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Simple and low-cost technology for irrigation from shallow aquifers in the Western Terai, Nepal

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ABSTRACT

The paper briefly outlines the hydrogeological conditions of the Terai area and describes the simple and low-cost drilling technologies used over the past thirty years in developing its groundwater resources for irrigated agriculture. The results herewith presented derive from the author's personal experience of the area and from the review of numerous studies and researches, most of which are reported in the references.

The Terai area is a very rich groundwater reservoir, made up of thick alluvial deposits transported in the lowlands by a number of watercourses originating in the northern hilly and mountainous areas. Proceeding from north to south, the alluvial deposits become progressively finer and inter-finger with each other. It is the most productive area of Nepal with rice and wheat as main food grains. The irrigated areas of the Terai Plain can be further expanded using simple and low-cost shallow tube wells drilled manually or by machine, and equipped with centrifugal diesel pumps, rower, and treadle pumps. The results of the 40,000 shallow tube wells drilled in the area have proven that shallow aquifer potential is very high, and this justifies the expansion of the present irrigated area to benefit also poor and marginal farmers.

The author stresses that the new development strategy should be based not only on the experience gained from the past thirty years, but also on improved technology and on renewed financial input in the forthcoming projects. For a well co-ordinated development of the area, it will be necessary to adopt a model in which the people will be fully involved in the planning as well in the implementation, and also participate in the operation and maintenance of wells and irrigation water systems. The new development strategy should aim at expanding progressively the present irrigated area to cope with the rate of the population growth.

INTRODUCTION

The author visited the Terai area on a World Bank mission in 1978, when the development of groundwater for irrigation and domestic water supply was in its infancy. The scope of the visit was to carry out a rapid groundwater assessment of the Bardiya, Kailali, and Kanchanpur Districts, and suggest criteria for the development of shallow aquifers in the resettlement areas to be used for irrigation and domestic water supply. The visit was concluded with the preparation of a document (Faillace 1978) that contributed to financing a project, which helped to develop the shallow aquifers in the above-mentioned districts. Since then, a number of groundwater studies and assessments have been carried out regarding the shallow as well as the deep aquifers of the Terai Region (ADBN 1988; FAO 1994a, 1994b, 1995, 1998; Gautam and Shrestha 1997; DOI and IFAD 1992; IFAD 1993, 1994, 1998; International Development Enterprises 1998; Kansakar 1997; Koirala 1998; Koirala and Gautam 1998; Shrestha and Upreti 1995; Tillson 1985; UNDP 1989).

The author considers that the experience gained in the Terai area in developing shallow aquifers for irrigation using simple and low-cost technology is highly valuable and well worth its replication in all areas of the world, with similar hydrogeological and social conditions. And this, in effect, is the main objective of this paper.

THE TERAI PLAIN

The Terai is a narrow belt, generally not exceeding 30 km in width, located between the foothills of the Himalayas and the Gangetic Plain along the border with India. It is the most productive area of Nepal, with rice and wheat as main food grains. The agricultural development of the Terai started only thirty years ago, after the eradication of malaria.

The climate is subtropical, with generally less than 1,500 mm of rain per year in the western side, and about 1,000 mm per year in the eastern side. The temperature reaches more than 40° C in summer while during the winter months it ranges between 7° and 23° C. Periodic droughts affect the region.

A REVIEW OF GROUNDWATER DEVELOPMENT IN THE TERAI

Deep aquifer investigation started in 1971–1972 with the assistance of the United States Administration for International Development (USAID) in six districts of the Central, and Western Terai. One of the deep tube well projects, the Bhairahawa Lumbini Groundwater Project, started in 1976 and is still ongoing in its third stage. Altogether, until now, more than 350 deep boreholes have been drilled in the Terai. Each deep electrically powered well, generally deeper than 100 m, yields about 100 l/s and potentially may irrigate between 40 and 120 ha.

The development of shallow aquifers in the Terai is due mainly to the Agricultural Development Bank of Nepal (ADBN), which started to install shallow tube wells (STWs) for individual farmers under a loan agreement in the early seventies.

Several studies have been done on shallow aquifer development in the past thirty years. The first comprehensive one, however, was carried out by D. Tillson (1985), who reported in tables the district areas identified for irrigation and the number of potential STWs for each area.

The World Bank, UNDP (1989), International Fund for Agricultural Development (IFAD 1993, 1994, 1998), USGS, FAO (1994a, 1994b, 1995, 1998), as well as bilateral aid programmes have helped with specific projects to assess the groundwater conditions of the shallow aquifers in the Terai Region.

The development of shallow aquifers is due to the efforts of the Groundwater Resources Development Board (GRDB), which started drilling of boreholes in the early seventies in the Terai area. The GRDB was followed by the ADBN. The Department of Irrigation (DOI), under the Ministry of Agriculture, started the drilling of boreholes in 1983. Subsequently, the DOI initiated the implementation of the Irrigation Line of Credit (ILC) programme, financed by the World Bank in 1992, which deals with shallow as wells deep aquifer exploitation.

HYDROGEOLOGICAL CONDITIONS

The Terai is a very rich groundwater reservoir, made up of thick alluvial deposits transported in the lowlands by a number of watercourses originating in the northern hilly and mountainous areas. Proceeding from north to south, along the pediment of the Siwalik Hills, known as the Bhabar zone, the deposits are very coarse and contain boulders and gravel of different grain size. They are extremely permeable and represent the main recharge belt of the alluvial deposits extending southwards where the alluvial deposits become progressively finer and inter-finger with each other. In the recharge belt, the groundwater is mainly under phreatic conditions. While proceeding southwards, alternating pervious and impervious layers (mainly silty clay) are met. The semi-pervious and impervious layers have created semi-artesian and artesian conditions in the lowlands (Tahal Consulting Engineers 1977).

The groundwater flow is generally from north to south, with a hydraulic gradient ranging from 1 to 5 m/km. The shallow aquifers are characterised by a number of interconnected lenses of sand, gravel, and pebbles.

The Terai is a relatively flat or gently undulating area with elevation ranging from 150 to 80 m above sea level. The static water level in boreholes is generally very shallow, ranging from 5 to 15 m in the northern area and from 2 to 5 m in the southern lowlands. The water level fluctuation ranges from 5 to 10 m below ground in boreholes drilled in the main recharge belt, and from 1 to 5 m towards the southern flat area.

Recharge is due mainly to rainfall and from inflow of streams whereas substantial recharge occurs also from subsurface inflow from the Siwalik Hills. The main recharge zone is the Bhabar Belt, crossed by all watercourses draining the Himalayan Mountains. In the southern low-lying belt, the recharge of confined aquifers is due mainly to the lateral flow from the northern belt.

The discharge in the western part of the Terai is estimated to be more than the recharge values in the area. This is due to the underflow from mountain areas. The higher discharge value indicates that even when extracting more water than locally infiltrated, there will not be a depletion of groundwater. According to Kansakar (1997), the groundwater used in the Terai represents only 6% of that annually recharged.

GROUNDWATER POTENTIAL IN KANCHANPUR, KAILALI, AND BARDIYA

According to FAO (1994a), the estimated irrigable area in the Kanchanpur District is 400 km^2. About 8,500 ha of land is presently irrigated by STWs and an additional area of about 11,000 ha of land is potentially suitable for groundwater development by STWs.

The shallow aquifer potential is very high in the three districts and can be economically exploited by manual drilling. Some areas are very promising also for borehole drilling by machine, especially where manual drilling is not appropriate due to coarse material. Aquifers in the whole area are quite heterogeneous due to the inter-fingering of the alluvial deposits. The average discharge of the STWs drilled by the GRDB and ADBN is about 15 l/s.

STRATEGY FOR GROUNDWATER DEVELOPMENT IN THE TERAI PLAIN

The rural poor of the Terai find it difficult to free them from poverty, as they do not have sufficient land to cultivate unless they use intensive irrigation. Crop yields could be increased by 50–100% by using intensive irrigation and modern farm practices, including improved seeds, fertilisers, and pesticide.

During the past 30 years, the number of STWs has exceeded 40,000, most of them promoted by the ADBN (thanks to its soft loan, subsidy policy, and technical assistance). As reported by Koirala (1998), the ADBN is subsidising about 3,000 STWs per year.

The subsidy granted by the government on drilling STWs for irrigation is subject to a number of bank requirements, among which is the land availability for the type of boreholes. For a standard 100 mm boring, the available land should be at least 1 ha (1.5 *bighas*); less land is required for smaller borings.

Community tube wells require more land than those of individual ownership, however, they may be subject to conflict, and often it is difficult to have a continuous irrigable area whenever the plots are too small. In addition, a number of other problems, including castes and ethnic heterogeneity, may be the cause of incurring difficulties in forming sustainable community groups. Government, in spite of such difficulties, encourages the creation of farmer irrigation associations or the association of water-user groups, which contribute with a minimum of 15% of the STW cost, and become responsible for its operation and maintenance. In case of the ILC tube well systems, the total cost is 360,000 rupees (comprising the cost of tube wells, pump houses, pump installation, and water supply system). The established command area in this case is about 6 ha. The groups include between 7 to 16 farmers having various sizes of farm holdings.

Due to difficulties in efficiently organising the farmers, the ADBN has reduced the area covered by the 100 mm diameter STW to 4 ha, although the reported area is less than 2.5 ha per well. However, for smaller diameter tube wells, the subsidy is given also for extensions of land covering only 1 ha.

SHALLOW TUBE WELLS

The definition of STWs refers (in the Terai area) to a borehole not deeper than 60 m. There are various types of STW and their diameters are of 38, 50, 100, or 150 mm.

Most of the borings are done manually by local drillers (*mistries*). Tube wells may vary in depth according to local conditions and the methods used. Casing may be of bamboo or mild steel (MS) pipes. The manually drilled boreholes have a relatively short life: generally around 5 years if cased by bamboo pipes, and 10–15 years for mild steel pipes. The ILC programme in the western and mid-western districts has drilled most of the tube wells by machine, while in the far-western districts the tube wells were drilled manually. The ILC tube wells are of three categories: STWs < 60 m; medium deep tube wells (MDTWs) = 60–100 m; and deep tube wells (DTWs) >100 m. These tube wells have a command area of 10, 20, and 40 ha, respectively. The actual command area, however, ranges between 6.1 and 27 ha. Wells are generally constructed in clusters, whenever this is possible.

MANUALLY DRILLED STWs

STWs are generally drilled by simple indigenous methods and they are, in most cases, not deeper than 40–50 m. The tube wells drilled by the public organisations are machine-drilled and are concentrated in areas having the best shallow groundwater potential. The time required to complete a shallow tube well depends upon a number of factors, and generally it takes from 3 to 10 days. Several methods of drilling are practised in the Terai. The hammer method is generally used in penetrating coarse material such as gravel, boulders etc., while the sludge method is used in drilling finer deposits.

Several drilling methods with emphasis on low-cost indigenous technology have been applied in developing shallow aquifers for irrigated agriculture in the Terai. The percussion hammer-drilling method is called *thokuwa*, whereas another percussion method, also manually operated, is called *bogi*. The rotary, or sludge method, is locally called *dhikuli*, and it implies the use of a drilling machine. The manual rotary is locally named the *donkey* method.

Thokuwa method

This method consists in driving into the ground a steel pipe, pointed at the lower bottom end. The pipe, generally 100 mm in diameter or less, has a slotted or perforated section to allow the inflow of water; it is driven down by using a 100 kg steel bar hammer.

The optimum depth reached by the *thokuwa* method is in the order of 10–20 m in loose material. Once the screen section has been driven into the aquifer, the well is developed by the reciprocating action of a hand pump, which removes silt and clay.

A common problem of this method is the clogging of the screen section in clayey sediments and, consequently, it becomes difficult to develop the well. Another problem is the damage that may occur to the screen covering the perforated section; also the pipes and the couplings may be damaged while hammering down the pipes.

This method is generally used in very shallow water-bearing coarse sediments. It was introduced in the Terai in the early 1970s but, at present, has a rather limited application.

Bogi method

This method is applied in drilling through soft as well as hard rocks by using a heavy-duty bailer called "*bogi*", consisting in a cylinder with nearly a 1-inch-thick wall, 1.5 m long, with a sharp bottom edge (shoe). The bottom of the bailer has a flat valve, which retains the cuttings; these particles are removed by lifting the cable on which the bailer is hung. The *bogi* is lowered and lifted in a reciprocating action, manually operated. Drilling through loose or semi-cemented sediments, as is the case in the Terai, a protective casing prevents caving in; in consolidated rock no protective casing is used.

Water is added while drilling to loosen drilling material and clean debris from the bottom of the hole. The protective casing, generally 150 or 200 mm in diameter, is inserted and progressively driven down. Sand-filled bags are used to add weight while twisting and rotating the casing to its final depth.

Once the expected depth is reached, hydraulic jacks are used to remove the protective pipes, while the gravel pack is progressively inserted.

This method allows drilling a 200 mm diameter hole to a depth of 60 m and to collect representative rock samples. This helps to identify position and thickness of the water-bearing layers so that the screens are installed in the most promising sections of the aquifers. The 200 mm diameter permits gravel packing the well having a 100 mm diameter casing. In the Terai most of the drilled holes have 150 mm diameter and no gravel packing is inserted.

Dhikuli or sludge method

Drilling is carried out by jetting water under pressure. Water is not re-circulated if pumped from a nearby river, pond, or stream. Otherwise, water is re-circulated by using two small basins; one is used as a settling tank and the second for pumping water into the borehole. The muddy water brings up the sand and fine gravel or cuttings through the annular space due to the reciprocating action of the drilling bit. The mud, sand, and cuttings are removed from the top of the drilling pipes by using the hand as a check valve at the top of the boring pipe, opening it as the pipe is driven down and closing it when the pipe is lifted up. The hole can be enlarged up to 200 mm by reaming it by means of a large conical coupling. The maximum expected depth is 60 m. Once the required depth is reached, the drilling pipes are removed and the casing and screen are inserted into the hole. Subsequently, the well is progressively developed using over-pumping techniques.

Manual rotary method

This simple method consists in advancing the drilling pipes by rotating them manually. The bottom drilling pipe bears the drilling bit at its lower end. The drilling pipes convey water, which is pumped down by a hand-operated pump, locally called "*donkey*" pump. As the drilling bit advances, the mud carries up the silt, clay and courser material through the annular space. The mud is re-circulated after passing through the settling basin where the carried material is deposited and collected for lithological analysis. A tripod for an easier raising and lowering of the drilling pipes facilitates the entire operation.

The diameter of the hole is generally 125 or 150 mm and easily allows for the insertion of a 100 mm casing and strainers, once the drilling pipes have been removed. Well depth may reach 60 m. Well is developed by pumping it progressively with higher discharge to avoid bridging of the strainers.

Cavity wells

A cavity well can be developed if the aquifer has a thickness of at least 4–5 m of clean sand. The hole is then cased down to the contact of the sand layer. Sand is removed progressively from the bottom of the hole by the bailer until no further caving-in occurs. A large cavity, acting as an active reservoir, is formed at the bottom of the casing. If water is under semi-artesian pressure, as often it happens, the static water level will be very close to the ground surface, allowing the use of the centrifugal pump. The cavity well does not need screened pipes, and it is cheap and durable.

Pipes and screens used in STWs

Most of the pipes used are manufactured in northern India. The size of the pipe varies according to the well diameter. In most of the STWs equipped by powered pumps, their diameter is generally 100 mm. Smaller diameter pipes are also used for treadle pumps and hand pumps.

Screens are of various types. Copper-mesh screens are generally used to wrap perforated pipes. They are costly and are often clogged by the mica contained in the fine sand. Locally made coconut strainers have been used since early seventies. They are rather cheap and may last 10–15 years. The frame for the coconut strainer is constructed by welding 12–14 iron rods of 6 mm in diameter and coiling the coconut string over it.

MACHINE-DRILLED STWs

STWs are mostly drilled by the simple manual methods described above. However, machine-drilled wells are being increasingly introduced. The development of machine-drilled wells takes place using compressed air in addition to pumping method. In spite of the considerably higher cost of the machine-drilling compared to manual drilling, many farmers give preference to machine drilling, especially if they form a group amongst themselves. The machine-drilled tube wells generally have a larger diameter to allow for the setting of the gravel pack. The life of a machine-drilled borehole is estimated at least ten years while the manually drilled well has an average life of five years. In machine-drilled tube wells appropriate screens are installed. The drilling diameter of the machine-drilled is 200 or 300 mm, while that of the manual drilling is generally not larger than 150 mm.

It appears that in some areas, manual drilling is more economical and feasible than in others. The identification of such areas will help to reduce drilling costs.

MOST FREQUENT PROBLEMS OF STWs

The problems of STWs are due to a number of technical and social factors. Those caused by technical factors, are due to lack of technical supervision during the well construction, poor well development, incorrect positioning of the strainers, and lack of gravel pack. All this may cause fast clogging of the strainers, resulting in excessive drawdown, with water level dropping at the suction point of the centrifugal pump. These problems contribute to shorten the life of the wells and increase the cost to pump the required volume of water.

The problems caused by social factors are due to the excessive fragmentation of the land in small plots and, consequently, to the inability of constructing efficient water distribution systems. The non-continuity of the potentially irrigable land prevents to exploit the wells efficiently. The reduced number of pumping hours per year to an average of 200 only, is another major problem resulting in the under utilisation of the wells. Some wells, in fact, are used on an intermittent basis, or even kept as reserve in case of drought. In spite of these difficulties, small farmers, in particular, obtain greater benefits than larger farmers as they are more motivated and are directly involved in field works.

CENTRIFUGAL PUMPS

Various types of centrifugal pump from different manufacturers are used. Their power ranges from 5 to 8 HP. The ADBN had, in the past, given a subsidy of 40% for individual farmers and 75% for group farmers who purchased the pumps. The same subsidies were given for the drilling of the borehole.

The centrifugal pumps are used in boreholes having their water level no deeper than 5 m. In case of a deeper water level, a sump 1 to 4 m deep is dug and the pump is set at the bottom of the sump with the suction pipe inserted into the borehole after the exceeding casing section has been cut off. The motor is set on the ground surface and it powers the pump by means of a driving belt system.

HAND PUMPS

Hand pumps are installed mainly for domestic water supply (drinking, washing, and bathing). Some farmers use them also for kitchen gardens and small irrigation. As the cost for the installation of a hand pump is around NRs 2,000– 2,300, most of the pumps have been installed without the ADBN subsidy. In some cases, more than one farmer uses a borehole equipped with a hand pump, and the water is used mainly for the cultivation of all kinds of vegetable, according to the season. The demand for hand pumps is not high as no subsidy is presently given by the ADBN for hand pump installation.

Hand pumps are cheap and accessible to marginal farmers: even children can easily operated them. Spare parts are readily available locally. The disadvantage is that the water delivered is minimal and only mini plots can be irrigated.

ROWER AND TREADLE PUMPS

The rower and treadle pumps are simple reciprocating pumps used for the irrigation of small plots. The difference is that the rower has one reciprocating barrel, while the treadle has two. Both of them are operated using muscle power. Their discharge varies from 0.5 to 2 l/s and they can irrigate from 0.1 to 1 ha of land. They are also used for domestic water supply and for watering stocks. Farmers also use them for kitchen gardens and for vegetable farming, especially in areas near marketplaces. The rower pump is very popular because it is used extensively for domestic water supply. Marginal farmers, having small plots, are the main users of these pumps, whereas the other farmers prefer STWs equipped with centrifugal pumps because the treadle pump requires the full engagement of a person to operate them. It seems, however, that, over the years, the popularity of the reciprocating pumps has decreased (farmers prefer the 100 mm diameter tube well equipped with diesel centrifugal pump). But, because of their low cost, the demand is still quite high, and the suppliers often have difficulty in satisfying the demand, especially from the poor and marginal farmers. The treadle pump installation is shown in Fig. 1 and 2 (*reproduced from:* International Development Enterprises 1998).

The rower and the treadle pumps were introduced by the ADBN in 1986 and used in mini boreholes, drilled manually, with a diameter of generally 50 mm, into which 40 mm PVC pipe or GI pipe with 1 to 2 m strainers are inserted.

The treadle pump can be used only in areas where the water table is close to the ground surface. It discharges more water than the rower pump, and is easier to operate. Furthermore, it does not lead to back pain during the long operation time. In spite of this, the rower pump is widespread in the Terai, as compared with the treadle pump. In fact, from the study of Shrestha and Upreti (1995), out of 1,392 pumps installed in Dang, Banke, Bardiya, Kailali, and Kanchanpur Districts in the Western Terai, only 28 were treadle pumps, while the others were rower pumps. In most cases individual farmers use these pumps.

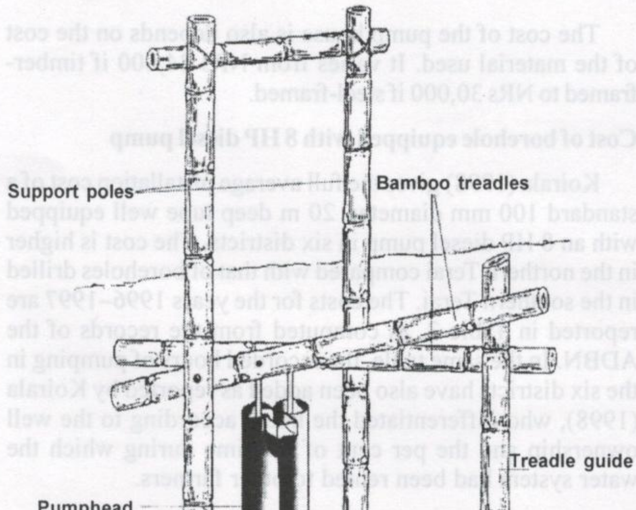

Fig. 1: Bamboo treadle pump

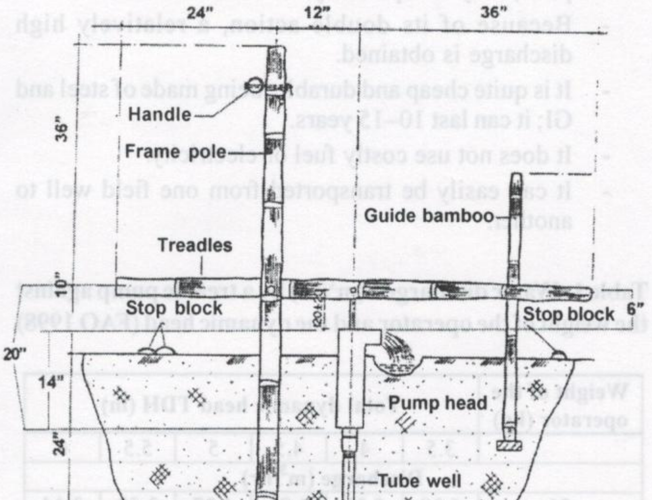

Fig. 2: Birds eye view of treadle pump

Pumping mechanism of the treadle pump

The rower pump is single-acting while the treadle pump is double-acting, meaning that water is delivered under pressure by both the upstroke and the downstroke. This is due to the movement of the two pistons, which act for suction and delivery, resulting in a nearly continuous flow of water.

The pump base has two halves for inlet and outlet; also the base of the cylinder accommodates the inlet and outlet valves. When the piston is pushed down, the outlet valve opens and water is discharged while the inlet valve is closed. Simultaneously, the other piston moves up and creates a vacuum in the cylinder, and the inlet valve opens and sucks water into the cylinder while the outlet valve is closed.

The treadle pump is operated by gently walking on two pedals (treadles) made of wood or bamboo having a length of about 1.8 m. A detailed description of the treadle pump is given in FAO (1998) and International Development Enterprises (1998). The performance of the treadle pump depends on the water depth, number of strokes and, to some extent, on the weight of the operator. In fact, the heavier and more muscular is the operator the higher quantity of water is delivered.

Table 1 summarises the average results of one of the three pumps tested. The results, however, differ only slightly from each of the three pumps.

Main advantages of the treadle pump

- It is easy to install, operate and repair.
- One or two persons can pedal for several hours, making the same effort as they would by walking.
- Maintenance costs are generally low; leather cups are those parts that may require periodical replacement. All components are simple mechanical parts, easy to replace by the same farmers.
- Because of its double action, a relatively high discharge is obtained.
- It is quite cheap and durable, being made of steel and GI; it can last 10–15 years.
- It does not use costly fuel or electricity.
- It can easily be transported from one field well to another.

Table 1: Water discharged (m^3/hr) by a treadle pump against the weight of the operator and the dynamic head (FAO 1998)

Weight of the operator (kg)	Total dynamic head TDH (m)					
	3.5	4	4.5	5	5.5	6
	Discharge (m^3/hr)					
56	6.39	5.33	4.83	4.27	3.58	3.14
59	6.86	5.68	5.14	4.47	4.01	3.28
62.5	6.56	5.40	4.63	4.21	3.75	3.23
70	6.79	6.26	5.30	4.54	3.95	3.50
Average	6.65	6.67	4.98	4.40	3.82	3.29

Main disadvantages of the treadle pump

- The maximum discharge is in the order of only 6 m^3/hr.
- The area irrigated is only 1 ha.
- The maximum head is 5 m; therefore the pump can be used only if the water table is very high.
- The use of lubricants may contaminate the water and prevent that water from being used for drinking.

COSTS OF BOREHOLES AND PUMPS AND ANNUAL HOURS OF PUMPING

The cost of a borehole is subject to a number of factors such as the nature of sediments, the depth of the water table, the method used etc. The same applies to the cost of pumps depending from the HP, the fuel used, the maker etc.

Cost of boreholes

According to FAO (1994a), the cost of a 45 m machine-drilled borehole is estimated at NRs 100,000 while that drilled by *dhikuli* method, having the same depth, is NRs 45,000. A borehole drilled by *thokuwa* method to a depth of 20 m is estimated at NRs 24,000. These estimates include manpower and daily allowance, diesel and lubricants, and repair and maintenance of drilling equipment. They include also all the miscellaneous items required to complete and develop a gravel pack in case of machine-drilled borehole. It is, however, necessary to consider at least an increase of 20 % to balance the inflation that has occurred in the past six years.

Cost of diesel pumps and pump houses

The cost of centrifugal diesel pump varies according to the HP and the manufacturer. Cost varies from about NRs 21,000 for a Nepalese pump of 5 HP to NRs 34,000 for an 8 HP Japanese pump. Indian pumps of 8 HP cost NRs 10,000 less than the Japanese pumps.

The cost of the pump house is also depends on the cost of the material used. It varies from NRs 24,000 if timber-framed to NRs 30,000 if steel-framed.

Cost of borehole equipped with 8 HP diesel pump

Koirala (1998) gives the full average installation cost of a standard 100 mm diameter, 20 m deep tube well equipped with an 8 HP diesel pump in six districts. The cost is higher in the northern Terai compared with that of boreholes drilled in the southern Terai. The costs for the years 1996–1997 are reported in Table 2, as computed from the records of the ADBN. In the same table, the recorded hours of pumping in the six districts have also been added as reported by Koirala (1998), who differentiated the hours according to the well ownership and the per cent of the time during which the water system had been rented to other farmers.

Cost of rower pumps and treadle pumps and well sinking

The cost for the sinking of the drilling pipes to a depth of 12 m and for the installation of the rower and treadle pumps is practically the same, resulting in a total cost of NRs 3,000

Table 2: Average cost of boreholes in six districts in northern and southern Terai (Koirala 1998)

Districts	Northern	Southern	Annual hours of pumping			
	NRs '000	NRs '000	Own farm	Rented out	Total hours used	% of time rented out
Kanchanpur	50	35	70	44	114	38.6
Banke	36	34	49	46	95	48.4
Rupandehi	38	32	105	97	202	48.0
Bara		31	153	38	191	19.9
Dhanusha	44	41	174	34	208	16.3
Morang	39	34	110	52	162	32.1

and 3,200, respectively. The cost includes the sinking of the pipes (NRs 600), uPVC pipe 40 mm in diameter (NRs 900), ribbon PVC screen (NRs 250), rower pump (NRs 1,000), and transportation of material (NRs 250).

Cost of operation of STWs

Koirala (1998) gives a very accurate cost analysis. He evaluates the various factors affecting, directly or indirectly, the cost of operation. From such an analysis, it results that the very high cost of operation is due mainly to the extremely low number of hours used for irrigation, resulting in only an average of 162 hours per year.

The average cost of water per cubic metre in the six districts is NRs 16.87, with the highest in Kanchanpur (NRs 26.35) and the lowest in Rupandehi (NRs 9.87). Koirala estimated that by increasing the number of hours to at least 500 per year, compared with the potential hours of 1200 during which the system could be operating, the cost of water could be decreased by 57,46,62, and 61 per cent, respectively in Kanchanpur, Banke, Rupandehi, Bara, and Morang.

The operational cost could be reduced from NRs 64.89 for an 8 HP pump-set to NRs 47.34 for a 5 HP pump-set. Investment and operational costs would also be reduced if electricity were readily available in the rural area. The replacement of the diesel pumps with electrical powered pumps would offer a number of technical and economical advantages.

GROUP OWNED STWS AND WATER MARKETING

Shrestha and Upreti (1995) found that, in five districts of the Western Terai, all the surveyed wells had been drilled by indigenous methods and all the group-owned STWs were equipped with diesel pumps. Members of group-owned STWs varied from 3 to 13. The well depths varied between 7.6 to 35.5 m. The land irrigated by individually owned STWs was 29,024 ha and that irrigated by group-owned STWs was 1,291 ha. There had been a strong demand for group-owned STWs in the past because of the high subsidy (75%) obtained by the group in comparison with the subsidy (40%) obtained by the individual farmers. This had encouraged small farmers to join in groups and, consequently, intensify irrigated agriculture. This subsidy has recently been reduced to 60% and 30%, respectively, for the groups and individual farmers.

The average size of the command areas for group-owned STWs is 5.5 ha, while that of co-owner individual farmers is 1.8 ha.

Water selling is becoming an increasing practice by those with group-owned wells. The cost of water varies from NRs 40 to 60 per hour according to the period that the selling takes place and from district to district. Due to the high initial investment cost and the high cost for operations, many farmers prefer to pay for the rental of STWs on the basis of hours of operation. The rental charge for both the borehole and the pumps is about NRs 50 per hour. Considering the rental charges are partially subsidised, it appears that buying water is a better choice than owning and equipping one STW.

The introduction of small pumps (2 HP) to be used in mini-borings can open new affordable prospects for poor farmers and help to expand the agricultural area of the Terai.

WATER USE AND BENEFITS

In the six districts mentioned earlier, the main irrigation crops are paddy and wheat, followed by oil seeds, pulse, maize, and sugarcane. In Bara and Morang Districts, according to Koirala (1998), farmers use their STWs also for the cultivation of vegetables. The return in 1 ha of irrigated land, after deducting all the various expenses, is about NRs 100,000 for bitter gourd, over NRs 75,000 from potatoes and cucumbers, and 154,000 from cauliflower grown.

The use of STWs is limited to 4–5 irrigations during the cropping season for paddy and wheat. The crop production ranges from one and a half to three times with increased use of fertilisers and selected seeds. A more intensive use of STWs takes place in case of vegetable garden irrigation.

DISCUSSIONS AND CONCLUSIONS

FAO (1994a) estimated that 360,000 ha of land could be irrigated by groundwater, out of which only about 110,000–120,000 ha are presently being irrigated, leaving about 250,000 ha potentially suitable for groundwater irrigation (200,000 ha from shallow aquifers and 50,000 ha from deep aquifers).

According to this estimate, the land and water resources of the Terai are still far from being exploited to their fullest capacity. It therefore appears clear that there is a need to expand the irrigation practices by increasing the number of tube wells to be drilled yearly to satisfy the demand of the farmers, especially the marginal ones. In the past five years, instead, there has been a declining trend in the number of tube wells drilled in the Terai, amounting to an average of only 500 boreholes/year (Koirala 1998). Also, the command area for each borehole has declined. This is due to a number of reasons, such as the decreasing of the subsidy, the increasing cost of tube wells, the limited use of the tube wells in terms of hours of pumping, the high cost of operation, and the lack of cash to buy diesel fuel and for pump repair. Furthermore, the return has been relatively low for the paddy and wheat, the main crops irrigated by STWs.

For better co-ordinated development, it will be necessary to develop a model in which the people will be fully involved in the planning as well in the implementation of the water works. Their participation will also be necessary in the operation and maintenance of wells and of the irrigation water systems. The policy regarding the subsidy and loans should also be revised in the light of the experience and analysis of data of the past years.

The FAO and IFAD are presently involved in agricultural development in the Terai by funding projects aimed at increasing productivity by introducing activities that have the people's full involvement through the formation of farm groups, extension programmes, the formation of management of farmer groups etc.

The results of such projects may help to formulate the appropriate model to further develop water and land resources in the Terai Plain.

Vast areas of the Terai can be exploited economically by STWs equipped with centrifugal diesel pumps, rower, and treadle pumps. Manual as well as machine-drilled boreholes can further contribute successfully to the groundwater development of the Terai. The new development strategy should be based not only on the experience gained from the past but also on improved technology and on renewed financial input in the forthcoming projects. Furthermore, it will be necessary to remove the present difficulties, which have caused the inversion of the trend of the expansion of the STWs, by meeting the farmers' requests, in helping to overtake their financial and technical deficiencies. It will be necessary to improve farmers' efficiency and aggregation to cope with the fragmented holdings, create clusters of wells for easier technical assistance and for extension activities and, finally, improve communication and expand the rural electrification of the Terai Region. The new strategy should aim at expanding the present yearly countrywide irrigation (estimated between 18,000 and 35,000 ha) for coping with the present population growth.

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