and subsequent waterlogging and soil salinization. At present 4000 km$^2$ area is critically affected by rise in saline water table and this area may ultimately increase to about 20000 km$^2$.

The saline waterlogged area is predominant in Rohtak, Jhajjar, Bhiwani, Sirsa and Jind districts. Sethi *et al.* (2012) reported physiography, soil types and other features of these areas having problems of salinity and waterlogging.

#### *Drainage basins in Haryana*

About 80% of the surface area of Haryana is agricultural land of which 57% (~ 20,000 km$^2$) is irrigated; approximately 8,000 km$^2$ with groundwater and 12,000 km$^2$ with canal water (HOPP, 2006). The state is divided into three drainage basins (Ghaggar, Inland and Yamuna) covering about 44212 km$^2$ area. The Inland basin is flat and does not have a drainage outfall into the rivers. The rainwater in the inland drainage basin either infiltrates or gathers in pools and in village ponds. Some critical areas have been provided with surface drains which are out-falling into irrigation canals through lift pumps. The surface runoff created by the monsoon rains, drains into the Ghaggar or Yamuna rivers in narrow areas along these streams through a network of surface drains.

The geo-physical map of the state (Fig. 1) indicates that there is depression in the central region where surface water flows from north-eastern and south-western sides to this area causing inland salinity. The contours in the map show that 215 m contour is the lowest one which goes from Delhi to Sirsa almost as a straight line.

The north-eastern part of the state, which is underlain with fresh groundwater, is facing an annual net groundwater decline as a consequence of mining of the groundwater for irrigation. Rest of the state (65% or ~28,000 km$^2$) is underlain with brackish to very saline groundwater and mostly depends on canal water for irrigation. Deep percolation losses both in the conveyance system and in the irrigated fields result in a rapid rise of the water table ranging from 10 to 30 cm per year in the last three decades. Most of the critical areas are concentrated in the Rohtak-Sonipat-Gohana area and to a lesser extent in the Hisar-Hansi. According to an FAO study (FAO, 2013), it was expected that in the next three decades, the area under critical water table depth may register a four-fold increase in case no curative measures are taken. When the groundwater is relatively fresh, the high watertable level can cause a temporary increase in crop yields until the soil becomes too saline. Nearly all districts in Punjab, Rajasthan and Haryana are in the "unsafe" category (Table 1).

The groundwater problem in Haryana has two dimensions. The first is that of rising groundwater table in the areas with poor-quality aquifers,

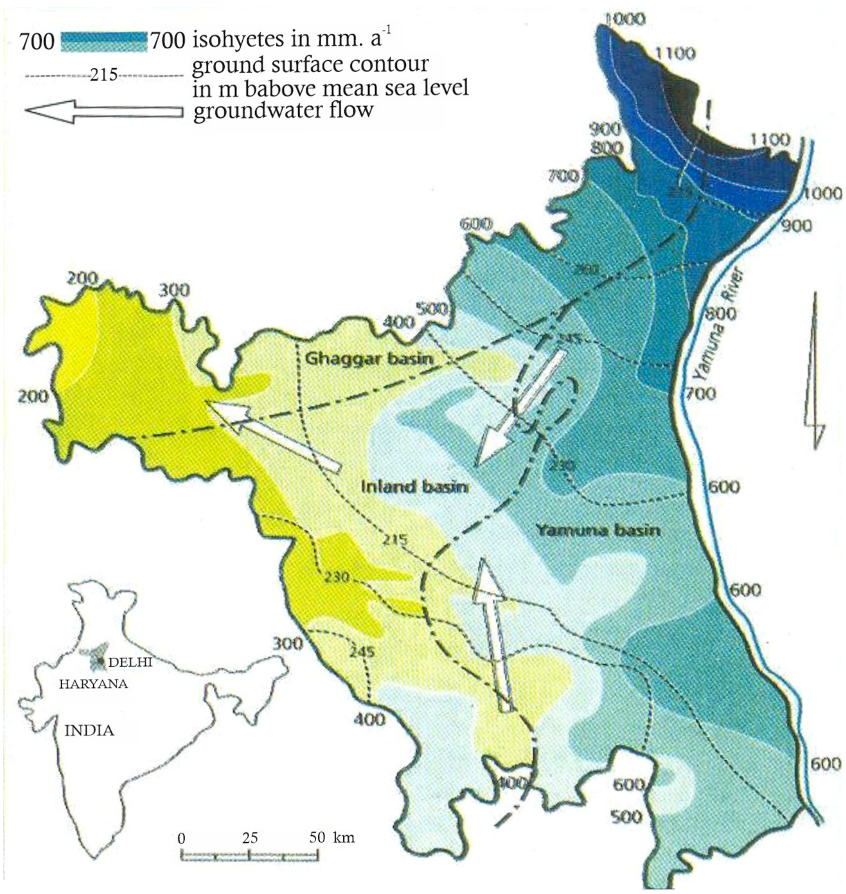


**Fig. 1** Geographic domain of Haryana state

**Table 1.** Proportion of 'unsafe' Districts (GWD>70%) in Haryana and Punjab states

| States | District in unsafe category (%) | | State area affected (%) | | State population affected (%) | |
|---|---|---|---|---|---|---|
| | 1995 | 2014 | 1995 | 2014 | 1995 | 2014 |
| Haryana | 63 | 89 | 46 | 93 | 55 | 97 |
| Punjab | 50 | 94 | 43 | 95 | 52 | 97 |
| All India | 9 | 30 | 5 | 33 | 7 | 35 |

CGWB (1995, 2014)

leading to secondary salinisation and waterlogging. The second is of declining water tables due to over-pumping of groundwater in fresh water quality aquifer zones.

**Waterlogging and salinity problems**

Waterlogging refers to the state of land on which the groundwater table is permanently or even temporarily located at or near the soil surface. As a result, the yield of crops commonly grown is reduced below the normal for the land, or if the land is not cultivated, it cannot be put to its normal use because of high sub-soil water table (Parkash and Mohan 2016). According to Singh (2013) both air and water in appropriate proportion are essential for plant growth and a slight disturbance in this delicate balance effects the physiological growth of the plant. The critical depth depends on the kind of crop, but waterlogging is commonly defined as "light" and "moderate" when water-depth remains within 3 and 1.5 m for substantial parts of the year, respectively. The severe degree occurs when the water table is at 0-30 cm depth, and also when ponding takes place and water rises above the surface (FAO, 1994). The Working Group of Ministry of Water Resources on Waterlogging, Soil Salinity and Alkalinity (MoWR, 1991) also prescribed similar norms for defining waterlogged, saline and alkaline areas.

In Haryana, one third of the agriculture lands are facing the problem of salinity and waterlogging. The water table has risen to variable depths in different regions including Hisar, Sirsa, Rohtak, Jhajjar and some villages of district Charkhi Dadri. It has deteriorated a large chunk of land barren. As per working group (Natural Resource Management) report of Haryana Kissan Ayog (2012), out of 4402 thousand hectares of area in Haryana, more than 50,000 hectares suffers from shallow water table i.e. less than 1.5 meter deep and the degree of salinity in the waterlogged areas varies between 35-40 dS $m^{-1}$. Nearly 50% area faces rising groundwater table and salinity problems and about 10% area (0.44 m ha) has already become waterlogged. Narjary *et al*. (2017) reported that the problem of waterlogging and salinity has severe ill effects on the economic conditions of the small and medium farmers and therefore, their say must be ensured.

Different researchers have identified some main reasons of water logging and salinity.These include closed drainage system, groundwater unsuitable for irrigation, adverse geological conditions, inappropriate cropping pattern and seepage from canal network. In addition to these, deep percolation of a part of the surface water irrigation, applied to meet the high evapo-transpiration demand of the crops grown in arid and semi-arid climate; also leads to rise of saline water table. The groundwater in most of the cases contains soluble salts which come on the surface as the water table rises. Initially, it affects the area in patches. At few places waterlogging is also due to blockage of natural flow of water by the construction of roads and embankments of canals and minors. At present, about 433892 hectare area is waterlogged with water table ranging between 0-3 m. Out of which 54,130 ha falls under critical waterlogging category, where no crops are possible, having water table within 1.5 m. Likewise about 9% area is under potential waterlogging and if preventive measures are not taken here than this will also be rendered as waste land in future.

The Haryana State Minor Irrigation (Tube-wells) Corporation Ltd. (HSMITC) in co-operation with the Food and Agricultural Organization of the United Nations (FAO, 2013), carried out a detailed hydro-geological investigation. This has revealed its lateral and vertical dimensions and hydro-geological characteristics. The groundwater occurrences, movements and behavior, in terms of water level fluctuation with time and space, confirms the coexistence of over exploitation as well as waterlogging in the area.

## Groundwater basins of Haryana

Ground water basins are delineated as per the flow of groundwater direction by using water table contour maps drawn on the basis of elevation of depth to water table with respect to the mean sea level. Haryana state is divided into seven basins, of which three are main as shown in the map (Fig. 2). These include river basins namely the Yamuna basin (16,330 km$^2$) and the Ghaggar basin (10,675 km$^2$) and an internal basin (17,207 km$^2$). The internal basin is physio-graphically depressed. In the absence of any natural drainage outlet, the internal basin has serious waterlogging and salinity problems.

Presently out of total 119 assessed blocks in the state, 64, 14, 11 and 30 fall under over exploited, critical, semi- critical and safe category, respectively. The Central Ground Water Authority (CGWA, 2014), New Delhi has notified 21 blocks to regulate groundwater development in the state. In Haryana, there are approximately 8.48 lakh tube-wells, out of which 2.98 and 5.50 lakh are diesel and electricity operated, respectively. The groundwater quality in about 65% of the area in deep aquifers of the state is not good for irrigation due to salinity (Electric Conductivity (EC) being >2 dS m$^{-1}$). Similarly, about 10% area of the state suffers from waterlogging as on June, 2018. The average depth of water table among the districts of Haryana is continuously increasing but the situation is very critical in the districts namely Gurgaon (now Gurugram), Kurukshetra, Mohindergarh, Rewari and Kaithal.

During the period from 1974 to 2014, the depth of water table nearly doubled in Gurgaon, Kurukshetra, Mohindergarh and Rewari. Interestingly, the water table declined in both the regions i.e. where it was shallow as well as deep (such as Mahendargarh). In contrast, the water table has risen by nearly 2 to 8 m in the areas of Bhiwani, Jind, Hissar, Rohtak and Sirsa. Of 114 hydro-geological blocks in Haryana, 48 per cent are over-exploited.

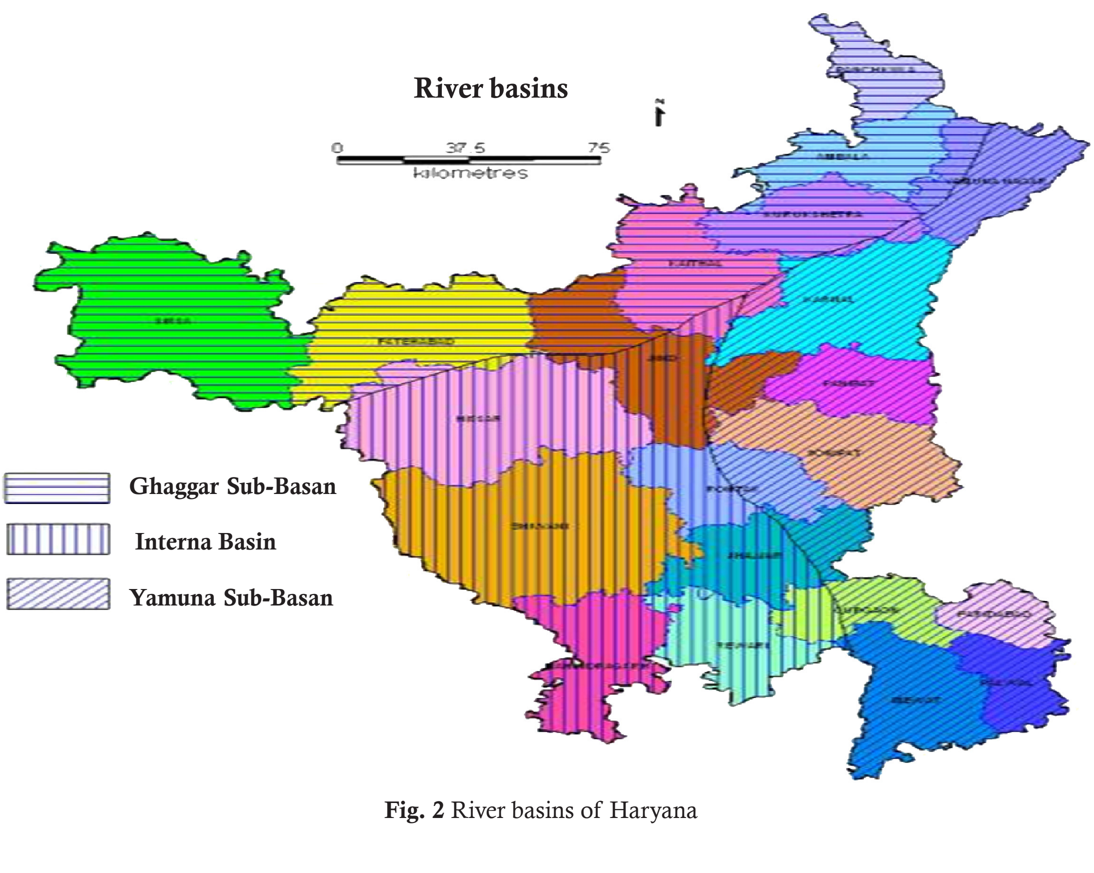


**Fig. 2** River basins of Haryana

### Waterlogging and salinity development

The surface water irrigation facilities, developed with tremendous efforts but without adequate planning, execution and anticipation of subsequent drainage problem, are geopardizing the sustainability of the present level of agricultural production in the state. The problem has been further aggravated by the natural flow of the ground water from north-east to south-west and non-existence of any natural drainage basin or the out let (Singh, 2013). As such the twin problems are the result of a multitude of factors which include: depressional location of the area coupled with the lack of proper drainage system, poor percolation because of impervious layer below, and constant seepage from canals; under exploitation of groundwater resources due to poor quality and excess application of canal water via conventional flooding; and presence of cracks in lined beds (Uppal and Mangat, 1981). In addition to the above, Goel and Kumar (2003) added that the inadequate and faulty planning for regulating the canals also contributed towards the problems. The excessive release of water creates flooding condition at the downstream side and at the time of normal release there is drought like condition at the tail end because of pilferage of water by the farmers.

### Effects of waterlogging

Waterlogging is adversely affecting the cropping patterns and crop productivity in irrigation command area of south-western part and resulting in huge socio-economic losses. Therefore, there is a serious threat of the region turning into a desert over the longer run, if appropriate actions are not taken now (Pathania *et al.,* 2018). The total cultivated area is decreasing and the demand for crop products is increasing. There is a huge pressure on canals to support agriculture, livestock and domestic consumption including drinking water. Natural fresh water lakes are not found in the area. Further, the ponds in the villages are filled by water available from canals. Despite the impressive achievements in agriculture, the cultivated area is decreasing, soil salinity is increasing, and water table is rising at different places. Adoption of rice –wheat cropping system has resulted in over use of water. Due to the new agricultural technology, the demand for water, chemical fertilizers, insecticides and pesticides increased very sharply, which further induced the problem of waterlogging and water depletion, soil degradation and health problems (Parkash and Mohan, 2016). Some of the environmental effects of waterlogging include (Parkash and Mohan, 2016): production of methane to add greenhouse effects; consistent low soil temperature; low crop yields; due to anaerobic conditions, loss of beneficial aerobic bacteria i.e. biodiversity of the soil; promotion in growth of water-loving weeds which compete with the crops for nutrients; and transformation of agriculture land into marshes. Similar effects of waterlogging on plant growth and income have been summarized by Pathania *et al.* (2018).

The general crop productivity losses due to waterlogging and soil salinity are estimated at ₹ 10,000 per ha in irrigated agriculture (Lohan, 2008). Where the lands are a mix of normal fields and fields affected with soil salinity, the average potential damage has been estimated at about ₹ 3,300 per ha in the Gohana Pilot area of HOPP. The salinity and waterlogging also have an effect on vector borne diseases, water supply and sanitation. It also damages buildings, roads and other structures and increases their maintenance costs.

### Sub-surface drainage projects and their impact

The problems of salt-affected soils were first noticed in Haryana (then Punjab) in 18th Century when few soil samples near Munak in Karnal district were analyzed. But the problem at large scale came to notice when irrigation water from Bhakra canal (with more water allowance) arrived in the semi-arid areas of erstwhile district of Rohtak and other adjoining areas. The Haryana Operational Research Project (HORP) was started in early nineteen eighties with technical and financial assistance from the Dutch Government at Sampla village in Rohtak and in the research farm of Haryana Agriculture University (HAU) Hisar. The research and development work of the two HORPs was assigned to the CSSRI Karnal and HAU Hisar, respectively. Three methods of saline land reclamation were tried i.e., sub-surface drainage, bio-drainage, and vertical drainage. The experiments were laid with different parameters like depth of drainage, line distance between the two sub-surface drains. Based upon the findings of this project, one operational pilot project was started at Gohana and Kalyat. After that in mid-1980s, the Agricultural Department Haryana started ten small sub-surface horizontal technology projects (each of 10-20 hectares) of at different places mostly on Panchayat Lands with the technical support from CSSRI Karnal. At few places the outcomes were encouraging; however, at others the projects remained ineffective.

***Haryana Operational Pilot Project (HOPP)***

The HOPP experiences and positive outcomes resulted into the sanction of operational pilot project at Gohana and Kalyat. The project covered 1000 hectares at each site with the financial and technical support from the Dutch Government. The HOPP was formulated as a pilot scale project at an operational level to assess the social, technical and economical parameters of mechanized pipe drain installation in farmers' fields. The project was started in 1995 and could be considered as a new dawn in the field of mechanised drainage with arrival of an agricultural pipe drainage trencher gifted at the end of 1996 by the Govt. of the Netherlands. This was the second largest project for saline land reclamation implemented in the country. The objectives of the project were: the transfer of technology (equipment, knowledge and skills); the construction and operation of two horizontal subsurface drainage schemes (SSD), each of about 1,000 ha in Gohana and Kalayat; creation of a nucleus of an organization capable of implementing SSD on about 2500 ha per year and maintaining the resulting drainage network, and safe disposal of the saline drainage effluent of the pilot areas. Some officers from the Ministry of Rural Development Government of India, New Delhi visited the project area and interacted with farmers. After their satisfaction, a project proposal was submitted to the Ministry of Rural Development and they sanctioned about ₹ 190 million and department purchased two more trenching machines from the Netherland. With this, more work was taken up in Jhajjar and Bhiwani (Dadri area) districts with installation of sub-surface drainage system (Fig. 3).

The Gohana and Kalayat Pilot Projects represented canal seepage induced waterlogging and soil salinity problems. The site of the first pilot area is located on either side of the Bhalot sub-branch and Jawaharlal Nehru Feeder canal from RD 67 to RD 83 (5 km), occupying a 2 km wide strip on both sides in the villages of Bali, Moi, Katwal and Rewara. The site on its north-eastern side is bounded by Gohana-Kharkhoda road while on south-western side by Diversion Drain no 8. Topographically the area is flat with a slope of about 0.05% towards the canals thus, causing seasonal stagnation of water along the feeder canal during heavy rainfall. Most of the lands belong to the farmers except some public lands belonging to the village Panchayats, which are also used for economic purposes. The bulk of the waterlogged saline lands are lying barren with areas nearer the canal covered under some aquatic and semi-aquatic vegetation.

The Kalayat project area in Kaithal/Jind district was located along the northwestern side of the Kurukshetra-Narwana railway line and

**Fig. 3** Subsurface drainage machinery being used in Haryana

spread over the farmlands of four villages namely Kalayat, Kolekhan, Kurar and Kheri Lamba. It represented the general waterlogging and soil salinity problems with drainage outfall conditions into irrigation canals. Topographically, the area is flat with Bhana Brahmna drain as the main drain carrying monsoon surplus towards Sirsa Branch for pumping into the canal. Canal irrigation water was supplied through Bali minor and Kahni minor to the project area at an irrigation allowance of 0.18 cumecs per 1000 ha, which equals to about 40 cm of water. Thus, there is a considerable shortfall in meeting the irrigation requirement of various crops. The farmers depended on groundwater to meet part of the demand.

The total cost was worked out as ₹ 75644 per ha which also included ₹ 8000 as farmer's contribution. In the Indo-Dutch and Ministry of Rural Development (MORD) supported projects, an area of 2406 and 3325 ha and 2406 and 3325 farmers, respectively were benefitted. With the success of these projects, the farmers of other sites owning land suffering from such problems started demanding installation of subsurface drainage and extra funds were generated from different schemes such as Rashtriya Krishi Vikas Yojna (RKVY). With this the work of sub-surface drainage expanded in other areas of the state. In future, action plans on 2348 ha pending area and 1948 ha new area is to be included covering 76 blocks of 14 villages in Sonipat, Rohtak, Jind, Hisar and Faridabad districts. Farmers' drainage societies were constituted and registered for each drainage compact area. Farmers were sensitized about the project and actively involved in the project during different stages of implementation.

**Impact of sub-surface drainage on crop yield and farm income**

Initially, information on average crop yield and income of farmers was collected from some villages where the sub-surface drainage was not installed. It was found that the mean yield of paddy and wheat was 857 and 1179 kg ha$^{-1}$ and income of ₹ 2982/- and ₹ 4196/- ha$^{-1}$, respectively. After installation of SSD, the paddy and the wheat yield increased to 3257 and 3618 kg ha$^{-1}$, respectively and the income increased to ₹ 13978/- and ₹ 18965/- ha$^{-1}$, respectively (Table 2). The average family income from agriculture increased from ₹ 138370/- only before installation to ₹ 1176006/- after installation of drainage.

The crop yield and family income in some villages surveyed before and after installation of SSD in present project are shown in Table 2. The results, however, vary a lot in different villages and blocks depending upon the extent of salinity and management practices being followed by the farmers. For example, percent increase in yield of paddy varied from 28% in Siwana Mal villages of Safidon block to 76.2% in Bakra village of Beri block and percent increase in wheat yield varied from 10 to 37.3 (Table 3).

Thus, it is clear that the paddy and wheat yield and income from these crops registered a quantum jump after the operation of the drainage projects.

**Table 2.** The average crop yield (kg ha$^{-1}$) and income (₹ ha$^{-1}$) and family net primary income (₹) before (B) and After (A) the operation of SSD projects in selected villages of Haryana state

| Sr. No. | Village | Paddy yield | | Wheat yield | | Paddy income | | Wheat income | | Family net primary income | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B | A | B | A | B | A | B | A | B | A |
| 1 | Bhagpur | 2414 | 3244 | 2755 | 3655 | 7270 | 13306 | 10980 | 17640 | 631500 | 882750 |
| 2 | Basana | 1819 | 3919 | 2419 | 4606 | 4285 | 20185 | 7255 | 23546 | 279800 | 955000 |
| 3 | Siwana Mal | 2125 | 2422 | 2866 | 3336 | 7341 | 9407 | 19929 | 18683 | 723250 | 841550 |
| 4 | Bakra | 1947 | 3383 | 2300 | 3739 | 680 | 5856 | 4935 | 12142 | 375750 | 830000 |
| 5 | Gochhi | 1384 | 3336 | 1663 | 3657 | 2095 | 10620 | 2990 | 14146 | 1158900 | 1744750 |
| 6 | Katwara | 1848 | 3126 | 1952 | 3422 | 12891 | 23370 | 15797 | 27574 | 1433250 | 2509000 |
| 7 | Wazirpur | 1764 | 3116 | 2024 | 3459 | 2051 | 11705 | 6681 | 16555 | 335250 | 1099500 |
| 8 | Mokhra | 1534 | 3509 | 1873 | 3071 | 4554 | 17378 | 11680 | 21621 | 465550 | 545500 |
| | Average | 1856 | 3257 | 2231 | 3617 | 5147 | 13978 | 9656 | 18965 | 675406 | 1176006 |

**Table 3.** Percent increase in the paddy and wheat yield after the operation of the SSD projects in some selected villages

| Sr. No | District | Block | Village | Percent increase in crop yield after the project | | Remarks |
|---|---|---|---|---|---|---|
| | | | | Paddy | Wheat | |
| 1 | Jhajjar | Beri | Bakra | 76.2 | 14.6 | Fully functional |
| 2 | Jhajjar | Beri | Gochhi | 40.7 | 37.3 | Fully functional |
| 3 | Jhajjar | Beri | Wazirpur | 47.1 | 14.8 | Fully functional |
| 4 | Rohtak | Kalanaur | Basana | 37.1 | 22.2 | Fully functional |
| 6 | Rohtak | Rohtak | Katwara | 8.1 | 7.5 | Partly functional |
| 7 | Jhajjar | Beri | Bhagpur | 8.3 | 6.1 | Partly functional |
| 8 | Sonepat | Kathura | Kathura | 3.8 | 3.4 | Partly functional |
| 9 | Jind | Safidon | Siwana Mal | 2.8 | 1.0 | Limited function |

However, the increase was very high when the projects remained fully functional but that advantage decreased under partially or limited operation of the projects.

**Reclamation of saline/ waterlogged soils**

The solution to the twin menace of waterlogging and salinity is regulated by control of water table and salinity and in broad terms improved water management (for both irrigation and drainage). The strategy to solve these problems includes:

- To use a *surface drainage system* to prevent inundation of soils by monsoon rainfall and to evacuate part of subsurface drainage discharge to the place of reuse or final disposal.
- To use a *subsurface drainage system* to evacuate salts, which have been leached from the root zone by the downward percolation of excess rainfall and irrigation water
- To leave the deep, highly saline groundwater, as deep as possible.

Subsurface drainage evacuates excess groundwater along with the leached salts. For the state of Haryana, the possibilities for disposal of saline drainage water towards rivers, lakes etc. are severely limited. It is, therefore, necessary, to re-use the drainage water as much as possible, either directly or by mixing it with canal water. This implies the necessity to keep the salinity of the drainage water as low as possible and the depth of drainage should remain within the fresh or brackish water overlying the saline ground water.

Generally, the salinity of groundwater increases with the depth. Therefore, to minimize the salt burden of the drainage water, a drainage system aimed at skimming the upper water of the aquifer had to be selected for Haryana. Since a large part of the affected area is underlain with saline groundwater where presence of sweet groundwater and favorable aquifer is within 12 to 20 m, horizontal drainage system was selected for Haryana Operational Pilot Project (HOPP). Besides this, already the vertical drainage in the form of tube wells has been practiced widely in the state.

**Subsurface drainage**

Subsurface drainage (SSD) has proved as an effective technology for the amelioration of waterlogged saline irrigated lands by maintaining water table below desired depth and draining excess water and salts out of the area. However, it being a collective activity, needs appropriate institutional arrangements for farmers' participation (Ritzema *et al.,* 2008). Based on the experience of manually installed subsurface drainage projects, following observations are appropriate to made:

- The reclamation of waterlogged saline soils with subsurface drainage is a technically and economically feasible solution since it leads to considerable increase in cropping intensity, crop yields and shift to more remunerative cropping pattern.
- Subsurface drains of 65 to 80 m spacing and 1.5 to 1.8 m depth can provide adequate water table and salinity control for potential crop production in waterlogged- saline soils. For

arid regions of Haryana and Rajasthan, drain spacing up to 100 m can tried.

- Research output, from field studies and extensive numerical modeling results contributed to acceptance of shallower drains (1.4- 1.8 m) in arid and semi-arid regions of India and other countries.
- In areas with suitable outlets, rainwater leaching through drainage during the rainy season is adequate to maintain the favorable salt balance of drained fields. The quality of drainage effluent improves after 1-2 years to levels for possible use in irrigation. After reclamation through leaching, the water table rise due to the suspension of drainage during non- rainy season can contribute up to 50% crop water needs.
- Reuse of drainage water for irrigation of salt tolerant crops is an option to handle large volumes of saline drainage effluent. Drainage waters of about 10 dS $m^{-1}$salinity can be used directly or in conjunction with canal water in blending (mixing) or cyclic (sequential application) mode for irrigation of barley, wheat, and mustard in the winter season. Salts added through use of saline drainage water were leached down with monsoon rains or by a pre-germination irrigation with canal water.
- In inland areas without an outlet, evaporation ponds with the surface area of about 5-10% of the drainage area offer an interim solution for managing saline drainage effluent. The quality of pond water deteriorates with time and seepage losses can be significant during initial years in ponds constructed in the sandy substratum.
- Analysis of financial feasibility of manually installed SSD projects indicated a benefit: cost ratio of 1.26 and viable internal rate of return of 13.3%.

The cost of funding of SSD projects has been recommended as INR 74000 $ha^{-1}$ and INR 79000 $ha^{-1}$ for drain spacing ($D_s$) of 67 m and 60 m, respectively and pumped outlet in medium textured soils of Haryana and other north-western states.

***Performance of SSD projects in Haryana State***

Out of 10584 ha area provided with SSD over last 2 decades in Haryana, more than 8000 ha has been installed in the past 12 years. Currently, CSSRI is associated with design, monitoring and evaluation of 5 SSD projects implemented by the Haryana Operational Pilot Project (HOPP) of Ministry of Agriculture in 600-1000 ha area in Rohtak, Jhajjar, Jind and Sonepat districts. Some critical results on the performance of some SSD projects are presented below:

- Activities under HOPP are quite comprehensive involving detailed investigations starting from identification of the problem areas, preparation of designs, layout and cost estimates of SSD projects for funding and implementation of the project
- HOPP has 3 sets of laser-controlled trencher and bucket excavators and supporting machines. Each fleet of machines install subsurface drains in 300-400 ha area depending upon breakdowns or unexpected rains during summer (mid-April to end June) working months when water table is below 1.5 m.
- Due to less concrete progress on construction of pump house, distribution of pump sets to farmers' societies and farmers' participation in post-reclamation pumping of drainage water, the improvements in crop yields and economic return have remained non-satisfactory at a number of SSD projects in Haryana.
- The technology provides a net present worth of about INR 65000 $ha^{-1}$ with benefit-cost ratio of 1.76 and 20% internal rate of return. The material and mechanical installation costs cover about 60 and 40% of the total cost.

Despite bottlenecks in efficient pumping of drainage water, significant improvement in water table control, reduction in soil salinity and improvement in crop yields were observed in selected blocks of certain SSD projects where pumping was initiated either by HOPP or individual farmers' efforts. The operational cost of the drainage system in northwestern states is mainly due to pumping of the drainage effluent.

After one or two years of operation of the drainage system, the quality of drainage effluent improves to a level where it can be reused for irrigation. High costs, socio- economic and environmental issues relating to disposal of saline drainage effluent, need of community participation for system operation and existing institutional/ organizational constraints are the major deterrents to rapid increase in the pace of reclamation projects. Involvement of farmers, sharing of construction and operating cost and government subsidy are vital to the success of SSD technology. Keeping in view the quantum of the problem and despite tangible benefits in terms of productivity gains and on farm employment generation, adoption of this technology is quite slow. Major institutional and organizational changes and new business models are needed for expediting the implementation of SSD projects, especially in north-western Indian states.

***Disposal and management of saline drainage water***

Subsurface drainage water generally contains high concentrations of soluble salts and plant nutrients, and may sometimes also contains potentially toxic trace elements and pesticides. Depending on the location, hydrology and topography of the drainage basin, the possible methods for disposing saline drainage water in north-western regions include: (i) disposal into regional surface drainage system which are ultimately linked with major rivers flowing through the region, (ii) pumping into the canal distributaries that carry high flow discharge for most of the year and (iii) disposal into evaporation ponds in land locked depression areas not having a suitable drainage outlet. Options of disposal of saline drainage water into canal distributaries are covered briefly here while of bio- drainage are covered separately in another section.

***Sustainability issues of SSD***

The post-project sustainability in terms of continued operation, maintenance and flow of dividend as planned is very important for ultimate success of a program. Many projects look attractive at planning stage but loose steam during operation due to lack of community participation and end up with sub-optimal results. The sustainability concerns and issues should be main steamed in any project concept and design. The process of reclamation of saline and waterlogged soils is not a one step program. It involves series of operations both at pre- and post-project stages and need well-designed plan of handing based on the community participation for after-care and long-term operation. The capacity building of management committees has to be built up to a maturity level before handing over the projects at the village level. Based on the long experience of working with SSD projects, the sustainability issues are summarized as following:

1. Farmers are not coming forward to operate the system after its installation and handing-over because they consider it a Government project and expect the operation by state agency.
2. Machines deployed for the laying of system are not repaired in time due to paucity of funds at the field level causing delay in project completion.
3. Various types of machines and material are required for laying the system such as pipes of different sizes, filter material, sump pipes, diesel for machines and readiness of trenching machines, excavator, tractors, dozers etc. If any one of them is not ready in time then link in the chain is broken and work held up.
4. The work of sub-surface drainage is taken up in the hottest months of the year when weather conditions are hostile i.e., in April to June and at that time operators/drivers are reluctant to go to the field. Some incentives for working in such a hostile environment is demanded by the workers.
5. The well-planned monitoring and evaluation system at different stages of implementation is lacking.
6. The sub-surface drainage system is laid below the ground and it is not visible. The results are reflected in the crop yield at a later stage. People do not appreciate its usefulness until and unless they understand it finely at a later stage.

7. Farmers in the upper area of the sump do not co-operate with lower end farmers where sump is installed and complain that lower area farmers are using water of the upper area farmers.
8. After one or two years, salinity in the discharged water is reduced and it can be used again for irrigation and many farmers of upper area don't want this to happen.
9. There is no provision in the system to monitor and clean the system if clogged after its installation. This is the work which beneficiary should do or some maintenance funds should be credited to the management committees.
10. Keeping in view the inadequate staff strength, the work of sub-surface drainage is got done through contractors and department staff prepare the estimate and supervise the work being executed as per the specifications. The problems associated with the quality of contract work creep in leading to delay in payments
11. There is no technical cell at the Head Quarter in the department as a result of which there is always gap in planning, execution and monitoring.
12. Social component of the project is weak and should be strengthened to motivate the farmers to operate the pumps.
13. Benefits of this technology which are very impressive have not been well documented and shared at the higher level thereby getting low priority in the department portfolio.

***Issues to complement SSD***

- The water table can be lowered considerably by decreasing the area under rice cultivation.
- Promotion of low water demanding crops like cluster bean, mustard and pulses so as to decrease demand for irrigation water.
- Further, agroforestry with consideration of biodrainage can minimize the waterlogging problem. It is a cost-effective approach and involve participation at individual farmer level.
- There is a need to adopt irrigation practices with minimum surface flooding particularly in case of rice.
- Proper land leveling can also help in preventing the water collection in depression. Laser leveling with subsidy should be promoted.
- Soil structural stability can be improved by amending the soil with manures and incorporation of crop residues.
- Other suitable measures, like subsidizing low water demanding crops, providing suitable and approachable market place to sell the produce, may be adopted at government level.
- The constructed drains should be maintained so that these can be kept in good condition for easy flow of drained water.
- The problem of waterlogging in areas, where adjoining area has no groundwater and soil salinity, can be handled by pumping out the accumulated water for irrigation.
- Since waterlogging adversely affected the crop productivity in such saline waterlogged areas. So there is an urgent need to educate the farmers to promote rural non-farm activities. Besides this, government should provide low interest loan to the farmers for establishment of various income generating ventures.
- Last but not the least, to overcome the problem of waterlogging, crop insurance should be implemented earnestly.
- There is a need for the development of an appropriate organizational, technical and administrative framework to tackle the problem of waterlogging and drainage at the national and state level.
- There is an urgent need to review the existing canal system in the region and careful planning on the part of the state government for regulating the canals.
- The maintenance of the canals along with desilting should be done on regular basis to avoid seepage and overflow, which ultimately causes flooding in the neighboring areas. All the unlined canals should be lined in a phased program.

- The farmers should be encouraged and incentivised to install tube-well and tap the less saline groundwater.

## Alternate land-use options for management of saline and waterlogged soils

### *Afforestation/agroforestry for saline soils*

Based on long-term experiments, it has been established that trees like *Prosopis juliflora, Tamarix articulata, Acacia farnesiana*, *Parkinsonia aculeata* and *Salvadora persica* can be raised successfully on saline soils (ECe 25-30 dS $m^{-1}$) using sub-surface planting and furrow irrigation technique. Likewise, *Acacia nilotica, A. tortilis, Casuarina glauca, C. equisetifolia, Callistemon lanceolatus*, *Eucalyptus camaldulensis, Feronia limonia, Leucaena leucocephala* and *Ziziphus mauritiana* are suitable for soils with ECe 15-25 dS $m^{-1}$. Other species including *Eucalyptus tereticornis, Terminalia arjuna, Dalbergia sissoo, Emblica officinalis, Guazuma ulmifolia, Punica granatum, Pongamia pinnata, Samanea saman, Acacia catechu, Syzygium cuminii* and *Tamarindus indica* could be grown satisfactorily only at ECe< 10 dS $m^{-1}$.

Among forage grasses, *Leptochloa fusca, Sporobolus helvolus, Cynodon dactylon, Brachiaria ramosa, Dactyloctenium aegyptium, Dichanthium annulatum, D. caricosum, Panicum maximum, Digitaria ciliaris* and *Eragrostis* sp. are found suitable for silvo-pastoral systems on saline conditions. Species such as *Atriplex amnicola, A. lentiformis, A. undulata,* and *Leptachloa fusca* can produce 50% of potential biomass on saline soils of ECe 20-30 dS $m^{-1}$. While many others such as *Sesbania aculeata, Leucaena leucocephala, Medicago sativa, Lolium multiflorum, Echinochloa colonum*, and species of *Panicum* tolerate the maximum salinity up to EC 10-12 dS $m^{-1}$.

## Biodrainage

Biodrainage is *"pumping of excess soil water using bio-energy through deep-rooted vegetation with high rate of transpiration*" (Dagar *et al.*, 2016). This system consists of fast-growing tree species, which absorb water from the capillary fringe located above the ground water table. The absorbed water is translocated to different parts of plants and finally more than 98% of the absorbed water is transpired into the atmosphere mainly through the stomata. Conventional methods of drainage are not only costly but also cause eco- degradation and leaching of nutrients. Generally the plants have large leaf area, deeper roots and fast-growing habit. They are friendly with co-crops i.e., do not produce any allelopathic substance to inhibit growth of crops. The best example is *Eucalyptus* having very high rates of transpiration (about 1250 liters per day). Fast-growing species like cloned *Eucalyptus,* known for luxurious water consumption under excess soil moisture condition are suitable for biodrainage. These species can be planted in blocks along canals or in paired rows on acre-line or in wider spaces on raised bunds in the form of farm forestry or agroforestry. Other suitable species for block plantations are *Casuarina glauca, Acacia ampleceps, Terminalia arjuna* (Arjun), *Pongamia pinnata* (Papri) and *Syzygium cuminii* (Jamun) etc. But so far *Eucalyptus* has been found to transpire highest amount of water as it can be planted in closer spacing.

### *Advantages of biodrainage technique*

The merits of biodrainage technique over the conventional engineering-based drainage systems are as given below:

- Farmers realize benefits of drainage but are too poor to pay cost of drainage, whereas raising biodrainage plantations is relatively less costly and affordable.
- Biodrainage requires no maintenance after initial establishment
- No operational cost, as the plants use their bio-energy in draining out the excess ground-water into atmosphere.
- Ecologically safe as drainage effluent is not produced.
- Preventive as well as curative system for water logging and salinity
- Provides recreational areas and green open spaces, supporting beekeeping.
- Sequesters carbon and earn carbon credits
- Moderates the temperature of the surrounding by transpiration thereby proofing for heat and cold waves

- Mitigates greenhouse gases by absorbing $CO_2$ and releasing $O_2$
- Acts as a wind break and protect crops in agro-forestry system
- Provides higher income to the farmers due to the production of food, fodder, timber, fuel wood and other valuable products. It's worth increases with age instead of depreciation
- Biodrainage stabilizes soil on raised bed as highway avenue plantation
- In case of biodrainage, there is assured people's participation as the biodrainage plantations on farmers' fields belong to the individuals.
- The control of soil salinity and waterlogging provides additional land for cultivation
- Increase in cropping intensity and soil organic carbon build-up
- More choice among arable crops including pulses and oilseed which otherwise are sensitive to waterlogging and salinity
- Timely sowing of crops thus facilitating better yield and profits
- Higher crop yields and nutrient use efficiency
- Increased employment generation and poverty reduction

***Suitability of biodrainage***

The evaporation from the soil may take place up to a maximum depth of 4 m. Therefore, this 4 m soil depth should be kept free from waterlogging to minimize the process of secondary salinisation of soils and to sustain the crop productivity in canal command areas located in arid and semi-arid regions. For this, we need fast growing trees like cloned *Eucalyptus* having their root system penetrating at least up to this depth. The biodrainage technique could be applied in two contexts viz. curative (for critical waterlogged areas) and preventive (for potentially waterlogged areas). Along most of the canals, there is critical or potential waterlogging due to seepage. All these areas need to be planted with a belt of suitable deep-rooted trees. Further, as mentioned above, many districts such as Jhajjar, Rohtak and Sonepat have grave situation of waterlogging where respectively 45.5, 53.4 and 35.3 percent of total area is critical or potential waterlogged. This has not only caused economic crisis but also social concerns as youth without jobs have gone astray and engaged in unlawful activities. However, biodrainage can serve as a viable alternate option for the reclamation and management of waterlogged saline soils in canal command areas.

Situations where conventional surface and sub-surface drainage is not feasible and is costly, biodrainage alone or/and in combination with drainage should be practiced. This approach of integrating trees like *Eucalyptus,* having high transpiration rate as a part of farming in rising ground water areas of canal commands, has tremendous scope to reclaim land, improve productivity, increase forest cover, earn carbon credit for farmers and clean the environment. Now there is a strong case for developing policy guidelines for promotion of biodrainage for generating livelihood security and poverty alleviation of farmers in irrigated arid and semi-arid regions.

***Farmers' perception about biodrainage***

Initially, the farmers were not willing to have tree plantation on their farm lands because of the priority on the production of food grains and fodder. But, after observing the survival and growth and of parallel strip plantations of clonal *E. tereticornis* and accrued higher financial returns from wood production in experiments conducted at Puthi (Jeet Ram *et al.,* 2011; Dagar *et al.*, 2016), almost all the farmers of the village and surrounding villages have been approaching the Forest Department (Govt. of Haryana) to develop similar plantations on their farm lands. As a result, many thousands ha of waterlogged area on farmers' fields have been brought under biodrainage strip plantations in many districts under various schemes operated by the Haryana Forest Department. Rather farmers are demanding to plant trees under Community Forestry program in wider spaces between paired-strips in agroforestry mode so that they can harvest maximum benefits from *Eucalyptus* with understory arable/fodder crops in terms of lowering of water table and realizing economic yield. After lowering down of watertable, many farmers are also found cultivating vegetables in the inter-spaces.

Following recommendations may be made safely for biodrainage technique:

- Properly designed parallel strip plantations of *Eucalyptus tereticornis* on acre-line or in wider spaces (at 5-6 m space) in crop fields on raised bunds may be raised for the uniform reclamation of waterlogged areas of semi-arid regions having alluvial sandy loam soils.
- Biodrainage plantations must also be raised on potential waterlogged areas (specifically where ground water level is 3-6 m) to prevent their conversion into wet desert.
- Sewage water can safely be used for wood production raising *Eucalyptus* trees instead of using such waters for food and fodder crops.
- Community forestry program must be implemented/strengthened in all waterlogged districts with active participation of farmers
- Policy guidelines for promotion of biodrainage for generating livelihood security, earning carbon credit and poverty alleviation of farmers in irrigated arid and semi-arid regions should be formulated.
- As the trees take at least 5-8 years in getting mature, hence the tree plantations must be insured on reasonable cost so that any damage due to natural calamities must be met by the insurance company
- In waterlogged areas small wood industries must be established so that farmers are encouraged to grow *eucalyptus* and get reasonably good price for their wood products

**Scope of aquaculture in saline waterlogged areas of Haryana**

At the time of creation of the Haryana state in 1966, only 58 hectare of village ponds were under fish culture and total fish production was 600 Mg. The fish production has increased to 23,200 Mg by 1990, 33,040 Mg by 2000 and nearly 1 lakh tons by 2010 (Haryana Kisan Ayog, 2012); followed by more than 4 times during the last two decades constituting 2.1% of India's inland fish production. While area under fish culture has grown, there has been higher growth in productivity with average state yield being 4914 kg per ha per year (Haryana Kisan Ayog, 2012) which is twice of national average. Fisheries sector sustains 10,585 fish farmers directly, with another 22,595 persons engaged in fisheries trade. At present Haryana has 18,000 ha of aquaculture area and about one lakh tons of fish production. With the pond resources fully exploited in Haryana, the unutilized salt-affected and waterlogged areas also hold the potential for fisheries development in the immediate future.

As per the Working Group Report of Haryana Kisan Ayog (2012), only 123 ha (0.52%) of salt-affected areas and 104 ha (6.2%) of waterlogged area have been brought under fish culture so far. These little efforts / initiatives have happened only in the districts of Mewat, Palwal, Hisar, Rohtak and Sirsa which together account for almost 100% of area. Mainly carp culture is practiced in these marginal / problem soils. Lack of any major program or scheme targeted towards these areas; and that of technological backstopping through adaptive trials and demonstrations were major reasons for such dismal state. However, these soils were identified and considered as potential areas for fish culture (Haryana Kisan Ayog, 2012). Re-circulatory water system needs to be adopted for high yielding and high value species like Sea bass, Tilapia, Shrimp and Prawn. Technologies to undertake aquaculture in inland saline soils, by using saline groundwater have been developed by CIFE. Nevertheless, the farmers need to be encouraged to adopt these technologies in salt-affected fields by providing subsidy for construction of ponds and inputs and training of farmers and monitoring of farmers' ponds by fishery experts and officials. Integrated farming systems with fishery as a component are still in a pre-adoption stage in Haryana. The State Government may establish model integrated farming units with various combinations (of aquaculture, animal husbandry, poultry, piggery, horticulture, etc.) which complement one another and effectively utilize available resources. The farmers may be incentivized to opt for integrated farming systems.

**Fig. 4** Shrimp farming in Popra village District Karnal with saline water

The ICAR-CSSRI, Karnal, Haryana (India) has worked out the feasibility of commercial fish-farming in highly saline conditions (CSSRI, 2011, 2014) and demonstrated that fish growth of 400-600 g in 6 months and 600-800 g in one-year period was possible. Improved understanding of the physiology of white shrimp has resulted in the development of effective culture techniques (Fig. 4) and strategies for farmers utilizing low salinity water as available in waterlogged areas of Haryana. There is a need to standardize the cultural practice which should be region specific and develop the efficient market chain system. At the same time, we need to look upon the effective R & D to address the constraints of the farming system like the use of antibiotics and waste discharge disposal system for the sustainable growth of saline aquaculture. The saline aquaculture needs the introduction of low-cost, low-risk species for sustainable development of inland saline water aquaculture with special reference to small and poorer farmers. There is also need for starting Public Private Partnerships (PPP) mode to ensure the supply of inputs like seed, feed, support for marketing, processing and exports to consumers centers.

## Water management related technologies

### *Drainage (surface and sub-surface)*

It is well established fact that irrigation and drainage must go hand in hand for maintaining the hydrological equilibrium. The lack of planning for drainage has contributed significantly in present problem of rising water table in south western region in Haryana. Subsurface drainage system is quite effective in lowering the water table of saline ground water. However, there are two main problems associated with the operation of this system; a) there is no natural outlet in the state to take out the drainage effluent and b) the groundwater salinity-rise with the depth and fresh to marginal water is overlying the saline water. In view of the above, the water at the lower depth should be drained or pumped by the sub-surface drainage so that salt load of the drainage effluent is minimized. This can be achieved by installing horizontal or vertical drainage.

An optimal and appropriate drainage system offers the best remedial measure to tackle waterlogging problem. Broadly, the drainage systems are classified into two categories i.e. surface and sub-surface drainage. Surface drainage is the removal of excess water with the help of open ditches, field drains, and land grading and related structures suitable for the existing site conditions. The slope of the land should be such that it allows sufficient drainage towards collection or interceptor drain made to divert the flood and seepage water towards safe location. Sub-surface drainage in the form of horizontal, vertical or combination of both **is** required for soils with poor internal drainage capacity having high water table. Drainage wells are other form of sub-surface drainage. Although the implementation of this drainage system is expensive, yet it helps in avoiding waterlogging effectively and increasing crop yields. However, as the sub-surface drains tend to get choked in due course, their proper maintenance is necessary.

***Micro-irrigation system***

This method is becoming increasingly popular in areas with water scarcity and especially suited to semi-arid regions characterized by saline soil and saline groundwater. In order to reverse the waterlogging conditions, it is important to apply as little water as possible preferably in the root zone. This would progressively bring under control the degree of capillary rise and salinity levels in the root zone since salts get accumulated in the wetting front zone. Under drip irrigation system, soil remains quite moist due to frequent irrigation and the salt in the soil remain diluted. Using brackish and saline water through drip is one of the most effective ways to solve the problem of water resource shortage. Drip irrigation not only saves 40-60 per cent water but also helps in bringing the more area under high value, low water requiring crops, specifically, fruit orchards. Under brackish water irrigation, drip irrigation favorably modifies salt and water distribution in such a way that it reduces the adverse effects of salinity and alkalinity on soil properties and crop growth. The system also gets higher yield and better quality of fruit, lowers the annualized long-run cost of production and increases the farmer's income. The sprinkler system of irrigation can successfully be adopted in the areas where the EC of saline water is up to 6 dS $m^{-1}$ and canal water is also available for pre-sowing irrigation. Improved water management practices such as proper leveling of field, lining of channels and water courses, conservation of soil moisture are suggested in such areas. The impacts of micro-irrigation on socio-economic conditions of Haryana farmers have been discussed in the same issue of the Journal by Grewal *et al.* (2021).

***Mulching to reduce evaporation***

Reduction in evaporation losses under irrigated agriculture is particularly important to minimize salt accumulation in the root zone when the saline water is used for irrigation. The results from several experiments demonstrated the beneficial effects of mulching in the form of a better crop response as well as management of root zone salinity. Locally available material such as paddy straw can be used for mulching.

***Conjunctive use of surface and groundwater***

The conjunctive use of surface and groundwater serves the dual purpose of increasing the area under irrigation by utilizing the groundwater on one hand and lowering the adjoining water table on the other, thereby, reducing the possibility of waterlogging. Farmers using canal water for irrigation purposes should be sensitized and urged to switch over to the alternate use of canal and tube well water without any significant yield penalty for rice-wheat rotation. The exact ratio in which surface and groundwater should be used can be determined after testing the available groundwater.

***Crop management related technologies***

In addition to water management, certain crop management strategies are also helpful in mitigating the adverse effects of rising underground water table to certain extent. These include:

***Deep tillage***

Deep tillage is required for preventing soil damage by waterlogging. A harmful compacted layer develops within or at the bottom of the regularly cultivated soil layer and hinders optimal crop production.

***Choice of crops- diversification-shift from rice-wheat***

There is an urgent need for crop diversification to reduce the area under water intensive rice-wheat system. The shift in cropping pattern is very important to overcome the problem. Crops which require less water and tolerant to salt should be preferred. The crops like sorghum and paddy are well suited for cultivation in high water table conditions. Among plantation crops, date palm is emerging as a potential crop for waterlogged conditions. Jackfruit, *jamun* and *karonda* are other fruit species which can tolerate waterlogging to some extent. Aquatic economic species such as lotus, water spinach, water lily and water lettuce can also be cultivated. Also, the potential of oil palms can be explored in these areas.

***Sowing time and seed rates***

Seeding crops early and using long season varieties help in avoiding crop damage by water logging.

Crop damage is particularly severe, if plants are waterlogged between germination and emergence. First, sowing should be done in that part of the field which is susceptible to waterlogging. If waterlogging delays the emergence and cereal plant density is reduced <50 plants per $m^2$, then re-sowing of the crop is suggested. Increased seed rates give some insurance against uneven germination/reduced tillering and also increase the competitiveness of the crop against weeds.

#### *Cropping methods*

*Raised bed/Ridge plantation:* The level of land can be raised sufficiently high to support the plant growth under high water table conditions. But it involves higher costs. Therefore, to reduce the cost, raised bed/ridge plantation can be practiced. Ridges are made up to ~1m depending upon the situation and plants are planted on the ridges. Ditches can also be made on either side of the ridge to facilitate the outflow of extra water from the root zone. This system is widely practiced for growing annual crops worldwide. For perennial trees, the technique is highly useful, particularly, during initial establishment years. However, the specifications of this system for raising fruit orchards successfully and the constraints thereof are yet to be tested scientifically

#### *Optimal use of fertilizers*

Considering the scope of use of saline drainage water, optimal use of fertilizers has the potential to improve water productivity provided that the depth of water table is 1.0-1.5 m. The optimal use of fertilizers, particularly nitrogen can mitigate adverse effect of waterlogging and salinity to some extent. Further, the potential of foliar fertilization under stressed conditions has also been well established. Addition of organic manures and other related amendments are also beneficial under such circumstances.

#### *Weed management*

Weed density affects the crop's ability to recover from waterlogging. Weeds compete for water and the small amount of remaining nitrogen. Hence, the waterlogged parts of a paddock are often weedy. If herbicide resistance is not a problem, spray the weedy areas with a post-emergent herbicide when the paddock is dry enough to allow access, provided the crop is at an appropriate growth stage

### Farmers' perceptions of the problem and impact on livelihoods

Interaction with farmers and records of their perceptions with impact on livelihoods, about the waterlogging and salinity problems, is one of the objectives of this review. The members of the expert team interacted with the affected farmers during the field visits. Very interesting results have emerged from such individual and group discussions which are presented here in brief:

- One project at village Katwara covers about 1000 acres (405 ha) of land (40% of the total cultivated land of the village) under the sub-surface drainage. The groundwater up to 10 m depth is marginal while below that highly brackish. The village had 8 pumping stations of which four pumps are working regularly where the individual farmers had installed electric motors. Two beneficiary farmers informed that earlier production in their fields was about 2.5-3.0 Mg $ha^{-1}$grain yield (both of wheat and paddy) but with installation of drainage system, the average yield increased to about 5.5 Mg $ha^{-1}$. Almost 300 farmers were covered under the project. One farmer owns ~ 32 ha of land out of which 22 ha was barren. He hardly produced about 0.5 Mg $ha^{-1}$ total grain yield. But after installation of SSD, he used to get 5-6 Mg $ha^{-1}$ grain yield of each crop (wheat and paddy). He has installed a solar pump. In this area, people have also gone for *Eucalyptus* plantation in a big way to get extra income. A good sugarcane crop is standing where drainage system is working.
- Survey team visited village Kahni and interacted with farmers. There are four pumps in their block and all are electrified and the system is working efficiently. They informed that earlier about 75% area of the village remained barren and hardly one could get 1.0 to 1.2 Mg $ha^{-1}$ total grains. However, after installation of SSD they also started getting an average yield of 2.5-3.0 Mg $ha^{-1}$ for wheat and 4.5-6.0 Mg $ha^{-1}$ of paddy from the same

fields. One farmer who cultivates about 70 ha informed that earlier he used to harvest hardly 1.1-1.5 Mg $ha^{-1}$ of each crop but now harvests 5-6 Mg $ha^{-1}$ of each crop getting the advantage of SSD. Farmers were satisfied with the operation of subsurface drainage system and suggested that solar operated pump with proper enclosures can work efficiently in this system.

- The survey team visited Jhajjar district and found that the major problem was in Beri block and also in Dujana and Dighal villages. Forest department has planted *Eucalyptus* in large areas, some of those survived and some remained inundated for quite some time. Dighal, on Jhajjar-Rohtak road is a large village surrounded by ponds and ~1100 ha of land is impacted by the problem of waterlogging. Dandla is a link drain which overflows and accentuates the problem of rain water accumulation. Almost 50 percent area of the village is impacted and variable solution is not visible. The drainage system made along the road remains clogged. The entire village is surrounded by ponds of large size. The Gram Panchayat has given the ponds on contract for fish rearing. Since village wastewater also drains in these ponds, the water quality has deteriorated impacting fish rearing and also not good for livestock. Many houses and other buildings are also in depleting condition.
- The area of Kathua village situated on Gohana- Lakhan Majra road is very seriously impacted by the problem of waterlogging. The drainage is also chocked. Whole of this area is under wheat-paddy rotation. Recently a sub-surface drainage project has been implemented by the Soil Conservation wing of the state Department of Agriculture. There is a proposal of laying of sub-surface drainage system in 11 blocks in about 500 ha area. Out of these, in six blocks sub-surface system has been laid in ~about 280 ha. There are 38 farmers in this block. In sizeable area there is no cultivation of crops due to excessive waterlogging and salinity. At most places, engines have been provided but the diesel cost is so high that the committee formed by the Department is unable to collect funds from individual farmers to operate the engines. Farmers suggested that either the electric connections be given to operate the motors or solar system may be installed. Some of the farmers have lifted water from the sump wells by using their individual engines and irrigated the paddy crop during dry spells. They suggested that complete system in perfect operating condition should be handed over to the committee. They are dependent on the system and do not want to invest a meager amount for operating the system.
- As per the recommendations of the Haryana Agriculture University Hisar, and CSSRI Karnal, fishery should be tried in areas which remain permanently waterlogged throughout the year. The Department of Fishery, Govt. of Haryana tried this technology at several locations in such waterlogged areas. One of the demonstration areas was located in village Chiri near Village Kathura. It was informed that a big chunk of saline soil lies totally

**Fig. 5** Cultivation of fish in fish-ponds created in waterlogged ponded area in Chiri village

unproductive in this village. It is a low-lying area without drainage oulet where rainwater from upper areas collects. One farmer (Sunil Kumar), an enterprising man took 10 ha of highly waterlogged land on rent from the Gram Panchayat and converted into series of fish-ponds (Fig. 5). Starting from pond one, the excess water is drained into the next pond. He has put a pipeline to collect water and pump into the ponds. He is pumping out the excess water from nearby drain and putting it into the ponds thereby serving two important purposes of removal of excess drainage water for the benefit of crops and secondly use of the same water for income generating activity through fishery. He has also gone for duckery. The fish has to be fed regularly till the vegetative or algal growth takes place in the ponds.

- It was observed near Pilu Khera Township on Jamni–Bhambesa Road that large numbers of ponds around all the villages were affected by water logging. The runoff from the surrounding areas drains into these ponds and as there are no outlets, the pond-water stagnates and gives foul smell. The sewage water from the villages also drains into these ponds making it black which is not suitable for livestock drinking. However, there is large population of buffalo in the area and buffaloes are invariably taken to the ponds twice daily. The farmers informed that large stretches of land remain submerged under water for 4 to 6 months during monsoon and following months. The crop cultivation is restricted only to the relatively upper areas. The sowing of *Rabi* crops becomes a problem because of excessive moisture content in the soil. Farmers tend to opt for livestock rearing as a secondary occupation but there is acute scarcity of fodder. The farmers complained that no compensation is given by the Government when large areas get inundated by floods and crops are damaged. Till now, no sub-surface drainage project has come up in these villages. During heavy rains, ponds swell and water enter streets and nearby houses. The private and Government buildings are impacted as plasters do not stay due to excessive wetness in the foundations.

- The Lakhan Majra Sub-Division of the Department of Agriculture took up a sub-surface drainage project in village Siwana Mal during the year 2014. The subsurface drainage system has been laid and engines were provided to lift the water and put into the Siwana Mal drain. Farmers informed that out of 11 drainage blocks only one is functional and remaining ten are not working due to the problem in pumping of water. In the remaining pipelines, engines are there but they are not being used by the farmers because of the high cost of diesel and committees are unable to generate a corpus fund from 30 to 40 beneficiary farmers having variable land holdings and hence variable economic stake. It was informed that 200 liters of diesel was provided by the Department in 2014 and at that time all the 11 drainage blocks operated for one year which resulted in lowering of the salts as well as lowering of the ground watertable. But subsequently these remained non-operational mainly due to non-creation of corpus funds by the committee. Farmers were insisting that electric connection should be given at all the drainage points and in that case the annual expenditure would be much less on the electricity operation. Some farmers also suggested that solar powered lift systems should be installed which would be very cheap.

  One of the enterprising farmers (Mr Kalu) has taken 50 acres (~20 ha) of land on lease and installed two electric motors at his own cost to pump-out drainage water into the Siwana Mal drain. Because of his regular drainage-operation he is harvesting a bumper crop of basmati rice.

- Jhajjar district in general and Beri block in particular is most affected by the problem of waterlogging and salinity. Large patches of barren land are seen while travelling in this area. Beri block was selected for the present detailed study. A part of Bhakra village land was covered under HOPP through subsurface drainage in the year 2002. A major part of

**Fig. 6** Interaction with the farmers of Bhakra village in Jhajjar District

remaining waterlogged land is yet to be treated. A close interaction had taken place with the beneficiary farmers (Fig. 6). The information gathered from the farmers is summarized as under:

- ♦ No crop was possible in the command area before the project and fields remained submersed for most part of the year and farmers' condition was miserable.
- ♦ After the operation of the drainage project, the crop sowing became possible and gradually farmers started getting the yield of 4.0 to 4.5 Mg $ha^{-1}$ of each of wheat and paddy. There was quantum jump in family income of farmers covered under the project.
- ♦ Fortunately, there was 30 acres (~12 ha) of Panchayat land in these 80 acres (~32 ha) treated block which was given on rent to farmers. The land rent increased and the Panchayat also started getting good income.
- ♦ The Gram Panchayat (GP) got electric connection to operate the motor installed for water lifting. Now GP pays the electricity bills and has taken the responsibility of operation and maintenance. This way a major problem of operation was solved. This is an example which should be followed where ever possible.
- ♦ Yet large area of the village still remains to be covered and GP is requesting the department to take up the SSD project.
- ♦ The no-till farming is common in the area and wheat crop is sown with happy seeder.
- ♦ The paddy straw is not burnt but sold at the rate of ₹ 5000 to 7500 per ha. It is collected, chopped and sold in adjoining Rajasthan. This provides additional income to the farmers.
- ♦ Beri, a large block of about 5000 ha is suffering due to serious problem of waterlogging and the land of village Palra and Mangewal is covered under this block. The farmers in a joint meeting of these villages explained that they were trying their best to get the area under a drainage project. Fortunately, there is surface drain nearby where the drainage water can be let off. The paddy crop sowing was not possible in most part of the area and wheat sowing was possible only by end of December when wet soil became fit for tillage. In this case the problem of water-lifting was already solved.

- The sub-surface drainage projects in the state of Haryana were implemented under PM KVY as a centrally sponsored scheme but after 2015 it is implemented under a state sponsored scheme. A Deputy Project Director is looking after this scheme with headquarter at Karnal. The staff of the HOPP is posted in affected districts. The following information was gathered from the interaction with the Deputy Project Director and the officials in his office at Karnal in January 2020:

In the SSD projects, there is quantum jump in crop yield where projects were operational and water was lifted. Lifting of water by solar system is now being provided in the schemes. Under the new projects, the farmers would be asked to create a Cess-fund of ₹ 10,000 through cost-sharing mode and this fund would remain with the elected management committee for use during post- project operations. About one lakh acres (40,500 ha) is to be covered at a cost of Rs 368 crores. The average cost is around ₹ 75000 per ha

The interaction with scientists of HAU Hisar and CSSRI Karnal and experts in the field drew the inference that all the canals and common water courses should be lined. Along the canals a cutoff trench should be dug to intercept seepage water. This water could be used for irrigation. Belt of trees may be planted along canals to check seepage. Minimum-tillage should be promoted in paddy-wheat rotation and soil test-based application of fertilizers should be promoted. Bio-engineering research projects have generated useful information which may be used in formulating the projects.

## Impact of salinity and water logging on ecological and socio-economic conditions

During the mid-1990s, CSSRI was involved in monitoring and evaluation of two mechanically installed subsurface drainage projects of about 1000 ha each in Gohana and Kalayat blocks. These projects were executed by the Department of Agriculture of Govt. of Haryana with assistance of The Netherland Government. A number of SSD projects in 800-1200 ha pilot area each have been implemented in about 10500 ha area in farmers' fields in Haryana where annual potential loss due to waterlogging and soil salinity was estimated at more than INR 10000 million. Extensive monitoring and evaluation indicated 40-50% increase in the yield of soybean and wheat over non-SSD sites resulting in a benefit cost ratio of 2.6 and an internal rate of return (IRR) of 28%. It has been reported that the SSD system is working well even after 20 years of installation and bringing in 15 to 20% additional financial benefits for farmers as compared to non-SSD area.

The impacts of waterlogged and saline soils reclamation were studied both by research and development departments mainly to justify the economic, ecological and social benefits of the investments made. Waterlogged and saline soils apart from environmental degradation result in poor crop yields by as much as 80% (Shabala, 2011) and finally in abandoning the land from cultivation. In India, yearly crop loss due to waterlogging has been estimated to be more than 2 million tons (ICRISAT, 2009). The economic loss was estimated to be about ₹ 23,900 per ha with a total annual loss of ₹ 1669 million (about US$ 37 million) from the waterlogged saline area of Haryana. The crop yields and relative yield loss caused due to waterlogging and soil salinity of major crops were worked out by Joshi (1994) as presented in Table 4.

**Table 4.** Crop yield (Mg $ha^{-1}$) losses due to water logging and soil salinity

| Crop | Normal lands | Salt- affected lands | Waterlogged lands |
|---|---|---|---|
| Paddy | 3.99 | 2.18 (45) | 2.30 (42) |
| Wheat | 2.60 | 1.58 (40) | 1.86 (38) |
| Cotton | 1.63 | 0. 61 (63) | 0.37 (77) |
| Sugarcane | 63.68 | 33.02 (48) | 24.75 (61) |

*Values in parenthesis is percent reduction in yield

During evaluation of the Project, it was found broadly that the average yield of crops increased by about 25% and also brought more area under cultivation on account of installation of drainage system. There was no doubt that all farmers got benefit on account of installation of sub-surface drainage system and yield increase in both wheat and paddy which generally varied from 15% to 150%. Besides there was protection of culverts, nearby houses and bridges etc. as salinity effect had been reduced substantially. There were fewer incidences of mosquito and other insect related diseases in the areas where drainage work had been carried out. It was found that 98.7 and 97.1

**Table 5.** Improvement in percent area under low salinity and decrease under higher salinity in Block-JD 4 at Siwanamal SSD site of HOPP Haryana

| Soil depth | Year | $EC_e$<4 dS $m^{-1}$ Area % | $EC_e$4-8 dS $m^{-1}$ Area % | $EC_e$8-16 dS $m^{-1}$ Area % | $EC_e$>16 dS $m^{-1}$ Area % |
|---|---|---|---|---|---|
| 0-15 cm | 2012 | 01.3 | 21.8 | 66.2 | 10.7 |
| | 2015 | 20.5 | 54.3 | 23.2 | 2.0 |
| 0-30 cm | 2012 | 02.9 | 25.4 | 63.9 | 7.7 |
| | 2015 | 17.6 | 37.2 | 35.6 | 9.6 |
| 0-60 cm | 2012 | 06.6 | 34.6 | 56.4 | 2.4 |
| | 2015 | 18.7 | 46.0 | 30.0 | 5.3 |

percent area having more than 4 dS $m^{-1}$ salinity in 0- 15 cm and 0- 30 cm layer during 2012 reduced by 20.5 and 17.6% during 2015, respectively due to SSD activities (Kamra *et al*., 2019). The area having more than 8 dS $m^{-1}$ salinity in 0-60 cm zone reduced from 58.8 to 35.3% during the same period (Table 5).

The overall status of SSD project and crop yields of rice (CSR 30) and wheat during 2015-2016 was assessed. It was seen that the yields of rice and wheat crops in functional (pumping) blocks (JD 2 and JD 4) almost double of those in non-pumping blocks (JD 1 and JD 6) at Siwanamal site in Jind district (Table 6).

The socio- economic analysis of SSD indicated cost:benefit ratio of 1.5, IRR of 20% and employment generation of 128 man-days per ha every year. The material and mechanical installation costs covered about 60 and 40% of the total cost, respectively. There is wide spread awareness about the effectiveness of SSD in ameliorating waterlogged saline soils and it is expected that with efforts of farmers themselves, the crop yields in fully and partially functional blocks reach to level of normal soils. Similar results were reported for other SSD sites in Haryana. It is stated that farmers insist on going for paddy crop in waterlogged saline areas of Haryana due to not only better benefit:cost ratio but also because of more favorable marketing policies for paddy than other *Kharif* crops.

**Table 6.** Pumping status and crop yields in different SSD blocks at Siwanamal SSD in Jind district (2015- 2016)

| Drainage Block No. | Pumping status | Yield (Mg $ha^{-1}$) Rice | Wheat |
|---|---|---|---|
| JD 1 | Not Functioning | 1.5-2.0 | 1.0-1.5 |
| JD 6 | Not Functioning | 2.0-2.5 | 2.5-3.0 |
| JD 2 | Functioning | 4.0-4.5 | 3.5-4.0 |
| JD 4 | Functioning | 4.5-5.0 | 4.0-4.5 |
| JD 3 | Partial | 3.5-4.0 | 2.5-3.0 |
| JD 5 | Partial | 3.5-4.0 | 4.0-4.5 |
| JD 7 | Partial | 3.5-4.0 | 3.0-3.5 |

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