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Hydrogeology of the Bist Doab and Adjacent Areas, Punjab, India

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In India, as elsewhere, groundwater is a vital component of the ecosystem and its controlled use should not interfere adversely with the natural hydrologic cycle. However, its misuse causes many problems and may be observed in the Bist Doab and adjacent areas of the Punjab state where difficulties arise from water-logging, pollution by industrial toxic wates and overdraft in the phreatic aquifer. Remedial measures should include artificial recharge to groundwater in recharge areas by means of check impoundments and infiltration basins in order to overcome serious over-exploitation currently in progress.

Introduction

The Punjab (India) covers over 50,000 square km and is mostly a flat alluvial plain with elevations under 300 m, although there are isolated sand-dune hillocks in the south and southwest composed of eolian sand and silt from the flood-plains of rivers. On the northeast, the state is bounded by the Shiwalik Hills with altitudes ranging from 300-900 m. Paralleling the strike of this Himalayan sub-mountainous region is the Kandi Watershed extending from north-northwest to south-southeast for more than 160 km. This comprises many micro-watersheds, each of varying size, topography, vegetative cover and hydrology.

In most of the Punjab, the climate is continental with extreme summer heat alternating with rather cold winters. The mean annual rainfall ranges from 250

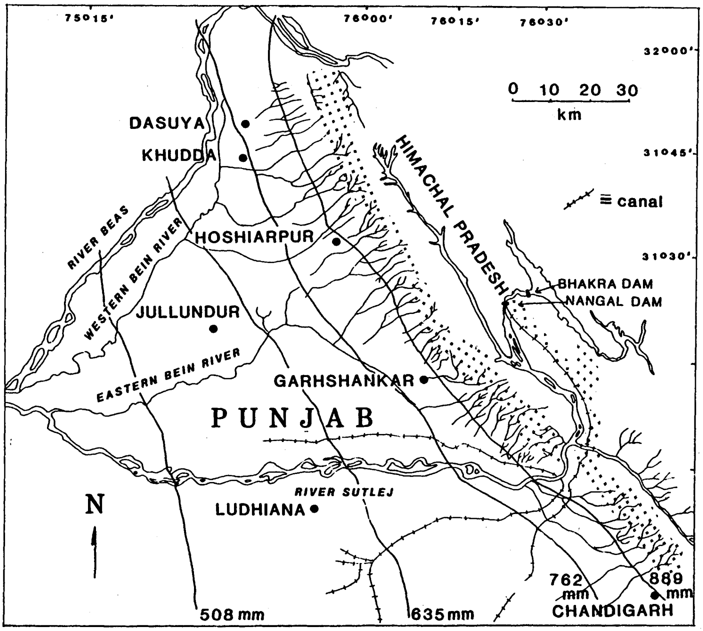

Fig. 1. The Punjab (India), showing the Bist Doab and the Kandi Watershed (stippled). Numbered lines represent isohyets in mm.

mm in the southwest to 1,000 mm in the foothills. There are three large perennial rivers in the state which are the Ravi, the Beas and the Sutlej. Two of these, the Beas and the Sutlej, are shown in Fig. 1 which also indicates the Kandi watershed which covers 4,600 square km. The three rivers mentioned above delimit irrigated areas called the Bari Doab (between the Ravi and the Beas) and the Bist Doab (between the Beas and the Sutlej). There is also the so-called old Sirhind Canal tract south of the Sirhind Canal. All of these irrigation areas supply an extensive canal network.

This paper is mainly concerned with the Bist Doab. Here, there has been a great increase in both governmental and private tubewell subterranean water extraction resulting in serious groundwater depletion problems. These are accentuated by water-logging induced by rising water levels in the southwest of the state. Pollution is also accelerating.

Above ground, extensive denudation has occurred in the Shiwaliks. Ephemeral monsoonal torrents ("choes") transport sediment from steep sided, irregular and highly erodible catchments principally to the southwest through the Bist Doab eventually to deposit as far away as the Beas River. In all, there are 141 choes possessing catchments varying from 20 to 56 square km in area.

Until the middle of the last century, the Shiwaliks were fertile hills with acacia and pine. However, following the eviction of landowners after the Sikh wars of 1845-1849, overgrazing and tree-felling devastated the vegetative cover. Hence, while the original fertile silt transported by the choes was useful, this has been replaced now by sand which has destroyed many hectares. In 1902, this led to the enactment of the Punjab Land Preservation (Choes) Act which restricted grazing, tree-felling, quarrying and other deleterious activities. Thus was recognized the adverse effects of vegetative loss in the foothills. From the 1950s to the 1970s, there were insufficient funds for reforestation and soil conservation. The continuing problem stimulated a World Bank appraisal report in 1980 as a result of which the Punjab authorities involved British commercial companies. In this connection, the author investigated groundwater and surface water conditions in the region.

It became clear immediately that degradation had to be arrested and flood control measures devised. The latter would combat water logging as would canalization, a measure proposed for one particular "control" choe called Dholbaha. Fortunately, the groundwater in the Bist Doab is fresh so that lowering the water table may be undertaken also. If this were not the case, such a procedure could not be followed successfully unless the saline water had an electrical conductivity of under 2,000 micromhos/cm at 25C°. Saline water is useful for irrigation only if mixed with fresh water from canals as K. P. Singh (1983) proposed.

In the Kandi watershed and the Shiwaliks, rehabilitation of the upper catchments is urgent. So too is promotion of irrigation coupled with flood control if farm lands are to be developed through terracing, impounding, horticulture etc.

Initially, a hydrogeological investigation of the Bis Doab is important and this is attempted here.

Geological Setting

Geomorphologically, the Bist Doab is divisible into three zones, i.e.

The Shiwaliks and the Kandi Watershed
The interfluvial plain between the Beas and Sutlej
The flood-plain area

The existing and earlier Beas, Sutlej and other rivers deposited a great thickness of Pleistocene to Recent sediments derived from erosion in the mountains. The relevant lithologies and sequences are as follows:

- Surface deposits (Recent).
- Sirowal sediments and occasional gravels to the northeast with Kandi coarse clastics including red clay beds to the southwest (Holocene).
- Boulder beds with interbedded clays (Pleistocene).

The alluvium at the surface reflects the latest stages of sedimentation in a process which commenced in the Tertiary. Cenozoic sedimentation involved sediments in the Shiwaliks which, according to R. R. Chaudhri and J. S. Dhanda (1980), can be divided into late, middle and early portions. The upper part ranges in age from middle Pleistocene downwards and comprises three members which are as follows:

- Boulder conglomerate (middle Pleistocene)
- Pinjore lithic arenites (late Pliocene)
- Tatrot sediments (Neogene)

The Pinjore beds are exposed about 5 km west of the town of Pinjore, also south of it as well as on the left bank of the Ghaggar River. They are composed of a variety of arenites, some with calcareous and others with ferruginous cement. There is also a lithic so-called wacke and the "marker" mineral is sillimanite.

As regards the source of the sediment, the polymictic composition indicates a heterogeneous provenance. Probably it is attributable to the influx of detritus from several streams draining the rising Himalayas. These debouch sediments in basins located transversally to the major Himalayan drainage system. The sources comprise pre-Cenozoic and Tertiary crystalline and sedimentary rocks exposed in the Simla Hills around Simla, (Fig. 2). This is demonstrated by the presence of undecomposed fragments of such parental rocks in the Pinjore sediments. Initially, the supply of sediment must have kept pace with the rate of subsidence, but, towards the culmination of sedimentation, the rate of sediment supply must have exceeded the rate of subsidence by far. The basin was rapidly infilled with pebbles, cobbles and boulders from the adjacent, rising Himalayas. Disrupted bedding, current bedding, ripple marks, scour and fill structures with imbrications have been observed in the Pinjore rocks exposed in the type area. The imbricate patterns show a southward flow of paleo-currents. This, together with the moderate to poor sorting of the detritus suggests that the Pinjore sediments were deposited in a shallow, subsiding basin.

Kankar is extensively developed in many of the sediments of the Bist Doab. This is a vernacular word for calcareous deposits occurring in various alluvial and eolian deposits in India. Their formation is a function of both surface and groundwater processes. The actual nature of the kankar varies according to the complex geochemistry involved. Occasionally, it comprises a biochemical precipitate.

A review of proposed classifications for kankar was given by S. C. Awasthi and V. K. Anand (1980). The parameters utilized include shape, size, hardness, composition, mode of origin and occurrence. Each has limitations. However, in the Punjab, kankar signifies calcium carbonate in nodular form with associated impurities such as silica, magnesium and ferric oxides, is of fragmentary character

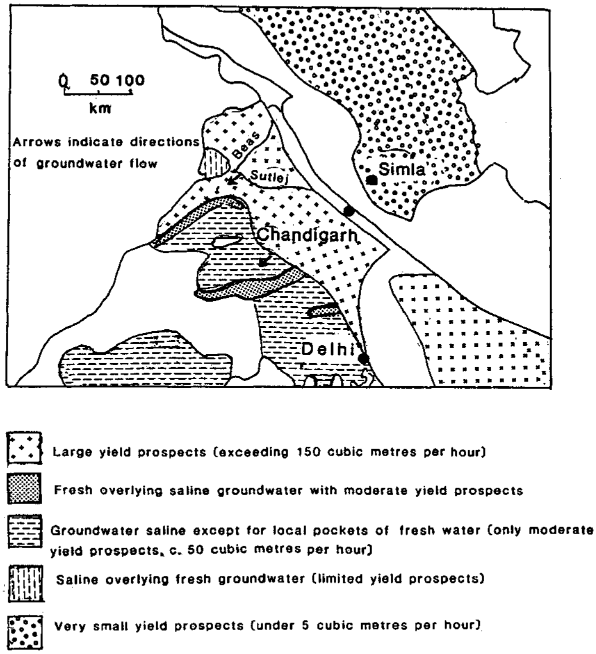

Fig. 2. Groundwater resources of the Punjab and adjacent parts of India. The general directions of groundwater flow are indicated by arrows.

and usually arises from the capillary action of groundwater in conjunction with the percolation of surface water through soil.

The area in the north of the Bist Doab includes gravels, alluvial fans and river terraces which flank existing streams and in some cases occupy ridges. The alluvial fans have been noted wherever streams enter the plains and the Maili and Dasuya choes have developed broad features of this type. Here, there is considerable infiltration during periods of large floods.

According to A. H. G. Mitchell and H. G. Reading (1978), the older Shiwalik trough of the Ganges has received sediments like those of the existing alluvial valley probably at least since the late Miocene and its axis may be migrating to the south in order to accommodate the thick Quaternary deposits of the present Ganges valley.

A sèries of core logging results (Fig. 3) were obtained from a set of boreholes drilled along a north-south traverse through the Bist Doab (cf. Fig. 1). A variable lithology of alluvial gravels, sands, clays and associated kankar is revealed and there are also mixed components. It may be noted that sands greatly favor infiltration and T. Dincer (1978) concluded that the phenomenon may be in part in the vapor phase as evidenced by fractionation of tritium and the oxygen isotopes 16, 18.

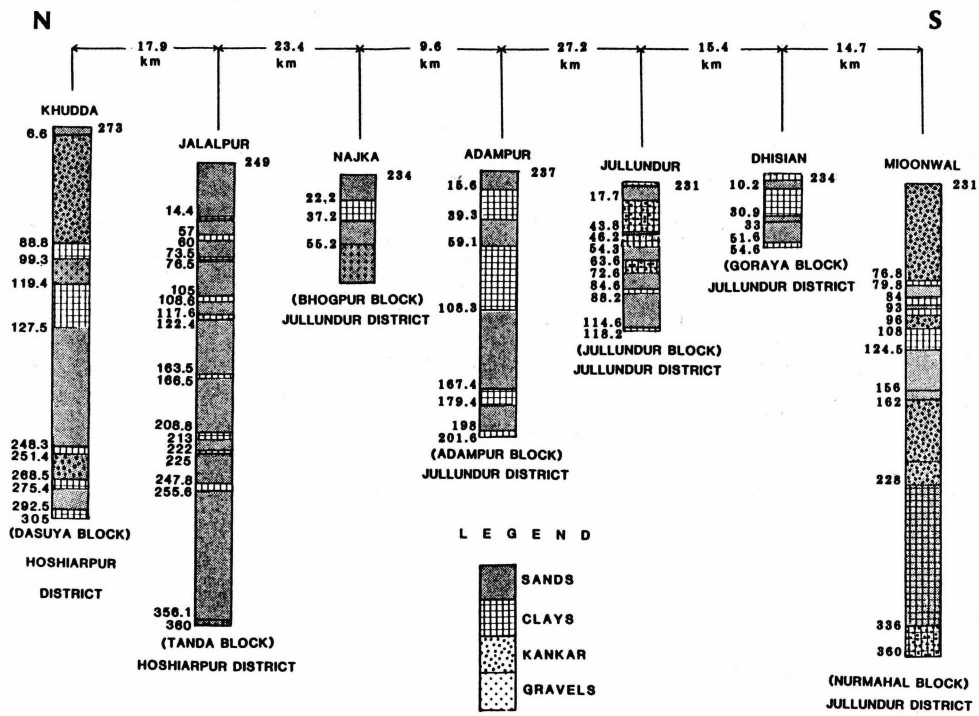

Fig. 3. Borehole core logs from seven localities in the Bist Doab lying along a north to south traverse. The grid at the top indicates the distance in km between the boreholdes. A multiple aquifer system exists in the sedimentary sequence.

Hydrogeology

Groundwater Mining

Over-exploitation of groundwater resources in the Punjab involved concomitant lowering of the water table in tubewells by approximately eleven metres during the last few years and over-drafting as well so that a situation of mining has been reached. At one of the choes investigated, Patiala Ki Rao (the site of a proposed impoundment), the average rate of groundwater extraction from the well field for 1976 was 58,565 m^3 per day. According to K. P. Singh (1983), the permissible exploitation rate for the period 1977-1991 here is 52,000 m^3 per day which would create a maximum permissible drawdown of nineteen metres in the center of the field. With the Sukhna choe, the figure for 1976 was 73,627 m^3 per day and the permissible exploitation rate of 110,000 m^3 per day for the period 1977-1991 would entail a maximum permissible drawdown of 24 m in the centre of the field. The total of 162,000 m^3 per day which could be derived from these two choes does not cover even half of the projected demand of the nearby city of Chandigarh which it is estimated will reach 408,000 m^3 per day by 1991. Augmentation of the groundwater is clearly essential.

Pollution

In addition, there is the grave pollution of the groundwater. It manifests itself in various ways.

Extensive saline areas occur in this part of India and in these it is neccessary to guard against the possible intrusion of brackish water into fresh water pockets. The salinity is diverse in origin as well as in direction and velocity of movement. Sporadic flash floods may permit water to reach sabkha-like localities to produce saline water which infiltrates and may percolate ultimately to reach the groundwater complex. Saline water may be contributed also by connate sources. No doubt, this explains why saline water is observed sometimes over and sometimes under bodies of fresh groundwater (Fig. 2).

It may be added that an United Nations project south of the Bist Doab in the Ghaggar River basin approached the Sirhind Canal tract as well as two brackish water areas. Proceeding southwest from Chandigarh involves entering an extensive region in which the groundwater yield prospects diminish from more than 150 m^3 per hour to less than half this amount and also the groundwater itself becomes progressively more saline until eventually it is dominantly so, except for localized fresh water pockets (Fig. 2).

Pollution also arises from effluence in communities near textile mills, tanneries and similar industries. Not only does this affect potable water supplies but in addition the natural ecosystem is influenced adversely. For instance, at Ludhiana (Fig. 1), an industrial center, there is a polluted phreatic aquifer which contains 1.6-2.0 mg/l of cyanide, 490-3 500 mg/l of sulphate and 2.9-18.5 mg/l of chromium (K. P. Singh 1982). Here, wastes accumulate in ponds and depressions. Some of the effluents from waste disposal sites obviously percolate rapidly through alluvial sediments, reach the aquifer and ultimately may be used inadvertently in the domestic water supply. Various illnesses result. Another example, which may be cited, is the Rivulet choe near Garshankar. This is the recipient of industrial waste discharged by a paper mill at a rate of c. 0.1 cumec and connects hydrologically with the phreatic aquifer which therefore will be polluted. It should be emphasized that pollution from other sources occurs in almost all the other choes as well.

Clearly, stringent effluent treatment controls must be applied if the problem of pollution is to be overcome. This would involve as a priority stopping the employment of abandoned dug wells for waste disposal purposes as has been the case in the past.

Water-Logging

This critical phenomenon can cause a rise of the water table to as high as the roots of crops thus reducing yields and promoting infertility in arable soil. In the Punjab, there are probably twenty million hectares where the water table extends anywhere from the ground surface to a couple of metres below. This is a major cause of lost agricultural production and results from canal irrigation. Often, water-logging is accompanied by salinization of soils. In the Bist Doab, this particular problem may be solved by lowering the water table through installing more tubewells, suitable flood control measures, canalization of rivers and drain construction. As mentioned earlier, the Dholbaha choe canalization was approved and entails not only control of water logging but also reclamation of formerly, periodically flooded land below the funnel-shaped control embankments to lie above the canal. Above these, monsoonal flood water is to be impounded for subsequent use in irrigation. Obviously, siltation will be a major problem avoidable if such flood water were to be artificially recharged to the groundwater system.

The Aquifers

In the Kandi watershed as well as in the rest of the Bist Doab, the aquifer situation is rather complicated (Fig. 3). In 1973, the Water Resources Directorate proposed drilling 62 state-wide and grid-distributed boreholes to collect essential data, but three years later a mere 11 had been completed. Each was accompanied by one or more observation wells, but pump testing was very infrequent. Some pump test results were obtained from Dasuya, Knudda, Hoshiapur and Garshankar.

In a well of 62 m depth at Dasuya, the 20 m zone was tapped and the transmissivity estimated at 60 ml/s/mm with a storage coefficient of 0.082.

For Khudda a 305 m deep well with a discharge of about 60 l/s was tapped at 56.7 m and the transmissivity was estimated to be 30 ml/s/mm with a permeability of 0.043 ml/s/square cm.

At Hoshiarpur, the 65 m deep well had the 9.1 m zone tapped and the transmissivity was found to be 20 ml/s/mm with a storage coefficient of 0.0017.

In the case of Garshankar, a 56 m deep well was tapped at 15.3 m and the transmissivity was estimated at 21 ml/s/mm with a storage coefficient of 0.00044.

G. Mahajan and J. K. Plaha (1980) gave the following general storage coefficients:

– The Shiwaliks	0.0013-0.0016
– The Kandi	0.0017-0.0040
– The Sirowal	0.0820-0.3180

In consequence, they suggested that the Sirowal aquifers are unconfined, but those in the Shiwaliks and in the Kandi are confined. Considering the huge areas, the diverse sediments and structural complications involved as well as the paucity of information actually available, these data must be treated cautiously.

Recharge to the Aquifers

The major source of recharge to the groundwater system is precipitation. Perhaps the most important catchment area occurs in the elevated regions of the adjoining state of Himachal Pradesh (Fig. 1) where the annual rainfall may exceed 1 m. The Beas, the Ravi and their tributaries also contribute and there is an extensive input from canal water widely used for irrigation in the state.

Just below the Shiwalik Hills, concentrated flashing run-off and flooding make sporadic additions as well. This is established by the low flows in the western Bein river as compared with the peak flows through the Shiwaliks. At Garhdiwala, east of the Dholbaha choe, the groundwater levels dropped over 3 m between 1926 and 1955 and then rose to 4.5 m above the original maximum level (to almost 8 m) by 1961. Thereafter, they declined by about 3 m. The groundwater high of 1961 may well have resulted from the wettest year so far recorded, namely 1955, when there were roughly 2,056 mm of rain.

Because of its geological and geographical contiguity, it may be useful to refer to the groundwater situation in the Punjab of Pakistan. The USA Geol. Survey investigated there and found that, up to 120 m, the aquifers are unconfined.

The Bist Doab Regime

The hydrological situation obtained by core sampling along the traverse mentioned in section 1 above and running north-south through the Bist Doab shows a number of successive and hydraulically interconnected aquifers of varying transmissivities, some being confined by clay aquicludes. Kankar is abundant.

The Punjab (India) has a population of almost twenty million and an annual growth rate of about 2 %. Although this state is one of the most prosperous in India, a quarter of its inhabitants live in conditions below the absolute poverty level. In the Kandi area. the choes flood every year and cause widespread damage (e.g. in the flood of 1977, at Hoshiarpur, 9 people and 63 cattle were killed, 650 dwellings were destroyed and there was extensive road and bridge damage together with a loss of crops from c. 5,000 hectares of arable land).

As there are so many choes and in view of the large size of the upper watershed (24,000 hectares) together with difficulty of access during the wet season, only a dozen or so selected choes were surveyed in order to supplement the traverse work and provide detailed data for the project area.

It was noted that the choes in question have complex ephemeral stream patterns. Nearby villages comprise mud-walled houses with some concrete and stone walls together with occasional tiled roofs in newer ones. They are surrounded by fields and their inhabitants know the need for remedial geotechnical activities.

In the plains area of the Bist Doab, the Beas and Sutlej are controlled by two dams (Pong and Bhakra) and cut through the Shiwaliks. They supply irrigation water and the water table near the Beas is 2-5 m below the surface. Along the Chandigarh-Hospiarpur road, it occurs at depths of 3-8 m. Below the Shiwaliks, it is lower – anywhere from 30-70 m depths. Clearly, the depth varies greatly areally, seasonally and from year to year. The relative proximity of the water table to the surface in the Bist Doab together with a limited zone of unsaturation would facilitate artificial recharge operations. These comprise a better mechanism for absorbing flood waters than the more expensive impoundments favored by various engineers in the state. Superficial structures such as reservoirs rapidly lose efficiency because of the very siltation which is destroying so many fields. Precipitation together with stream flows and extensive flooding already effect natural groundwater recharge. So does water spreading for irrigation. Artificial recharge could add appreciably to these processes and the water so stored in the groundwater system would not be liable either to siltation or evaporation. It could easily be effected in the thousands of hectares of sandy choe beds which would gain in fertility and acquire greater arable area.

The implementation of flood control measures in the northwest middle plains area which will cause a decrease in natural recharge is to be compensated for by a proposed Kandi canal which would permit natural seepage.

The establishment of a water balance for the Bist Doab is an important problem. Following the work of M. C. Chaturvedi (1971) on the conjunctive development of surface and groundwater resources, P. S. Datta, P. S. Goel, Rama and S. P. Sangal (1973) studied groundwater recharge in western Uttar Pradesh and, in later work, P. S. Goel, P. S. Datta and B. S. Tanwar (1977) measured vertical recharge to groundwater in Haryana state using tritium tracing.

In the same year, P. S. Datta and P. S. Goel (1977) published the results of studies of groundwater recharge in the Punjab using again tritiated water. They injected it at some twenty sites in June 1972 to measure vertical recharge to groundwater due to the monsoonal rains and irrigation. Their previous work in Uttar Pradesh showed that significant dilution of weak radiotracer occurred during movement through the soil. Hence, a higher activity was applied in the Punjab. The flow of the radiotracer towards the water table probably occurs by a layered displacement mechanism involving, molecular diffusion. Wide variations in recharge occur because of the diverse amounts of clay in the soils, differing depths to water and a wide range in amount of precipitation and irrigation water. For the 1972 monsoon, a contribution of 8.5 cm of water took place, i.e. almost 18 % of the annual rainfall (47 cm) and about 12 % of the total watering.

It is estimated that c. 5.5 billion m^3 water are available annually in the Punjab from all aquifers and this is equivalent to 11 cm of water cover. This exceeds the calculated recharge value and confirms overdrafting. However, World Bank data give a more optimistic picture of net extraction in the Punjab as 39 % of annual recharge for 1976-1977 with a 47 % figure anticipated for the early 1980s. No doubt, further investigation is necessary.

The hydrogeology of the Kandi area is reasonably well understood and the groundwater often occurs under unconfined conditions, the entire area being characterized by semi-arid conditions. Additional geological work in the alluvial plain is desirable in order to gather further essential information regarding the number, type and characteristics of aquifers outside the project area. Accessibility is not a problem because this plain has an average slope of about 0.4 m/km, hence it is almost flat. The matter grows ever more urgent because the Punjab is now one of the major wheat and rice producing regions in India.

Conclusions

Matters which must be dealt with if water resource problems in the Punjab are to be resolved satisfactorily include the introduction and application of stringent toxic waste products control, construction of linings for some water courses and a study of pollution plumes and their rate of movement by monitoring the chemistry of the groundwater.

In the saline areas, conjunctive utilization of surface and groundwater can reduce the salinity problem and provide an extra supply for irrigation. There are also freshwater pockets which can be exploited directly, although care must be taken to prevent any intrusion by salt water wedging.

More tubewells can be employed along rivers so as to reduce the water table level and retard water-logging.

However, the major problem is overdraft of the aquifers. The optimal solution appears to be artificial recharge into the groundwater system of the appropriate areas and also in old river courses using check embankments and infiltration basins during wet seasons.

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