Ingenious techniques for irrigation sustainability in Himalayan and Shiwalik foothill regions

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The groundwater resources of India play a major role in the irrigated agriculture. Therefore, expansion of these resources to increase agricultural production received high priority in the development programmes of the country. The area under irrigation by groundwater through wells is continuously increasing. On the contrary, contribution of canals and other sources is decreasing. However, it is also true that the groundwater abstraction by artificial means in the Himalayan and Shiwalik foothill regions is negligible. Installing deep tube-wells in such regions is a difficult and expensive task. Hence, in the mountainous regions, survival of biodiversity during the lean period of the year entirely depends upon the existence of self-draining groundwater aquifers. They may mark their presence by oozing out water in any form, e.g. springs, seepage lines or streams. Discharge rate and the perennial nature of these aquifers depend upon their catchment areas. Therefore, in this article, hydraulics of these groundwater resources is described and subsequently an effort is made to promote certain ingenious techniques based upon these perennial resources for attaining irrigation sustainability during lean period of the year. In the present scenario of water scarcity in the Himalayan and Shiwalik foothill regions, only such measures have equity and sustainability implications.

Keywords: Participatory irrigation management, perched aquifers, perennial streams, seepage line, sustainable irrigation resource.

WATER is one among the greatest looming commodities of the 21st century. Available freshwater amounts to less than one half of 1% of all water on the earth. The rest is sea water or is frozen in the polar ice. Global consumption of water is doubling every 20 years, more than twice the rate of human population growth. According to the United Nations, more than one billion people on earth already lack access to fresh drinking water. If the current trend persists, by 2025 the demand for freshwater is expected to rise by 56% more than is currently available. Increasing competition from domestic and industrial uses has further compounded the problem of water scarcity. The conflict between the increasing water demand by various sectors and the planet's unchanging supply of freshwater has already started and may get worse each year[1].

Other than domestic and industrial needs, agriculture is the major consumer of freshwater in the form of rainfall as a natural mean and in the form of irrigation as an artificial mean. Since rainfall is an erratic phenomenon, irrigation has been around for as long as humans have been cultivating crops. Irrigation is based on surface and groundwater resources, and among two, the latter has a major share. The entire world contains only 8.2 million km^3 of fresh groundwater[2]. Only half of the total groundwater supply is available, as the rest is situated below a depth of 800 m. Expansion of irrigation resources to increase agricultural production received high priority in the development programmes of several countries in the world[3]. Just 20% of the world's croplands is irrigated, however they produce 40% of the global harvest, which indicates that irrigation more than doubles land productivity[4]. Due to this, freshwater has been under tremendous stress. In some areas, water scarcity is already a major problem and a serious limitation to agricultural development. Farmers are under pressure to grow 'more crop per drop'. According to the international norms, if per-capita water availability is less than 1700 m^3 per year, then a country is categorized as water-stressed, and if it is less than 1000 m^3 per year, then the country is classified as water-scarce[5]. India's annual per-capita water availability will go below the water-stressed threshold level of

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1700 m^3 within the next two decades. The India Water Vision 2025 estimated the gross water demand for multiple uses to double in about 25 years from now[6].

The available groundwater for irrigation[7] in India is 361 km^3, of which utilizable quantity (90%) is 325 km^3. Out of the total irrigated area in India, the area under irrigation by groundwater through wells (tube-wells and other wells) has shown an increase from 29% in 1950–51 to 59% in 2005–06, whereas the area under irrigation by canals has decreased from 40 to 26% during this period[8]. Contribution of other water resources (except canals, wells and tanks) in irrigation was already less and it further decreased from 14 to 12% in the above-mentioned period. It is evident from the stated statistics that groundwater is being exploited more compared to other resources of water. However, it is also true that the groundwater abstraction in the Himalayan and Shiwalik-foothill regions is negligible. Tube-well installation difficulties and cost of the project are the major causes of non-abstraction of groundwater. Even after installation, water from the tube-wells for irrigating fields can only be conveyed either through an underground pipeline system or concrete channels with drop structures because of the uneven terrain of such regions. Huge investments for installing tube-wells and water-conveyance structures in such terrains make farmers incapable of undertaking these projects. Only at a few places in the Bhabhar region (lower foothill region with a deep water table, and having derived its name from the tall grass growing there), government tube-wells exist, whose primary function is to supply water for domestic needs. It is a well known fact that the Himalayan and Shiwalik foothill ranges receive good amount of rain though about 80% of this is concentrated during three months of the year (i.e. mid-June–mid-September). Except for a small fraction which infiltrates into the sloppy surface of the mountains, the rest gets converted into run-off and is drained to major rivers. Despite receiving good amount of rainfall, these regions face acute water shortage during months other than the monsoon season. The difference in the volume of water flowing down the rivers and drains during monsoon and the lean period is enormous, resulting in the too little and too much water syndrome – a common feature of the desert regions[9,10]. Due to the lack of any sustainable irrigation resources, farmers are bound to adopt rainfed agriculture, and because of the above-mentioned reasons crop production in these regions remains less. Investments incorporated for growing crops is sometimes not returned. The mountainous regions are blessed with deep and shallow groundwater aquifers. The deep aquifers generally stretch up to the alluvial plains. Other than these deep aquifers, numerous self-draining, shallow groundwater aquifers exist in these regions. They may mark their presence by oozing out water in any form, like springs, seepage lines or streams. Discharge rate and the perennial nature of these groundwater aquifers depend upon their catchment areas. How to explore, tap and manage these into sustainable resources for drinking and irrigation purpose is our capability. Thorough knowledge of the basic hydraulics of these shallow aquifers is the key to the efficient working of the water-tapping techniques. Therefore, in this article, fundamental bases of perennial nature of these shallow groundwater aquifers in the mountainous and Shiwalik foothill regions are described. Further, an endeavour is made to promote certain ingenious technologies based upon these groundwater resources for attaining sustainable irrigation facilities. In the subsequent sections, these technologies are discussed in detail.

Tapping seepage-line water

Before describing the method of tapping water, it is mandatory to understand what are seepage lines. The fundamentals of a seepage line are described schematically in Figure 1 *a*. It is a well known fact that the geology of mountains varies with depth. Presence of less or more impermeable layer either slows down or completely checks the deep percolation of infiltrated rainwater. Unable to find its way to the deeper layers, water gets stored in the pores of the formation material present above this impermeable layer of the mountain. These shallow aquifers can be considered as perched aquifers, with water table having the shape like an inverted bowl (Figure 1 *a*). Perched aquifers are common, although they may sometimes be only a few centimetres thick or be present only after a major infiltration event. In other cases they may be several metres thick and extend over large distances. Wherever this stored water in these perched aquifers finds an opportunity to intersect the sloppy land surface of the mountains (by artificial or natural mean), it oozes out in the form of a spring or seepage, with pressure equal to the head of water at that point. Where the flow from an aquifer is localized, it is termed as spring, and where it is diffuse, it is termed as seepage (or seepage line). A lot of information is available about springs in the literature. In the present article, discussion is limited only to the seepage line and its potential utilization as a perennial water resource. Nevertheless, at first instance, it seems that the discharge rate per unit length of the seepage line is not enough to be tapped. Here it is worth mentioning that these seepage lines only confirm the possible existence of self-draining aquifer, whose potential to become a perennial water resource of adequate capacity depends upon its catchment area, formation porosity and hydraulic conductivity. Merely knowing about the presence of the aquifer is not sufficient; one should be able to tap the required capacity of water from it. One such technique is schematically shown in Figure 1 *b*. In this method, a horizontal tunnel is excavated in the mountain beneath the seepage-line level. This procedure has two benefits: (1) it increases the exposed surface area of aquifer formation contribut-

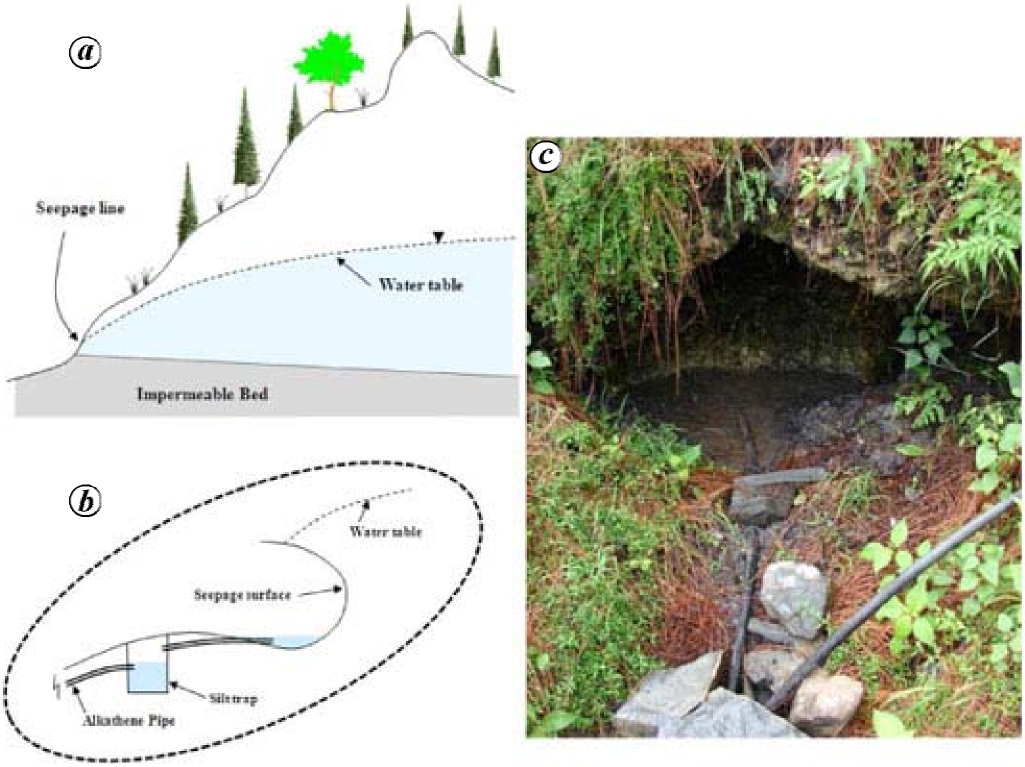

Figure 1. Tapping and conveying seepage-line water. ***a***, Schematic sketch representing the occurrence of seepage lines. ***b***, Conveyance of collected seepage water. ***c***, Photograph of the system.

Figure 2. A view of seeping water from aquifer formation inside the tunnel.

ing to the discharge, and (2) the discharged water is collected in the small pool formed due to excavation which can be easily tapped and conveyed through a pipe. A typical excavated tunnel for tapping seepage water is shown in Figure 1 *c*. Seepage water is allowed to collect in the small pool of the tunnel (Figure 1 *c*) before allowing it to pass through a settling tank/filtration unit present near the collection point. Generally, the water obtained using this method is completely free from any turbidity. The complete arrangement is open to the atmosphere. To avoid any problem of clogging during conveyance, such an arrangement is necessary.

If the water level in the aquifer lies above the elevation of the top of the tunnel, its complete exposed surface will contribute to the discharge. The discharge rate from the tunnel will increase by sinking its position with reference the seepage-line level since the hydraulic head above the exposed surface of the tunnel increases. But the tunnel elevation should not be lower than the desired outlet level, otherwise water will not flow with gravity.

The diameter and length of the tunnel depend upon the discharge capacity and strength against cave-in of the aquifer formation material. If the strength of the formation material is enough to restrict cave-in, the length may be increased. Otherwise, another tunnel should be excavated near the previous one to fulfil discharge capacity. If the conditions regarding the strength of the formation material of the tunnel are favourable, it is always preferable to increase the length instead of the diameter. A view of seeping water from a typical mountainous aquifer formation inside a tunnel is shown in Figure 2.

After passing through the filtration unit, turbid free water is conveyed to the desired location with the help of pipes. Tapping and conveying water through PVC pipes is more prevalent as these performed best under uneven terrain conditions. PVC pipes are durable, but costly, especially when water has to be conveyed from a longer distance. Nowadays alkathene pipes (manufactured by recycling plastic waste) are available in the market at a reasonable price; these perform well under low pressure conditions. The service life can further be increased by burying these underground. Water storage tanks are essential for this type of system. In mountainous regions, water storage tanks cannot be constructed of such a size so that flood irrigation could be feasible due to space constraint; therefore this limited stored water should be used wisely through drip or sprinkler systems.

Tapping perennial stream water

In the previous section, tapping of seepage-line water in mountainous regions has been described. During the monsoon season, due to the overland and interflow, numerous streams with moderate to heavy discharge rate can be observed in the mountainous and Shiwalik foothill regions. The life span of these streams depends upon the duration, intensity and frequency of the rainfall showers, and other than a few perennial streams, it usually varies from less than one day to more than a month, and in rare cases, a little more. In other words, majority of these streams exist till the monsoon recedes and are termed as 'seasonal streams'. On the contrary, streams which have the ability to sustain flow throughout the year are called 'perennial streams'. Even during the lean season (other than monsoon season) of the year, discharge rate of these streams may vary from a few litres per minute to hundreds of litres per minute. The entire Himalayan range witnesses such streams. It is worth mentioning here that the flow-bed conditions of the streams flowing in the mountainous region are altogether different from those flowing in Shiwalik foothill region. During the monsoon season, high-velocity run-off water flowing on steep bed slopes detach the finer particles such as sand, silt and clay from the basic formation material of the mountainous catchment and convey these to the rivers. In due course, the bed of the stream is left only with stones and boulders of various sizes. However, bed slope of streams flowing in the Shiwalik foothill regions is comparatively mild and as a result the river water, leaves behind the course-grained sand as a major content on the bed of the stream. This variation in the bed conditions of the streams affects the water tapping procedure and therefore, both cases are illustrated separately.

Tapping perennial streams in the Shiwalik foothills

Google earth image of one perennial natural stream in the Shiwalik foothills is shown in Figure 3. Let us try to understand the basic hydraulics of these streams (i.e. from where these streams are oozing out and what is the cause of their perennial nature).

Figure 4 shows that the self discharge of the groundwater occurs where the bottom of a river/stream valley lies below the water-table. The discharge may take place through the bed or bank of the stream and so may not be visible. However, such discharges account for the greatest proportion of flow from aquifers. A stream that receives water from an aquifer, like that in Figure 4, is termed a gaining stream. For a stream to flow throughout the year, even during lean periods without rainfall, it must have a source of water other than surface run-off or interflow. This water, which sustains the stream throughout the dry weather, is present, though less apparent at other times; it is termed 'baseflow'. Baseflow can be provided by groundwater discharge from an aquifer, from surface-water storage (as in the case of a stream that flows from or through a lake) or from the water infiltrated through the sloppy surface and seeping out slowly throughout the year. Which source will be prevalent for providing discharge to the stream, depends upon the hydro-geologic conditions of the mountainous catchment. Total flow rate of the stream during lean season depends upon the number of aquifers which come across along its length and contributes discharge.

Collection of pre-requisite data before diverting and tapping these perennial streams to the desired location, is the key task of the project. Water-course length between diversion site to end point, stream discharge rate with flow level during lean period, and the extent of unevenness of the terrain are the three essential parameters

Figure 3. Google earth image of natural streams in Shiwalik foothills.

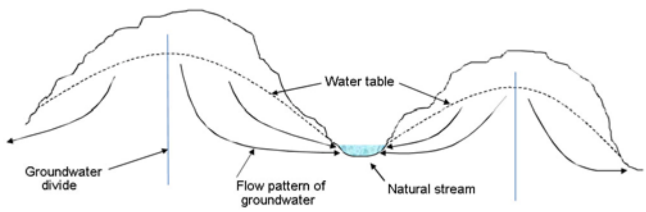

Figure 4. Schematic sketch showing the groundwater flow pattern to a gaining stream.

which should be known prior to the project implementation. Among these, the extent of unevenness of the terrain is the basic parameter. It decides the type of the conveyance system (open channel or pipeline) suitable for the area. Tapping level of the open channel or pipe-line system depends upon the flow level of the stream during the lean period. It should be lower than the yearly minimum flow level of the stream. The least discharge/flow rate of the stream during the lean period directs the users to choose a shape of the channel through which a minimum flow rate according to the channel gradient can be maintained to avoid siltation. If the difference in the flow rate of the stream during the lean period and monsoon season is high, a channel shape as suggested in Figure 5 should be opted. However, rectangular-shaped channels are mostly preferred due to their easier construction.

In case the area to be irrigated is located near or just on the bank of the floodplain of the stream, water is conveyed through open channels as shown in Figure 3. These open channels may be either of permanent type, constructed using cement concrete or may be temporary field-water courses. Here, it is important to mention that the construction of open channels, permanent or temporary, should be restricted to the field boundaries. Construction of any permanent structure in the floodplain of the stream should be avoided.

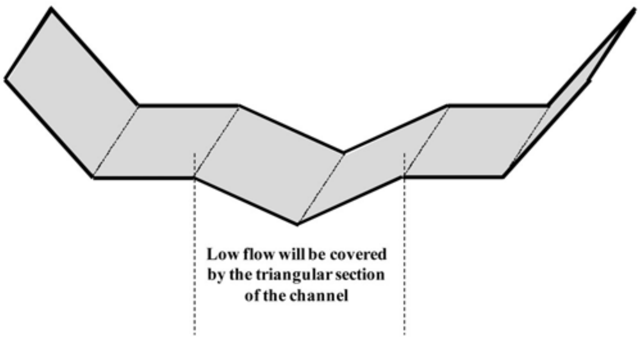

Figure 5. Open channel having both triangular and trapezoidal sections.

Figure 6 shows how to divert water from the stream to open channels. In this technique, flow level of the stream is raised by obstructing its entire flow width using bed material locally available. The height to which the level of the stream is raised depends upon the required depth of water (i.e. discharge rate) in the open channel.

In case the stream discharge is to be conveyed to a longer distance all the way throughout the uneven terrain, then it is always advantageous to use pipes (concrete or GI) instead of open channels. For this, a structure similar to that shown in Figure 7 should be constructed. To avoid any damage to the structure during high flows, it should be built away from the floodplain of the stream. The stream water diversion method will be same for this system also. Since pipelines (underground or on-surface) and not of open channels are used for conveying water in this system, the filtration mechanism is essential.

The schematic sketch of the structure in Figure 7 is shown without dimensions. This is because, other than the flow rate of the stream to be tapped, dimensions of the structure may also vary according to the safe location and area available for construction. Hence, in this article the main purpose is to clarify the principle of the tapping procedure. No doubt, construction of such a structure for a single farmer will be difficult. Therefore, this structure can be constructed and maintained with participatory management by the village panchayats or water users' association. Since the elevation of the filtration-cum-diversion structure will always be higher (because of the topography of the area) than the farmers' fields, water will flow under gravity.

Figure 6. Photograph showing the stream water diversion technique.

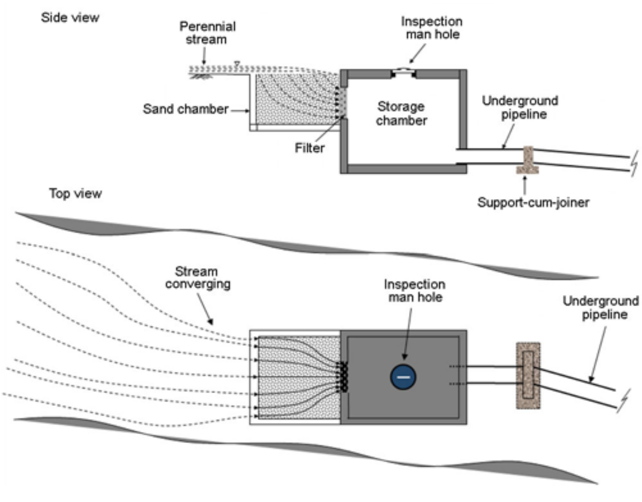

Figure 7. Schematic sketch of stream water filtration-cum-diversion structure.

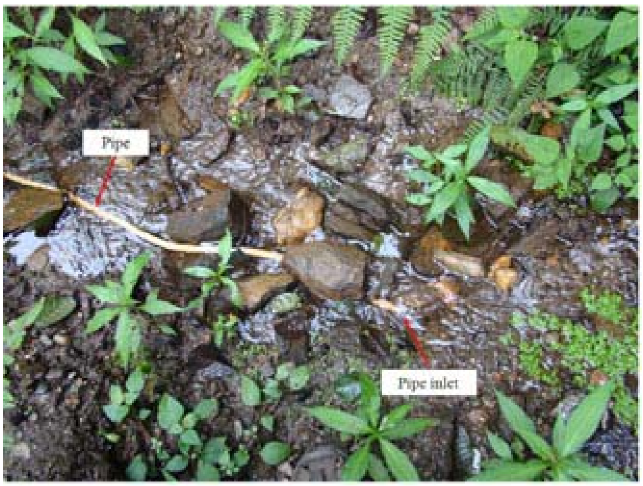

Figure 8. Tapping natural stream water using flexible pipe.

Tapping perennial streams on steep slopes of mountainous regions

For tapping perennial streams on steep slopes, small diameter flexible pipes as shown in Figure 8, are generally used. As mentioned earlier due to run-off at steep slopes, scouring of the bed occurs and it left only with stones and boulders of various sizes. Presence of stones and boulders in the natural drainage of the stream creates an uneven surface. Hence, tapped water from the tapping position to the desired location can only be conveyed through flexible pipes.

A small-diameter pipe fixed according to the desired discharge at a convenient location is placed against the flow of the stream. The inlet of the pipe is always kept at a certain water depth by placing a small weight on it, to avoid any air entering into the pipe. Otherwise, it may restrict the flow if the conveyance distance is more. In Figure 8, notice that water is entering the pipe inlet without passing through any filtration medium. The water flowing through these streams is generally turbid-free (except during the rainy season) and can be tapped without any filtration. Therefore, no special structure for filtration is required, unless the water is specifically used for drinking purpose. As mentioned earlier, in this technique also, PVC or alkathene pipes are used for conveying water from the tapping position to the water-storage tanks.

Conclusion

In this article, various techniques of tapping the groundwater resources in mountainous and Shiwalik foothill regions are described. In the present scenario of water scarcity, such ingenious techniques can assure accessibility to freshwater. The major advantages of all these techniques are their simple installation and easy applicability. No special equipment or training is required and in long run, these can be managed with little effort. Though the discharge rate obtained from these resources during the lean season is not enough to be used for flooding crops, this limited-capacity, assured water supply will be appropriate for considerable cropped area, if used wisely with water-saving techniques like drip or sprinkler system. In fact, it is beneficial because drip and sprinkler irrigation systems have proved to be more beneficial than flood irrigation in terms of water saving and crop productivity. Moreover, for a bigger tapping scheme, active participation of the farmers is required to its success; as farmers are the real stakeholders. Creating a sense of ownership, achieving equity in water distribution according to the crop needs, facilitating the users to have a choice of crops, cropping sequence, timing and period of water supply and collecting water charges are few important responsibilities of the participatory irrigation management. I would like to conclude that all the ingenious techniques described in this article for irrigation sustainability are environment-friendly.

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