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Sustainability of tunnel wells in a changing agrarian context: A case study from South India

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ABSTRACT

We analyze tunnel wells (*surangams*), traditional water harvesting systems, which have been innovated and nurtured by farmers in the Enmakaje panchayat in the state of Kerala in South India for decades. We show how the genesis and design of the indigenous knowledge-based water harvesting systems are shaped by agro-ecological conditions. We also identify issues that affect the sustainability of tunnel wells in the changing agrarian context in this region. The significance of tunnel wells is declining, even though the smallholders, who dominate the agricultural landscape, are highly dependent on tunnel wells to meet their water requirements. Grass roots efforts are needed to revive this traditional water harvesting system.

1. Introduction

Water scarcity, due partly to the seasonal variation of rainfall in India, imposes limits on agricultural production. To overcome this problem, the Indian National Water Policy, 2002, recommends the revival of traditional water harvesting systems to increase usable water resources (Ministry of Water Resources, 2002). This need is also emphasised by multilateral organizations, non-governmental organizations (NGOs) and academia (Narain, 2000). Indigenous knowledge-based water harvesting systems enhance the water status of a country and contribute to achieving sustainable agricultural production. They are expeditious and cost-effective methods of water harvesting, and they are appropriate for the local conditions in terms of ecological, technical and institutional feasibility. Several studies from India (e.g., Agarwal and Narain, 1997; Balooni et al., 2008; Iyengar, 2007; Kumar, 2003) and elsewhere (e.g., Christensen, 1998; Enfors and Gordon, 2008; Farshad and Zinck, 1998; Hill and Woodland, 2003; Mbilinyi et al., 2005; Motiee et al., 2006; Mvungi et al., 2005; Wessels and Hoogeveen, 2002) have highlighted the importance of conservation of traditional water harvesting systems at the grass roots. Such systems, which have proved to be more stable than large-scale irrigation systems (Christensen, 1998), when adapted to the biophysical and socio-economic environments in which they function, contribute to sustainable resource development. Research inputs are essential to complement efforts of the government and NGOs to sustain the indigenous knowledge-based water harvesting systems. This is important in the Indian context, where several of these systems have been declining (Agarwal and Narain, 1997).

We analyze 'tunnel wells' innovated and nurtured by local people in Kasargod district in the state of Kerala in India. Tunnel wells, called *surangams* or *thurangams* in local parlance, are instrumental in overcoming the water shortage experienced in some parts of this district and the neighbouring Dakshin Kannada district in the state of Karnataka. The agro-ecology of this region is a crucial determinant of cultivation practices and irrigation water requirements. The topography of Kasargod district is highly uneven with steep hills. In addition, 75% of the area of Kasargod district is covered by laterites (Balakrishnan and Saritha, 2007), which makes the digging of open dug wells, the major means of groundwater extraction in the state of Kerala, an arduous and expensive task. Tunnel wells, which are carved horizontally through the hills to tap a subterranean water course and are usually constructed at the base of hills, following a water bearing formation (see Fig. 1), are a better alternative, both technically and economically. The distance to be traversed horizontally, to obtain water from the aquifer, is much less than the vertical distance in

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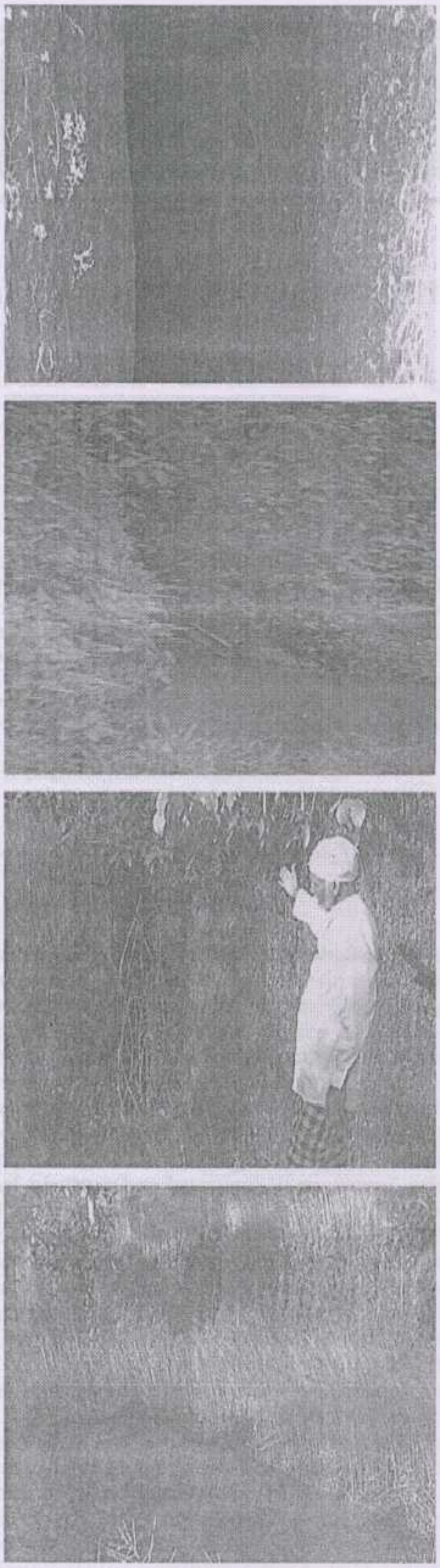

Fig. 1. Tunnel wells constructed at the base of hills in the Enmakaje panchayat.

the case of an open dug well. The water flows out of a tunnel well by gravity and is a perennial water source if the well is built at an appropriate location. Although the water from tunnel wells falls in the category of private property, the technology (tunnel well construction) is common, indigenous knowledge, which has been disseminated in this region over time. There are a few instances of water from tunnel wells being shared by a small group of users, as we find in this study.

In the above context, we show how the genesis and design of indigenous knowledge-based water harvesting systems and water extraction technologies are shaped by agro-ecological conditions. This is shown by Parajuli (1999) while analyzing the elements of social and agro-ecological conditions in farmer managed irrigation systems in the mid-hills of Nepal and examining their relationships with irrigation infrastructure, especially water division structures. In general, literature supports the fact that agro-ecological based technology, relying on indigenous knowledge, is the most practical way of realizing sustainable development (e.g., Adeel, 2008; Agarwal and Narain, 1997; Alteiri, 2002). There is also a growing realization of the relevance of the agro-ecological approach to food production and security (Bullock, 1997; Enfors and Gordon, 2008).

Two earlier studies (Nazimuddin and Kokkal, 2002; Prasad et al., 1991) have examined tunnel wells in Kasargod district – our study area, conducted by the Centre for Water Resources Development and Management (CWRDM), Kozhikode, India. Prasad et al. (1991) claim there was no prior systematic documentation of the existing tunnel wells in this region. Those authors focussed on the technical and operational features, including the hydrological and hydro-geological parameters, of tunnel wells, and suggested that this traditional water harvesting system deserves the attention of water planners, geologists and engineers. Prasad et al. (1991) found 570 tunnel wells in two *taluks* (*taluk* is an administrative unit) in Kasargod district. The results of that study were published by Basak et al. (1997) in a widely popular edited book '*Dying Wisdom, Rise Fall and Potential of India's Traditional Water Harvesting Systems*' (Agarwal and Narain, 1997).

Another, more comprehensive, study by Nazimuddin and Kokkal (2002) documented all existing tunnel wells in the Kanhangad Block panchayat, Kasargod district. The authors also examined ownership patterns, hydro-geological status, water resources potential, water quality, land use, and socio-economic aspects of tunnel wells. Both studies cover large administrative areas (panchayats) in the Kasargod district.

The scope of our study includes only one panchayat in Kasargod district and our sample includes only 40 farmers. While investigating the features of tunnel wells, we first provide an overview of the changing agrarian context in the region that affects the sustainability of tunnel wells. We analyze farmers' dependency on tunnel wells for meeting water requirements. We also examine the labour needed to construct tunnel wells, the diminishing water supply from tunnel wells, and the emerging forms of ownership and management in view of fragmentation of landholdings. We show that the importance of tunnel wells is declining in the fast changing agrarian context, even though this traditional water harvesting system is the lifeline of the smallholders.

The tunnel wells in our study area in South India are similar technically to *qanats*, the ancient underground irrigation systems found in arid regions of Iran (Farshad and Zinck, 1998; Motiee et al., 2006), Syria (Wessels and Hoogeveen, 2002), and in other parts of the world (see http://www.qanat.infor the website of Centre of Qanat Information (CQI)). According to the CQI, the construction of *qanats* expanded from Persia eastward along the silk route to China and subsequently spread to India, Saudi Arabia, North Africa, Cyprus, the Canary Islands and Spain (CQI quoted in Motiee et al., 2006). *Qanats* are long-distance water transfer systems and spread over a large area, each with a group of users, and managed by a community. In our study area, however, we found that tunnel wells are relatively small and involve only a few users. Water use is mostly confined to one user household or to a few user households. Nevertheless, we learn from the findings of studies of *qanats* (Adeel, 2008; English, 1998; Farshad and Zinck, 1998; Motiee et al., 2006; Salih, 2006; Wessels and Hoogeveen, 2002) as this traditional water harvesting system too is on the decline.

2. Research method

We conducted a case study in the Enmakaje panchayat in Kasargod district, where tunnel wells are the most prevalent water harvesting structures. The physiographic location of Enmakaje panchayat is suitable for the construction of tunnel wells. We selected a random sample of 40 farmers, all of whom use tunnel wells as one of the water sources for irrigation or domestic purposes. These farmers owned a total of 73 functional tunnel wells. We collected data describing the tunnel wells using a pre-tested questionnaire. The farmers described their landholdings, water sources, water dependency and water supply from tunnel wells, and the technical aspects (including design) of tunnel wells. We also obtained the history of tunnel wells, the issues confronted in sustaining tunnel wells, and the water status in the panchayat. We were assisted by a field investigator, a native of the Enmakaje panchayat. We also collected secondary background information on the Enmakaje panchayat from the Krishi Bhavan (Agricultural Office), Village Office and Village Extension Office.

3. Changing agrarian context

Enmakaje panchayat has an area of 8564 ha. Only a small area (97 ha) is under forest cover. Most of the land is cultivated or put to other uses. About 45% of the area is dryland. Cashew is the largest perennial crop and is mostly cultivated on the dryland. About 39% of the cultivated land is under perennial crops; mostly coconut and areca nut. These perennial crops are grown in areas with an assured water supply throughout the year. However, the cultivation of perennial crops is limited due to the lack of irrigation in Enmakaje panchayat, despite the decline in paddy cultivation during the last five decades, the deepening of existing dug wells, and the construction of new bore wells.

Paddy cultivation in the Enmakaje panchayat is now limited to 140 ha and most of the rice is produced under rainfed conditions. A similar reduction in paddy cultivation from 5512 ha in 1994–1995 to 2367 ha in 2003–2004 has been documented in Kasargod district, due to low economic returns, compared to the investment, and the large amount of water required to raise the crop (Balakrishnan and Saritha, 2007). Coconut and areca nut are produced on 60% and 23% of the irrigated area in Kasargod district, respectively. There is also increased farming of bananas and vegetables in the paddy fields (Balakrishnan and Saritha, 2007). This indicates substantial changes in the cropping pattern. There is also a change in land use from forest and cashew plantations on private land to other perennial crops including coconut and areca nut during the last four to five decades (Nazimuddin and Kokkal, 2002) in Kanhangad Block panchayat in Kasargod district.

The change in cropping pattern from paddy cultivation to perennial crops and other cash crops in Kerala has been reported in several studies (e.g., Jeromi, 2003; Joseph and Joseph, 2005; Mahesh, 1999; Menon et al., 2005; Venugopal, 2000). The major factors causing this change include the break-up of the traditional joint family system and fragmentation of landholdings, rural labour moving away from agriculture, strengthening of the public distribution system which makes rice available at a moderate price, and the change in producing for consumption to producing for the market (Mahesh, 1999).

Irrigation also has changed in recent years. Although paddy cultivation has declined in the region, the cultivation of perennial and other cash crops has necessitated year-round irrigation and increasing reliance on groundwater extraction. The irrigation scenario in this region is not encouraging. Only 31% (34,363 ha) of the cropped area in Kasargod district is irrigated (Balakrishnan and Saritha, 2007). Although nine rivers flow across the district, there are no major irrigation schemes. Only 3.3% of the irrigated area in the district is irrigated by canals, minor irrigation works or lift irrigation. The remaining area is irrigated by wells, tanks, and other sources (Source: http://kasargod.nic.in). Groundwater, extracted through open dug wells, bore wells, dug cum bore wells, filter point wells, and tunnel wells, accounts for about 47% of the irrigated area (Balakrishnan and Saritha, 2007). According to Balakrishnan and Saritha (2007), the use of bore wells for extraction of groundwater in Kasargod district increased steadily during and after the 1980s.

The Kerala State Groundwater Department provides technical assistance on the identification of suitable sites for bore wells, tube wells, filter point wells, open wells and other types of wells to government agencies, quasi government agencies, farmers, and individuals. It also provides heavy subsidies to marginal and small farmers[3] on survey, drilling, and electricity charges for pumpsets.[4] The current government policy of promoting water supply schemes based on groundwater development also acts as a disincentive in regulating over-extraction of groundwater in this region. This policy does not account for the fact that three out of four block panchayats in the district are classified under the 'semi-critical' and 'over-exploited' categories, which necessitates cautious groundwater development (Balakrishnan and Saritha, 2007). The Groundwater Department provides subsidies for drilling bore wells to marginal and small farmers, but only after investigating the hydrology, geological, geophysical and subsurface flow conditions of the site, and the groundwater recharge in the area (personal communication with District Officer, Groundwater Department, Kasargod). However, there is a lack of awareness of the environmental damages caused by excessive groundwater extraction (Nazimuddin and Kokkal, 2002), and the heavy subsidies serve as an incentive for groundwater exploitation using bore wells for irrigating perennial crops. Depleting water level primarily affects the smallholders, who are dependent upon tunnel wells and other traditional water harvesting systems as their major source of irrigation.

4. Analysis

4.1. High dependence on tunnel well water

Despite the spread of modern methods of groundwater extraction, there is still a high dependence on tunnel wells as a source of domestic and irrigation water, as reported by previous studies (Nazimuddin and Kokkal, 2002; Prasad et al., 1991). The water was found to be potable as per the standards set by World Health Organization and Indian Council of Medical Research (Prasad et al., 1991) and Bureau of Indian Standards (Nazimuddin and Kokkal, 2002). In our sample, water from tunnel wells is used for irrigation alone (22%), for domestic purposes alone (14%), or for both (64%). Tunnel wells are the dominant irrigation source, accounting for 67% of the 94 irrigation sources. Some tunnel wells are perennial, while others dry up in summer. In this case, farmers

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[3] In India, operational landholdings are classified into four categories depending on their size: marginal (below 1 ha), small (1–4 ha), medium (4–10 ha) and large (10 ha and above) (Government of India, 1995).

[4] Farmers with landholdings up to 2 ha are not required to pay electricity charges, farmers with more than 2 ha pay a fixed fee that does not increase with the amount of electricity used (Agricultural Officer, Kasargod district).

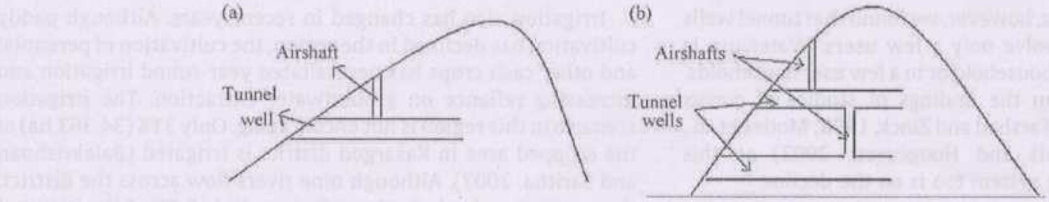

Fig. 2. Location of airshaft in a tunnel well in the Enmakaje panchayat (a) when there is low overlying soil mass and (b) when there is high overlying soil mass.

use water from other sources, such as open dug wells (19%), tanks or *kulams* (5%), check-dams or *kattas* (5%) and bore wells (4%). This shows the significance of traditional water harvesting structures in this region. The low incidence of bore wells can be attributed to the high initial investment required and unfavourable geographical conditions.

In our sample, 35 of 40 farmers have marginal (28%) and small size (60%) holdings. With increasing fragmentation, this number is increasing in the Enmakaje panchayat as elsewhere in Kerala. In Kasargod district, marginal and small landholdings account for 95.2% of all landholdings, with an average size of 0.47 ha (Source: http://kasargod.nic.in). Of 73 functional tunnels in our sample, many are owned by marginal (24) and small farmers (41). The medium farmers each own one or more tunnel wells. These tunnel wells irrigate 85% of the irrigated land (27 ha) owned by sample farmers. The need for continuous irrigation of coconut and areca nut, the predominant crops, together with the relatively low annual rainfall in the Enmakaje panchayat (2000 mm) and the absence of irrigation canals, makes the condition of tunnel wells crucial.

While all farmers in our sample depend on tunnel wells to some degree, the extent of dependency varies across categories. The percentage of small and medium farmers using tunnel wells alone as their irrigation source (29% and 25%, respectively) is lower than that of the marginal farmers (45%), who are unable to afford pumped irrigation. This underlines the social factors involved and the importance of building and maintaining this technology (Kloezen and Mollinga, 1992).

4.2. Ingenious construction and economic dimension

Site selection for digging a tunnel well is of great importance, given the high construction and associated costs. Several factors indicative of water supply are taken into account, such as the presence of certain hydrophilic plant species, the slope and elevation of the hills, the hydrogeology, and the soil texture. The well log, which is a detailed record of geologic formations, is also considered when a tunnel well is constructed inside a dug well. Some skilled workers can detect the direction of flow of water by pressing their ears to the walls of the tunnel well at midnight, which helps them identify the right path for excavation (Nazimuddin and Kokkal, 2002). They also report a few instances of the use of conventional water dowsing or witching techniques. Apart from the use of well logs, we did not come across the use of modern geological techniques or scientific techniques during the construction stage to ensure sustainable water supply from the tunnel wells.

Most tunnel wells (61% of the sample) are built in elevated places. Tunnel wells are also constructed at the bottom of a dug well (25%) or beside a pond (14%). However, these are more difficult to construct and require additional labour. They are mainly used to supplement the water supply from dug wells, which tend to dry up by February, or in some cases, to ensure a sustainable water supply. Three to four skilled and diligent workers are required to construct a tunnel well. If it is inside a dug well, five persons are required, and the wages are double that of workers constructing tunnel wells in elevated places. Wages are also higher under risky conditions such as loose soil (*saedi*) that may collapse during the construction process.

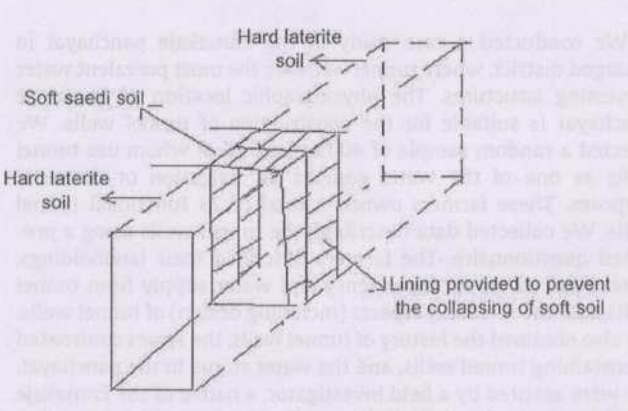

Fig. 3. Lining provided along the path of a tunnel well (in soft soil) in the Enmakaje panchayat.

The construction cost of a tunnel well is about INR (Indian Rupees) 350 per m length. The tunnel wells in our sample ranged from 3 to 150 m, with an average length of 26 m, which would cost about INR 9000. Only five were longer than 60 m. Since longer tunnels pose a risk of poisonous gases, airshafts may be provided to expel such gases and also to regulate pressure inside a tunnel well (Fig. 2). However, these are expensive to construct, and only 11% of the sample wells have an airshaft. These are all found at elevated places, in tunnel wells ranging from 18.75 to 60 m. When tunnel wells are constructed inside a dug well, there is no need to provide airshafts.

Farmers usually abandon their efforts if water is not found after digging for about 50–60 m. The optimal height (about 1.9 m) and width (about 0.75 m) of a tunnel well are based on the space required for a person to work comfortably inside. Any increase in size above this leads to higher construction cost. Tunnel wells are usually rectangular or dome shaped in cross section, to facilitate easy removal of the excavated soil. Where the soil is loose, a lining of laterite blocks on the sides may be provided (Fig. 3). This is a cumbersome and expensive process and only 3% of the tunnel wells in our sample have lining.

Tunnel wells may be independent or interconnected. Interconnected tunnel wells are dug one above the other, usually at higher elevations (Fig. 4). The water from interconnected tunnel wells may be collected in two ways. In the first case, water from each tunnel well falls onto the one below, until it reaches the bottom, and thereafter the water is conveyed to a storage tank. In the second case, water from all tunnel wells is collected in a storage trench and then conveyed to a storage tank. Interconnection of tunnel wells increases the water supply.

Water from the interior of a tunnel well is tapped using plastic/bamboo pipes or earthen channels.[5] A small bund may be

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[5] Water loss due to percolation is greater in earthen channels, with an average minimum discharge of 178 l/h as compared to 216 l/h in the case of pipes. During the summer, when the water supply is reduced considerably, the losses during conveyance are critical.

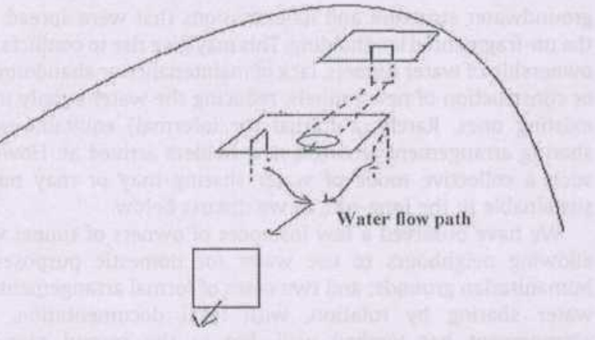

Fig. 4. Diagrammatic view of an interconnected type of tunnel well in the Enmakaje panchayat.

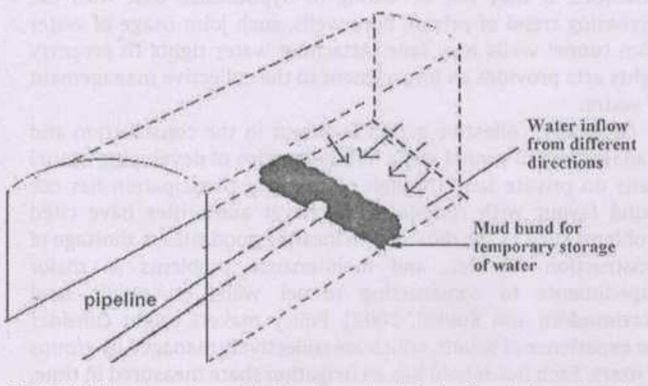

Fig. 5. Mud bund constructed inside a tunnel well in the Enmakaje panchayat.

constructed at the mouth of the well for temporary water storage (Fig. 5). This collects water seeping from different directions, which pipelines alone cannot tap. Water from tunnel wells is stored in either earthen or concrete tanks before being carried to the agricultural fields. Despite the higher construction cost, there is a growing trend towards construction of concrete tanks (11% of the sample) to avoid seepage losses and minimize maintenance work.

A major recurring expense related to tunnel wells is the annual maintenance work, usually performed during November to December, before the irrigation season starts. For tunnel wells built on hard laterite layers, maintenance work is necessary only once in four or five years. The cost of de-silting a well ranges from INR 50 to INR 5000 per tunnel well, depending on the soil type. Annual maintenance work on the earthen tank costs around INR 2000.[6]

The discussion above reaffirms that skilled workers with sound indigenous knowledge in constructing the tunnel wells have been contributing to the sustainability of this system. This discussion also reveals that there is an economic dimension to the sustenance of tunnel wells, as the construction and maintenance costs sum to a formidable expense for smallholders, who are dependent on them. Some form of government intervention and support is therefore a pressing need.

4.3. Dwindling supply of skilled workers

There is a decrease in skilled workers specialised in constructing tunnel wells over the years in this region (Nazimuddin and Kokkal, 2002). This could be attributed to the trend of rural labour moving away from agriculture, and other factors emerging from the changing agrarian scenario in this region. Given this, some farmers are turning to contractors for the construction of tunnel wells. The contractors try to reduce construction costs by reducing the width and height of the tunnels and employing unskilled labour, thus compromising the quality of the wells. Mechanization of digging also helps cut costs, but this is only possible for the initial 5 m; beyond which digging must be manual. Such changes in the mode of construction of tunnel wells signal a decline in this traditional water harvesting system.

Unlike the government's promotion of groundwater development through bore wells, there is no government agency providing subsidies to smallholders or technical assistance in the construction of tunnel wells. Nor have any banks come forward with special schemes to promote this system. This absence of institutional support may be attributed to localised prevalence of tunnel wells.

4.4. Diminishing water supply

Only 3% of tunnel wells have adequate water supply throughout the year. In half the wells, water supply follows a trend of good supply during the *kharif* season (early monsoon crops), moderate supply during the *rabi* season (late monsoon crops) and low supply in summer, while the other half of the wells have almost no water in summer. While discharge from the tunnel wells in our sample ranges from a maximum of 11,600 l/h to a minimum of 3 l/h, the wells with a discharge of more than 10,000 l/h are all of the interconnecting type. Water levels in tunnel wells vary from a maximum of 10–20 cm in the monsoon to a minimum of 1–2 cm in summer. Although the supply can be improved by increasing the length of the tunnel well, this is not always possible due to limits imposed by hard rock mass, loose soil, and other constraints. The issue of wastage of groundwater after rainy periods (Nazimuddin and Kokkal, 2002) also needs attention.

The location of a tunnel well is the most decisive factor affecting water supply. The construction of a new tunnel well in the vicinity affects the water supply of an existing well. When one tunnel well is constructed above another (drawing water from same aquifer), the water supply from the former is affected due to percolation loss. The presence of new alternative irrigation sources, especially bore wells, notably affects the water supply from the tunnel wells. Water supply has decreased over the years in 71% of the tunnel wells in our sample. While water flows from tunnel wells only through gravity, bore wells pump the groundwater at a rate greater than groundwater recharge.[7]

In addition to the 73 functional tunnel wells owned by the 40 sample farmers, we also observed 23 defunct tunnel wells, 60% of which were built inside dug wells as a supplementary water source. Most of these (78%) were abandoned at the stage of digging as there was no water yield (attributed to wrong site selection – loose soil, presence of rocky mass, or use of unscientific prospecting methods). Others became unviable over the years due to a drastic reduction in the water column caused by increased extraction of groundwater through bore wells. We did not observe any cases of revival of defunct tunnel wells, comparable to the building of dams in Jandaq, Iran, to recharge aquifers and conserve *qanats* (Salih, 2006).

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[6] Unlike tunnel wells, there are high maintenance charges in the case of *qanats*, which is one of the factors leading to their disappearance from Iran (Motiee et al., 2006). Wessels and Hoogeveen (2002) in their study of *qanats* in northern Syria, emphasize the importance of regular collective action to clean, maintain and keep the *qanats* flowing even in the dry season.

[7] English (1998) and Adeel (2008) suggest that water flow from *qanats* does not drain an aquifer, as the flow is controlled by the sub-surface water supply from the aquifer, and this makes the technology more sustainable.

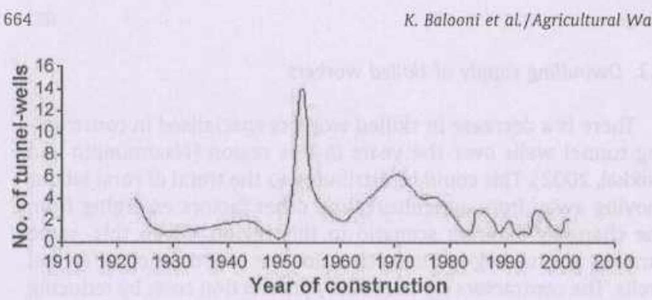

Fig. 6. Trend in construction of (sample) tunnel wells in the Enmakaje panchayat.

The transition from gravity based groundwater extraction to pumping by bore wells raises the question of equity in access to water. Smallholders, who are mostly dependent on tunnel wells and cannot afford to build bore wells even when subsidised, might in due course, become dependent on owners of bore wells for water, which brings an economic dimension to the problem as well. This needs careful examination.

There is a need to learn from the Iranian experience of qanats. Motiee et al. (2006) highlight how water harvesting via deep groundwater wells throughout the arid zones in Iran has disturbed the aquifers and resulted in abandonment of some *qanats* during the last 50 years. There are cases in which entire villages have been deserted due to ruined *qanats*. Motiee et al. also identify other factors such as population growth, greater demand for fresh water, high maintenance charges, declining agriculture and termination of traditional ownership and management of *qanat* technology in the decline of this traditional system. Wessels and Hoogeveen (2002) suggest that groundwater pumping should to be disallowed within a range of 3.5 km from a *qanat* tunnel.

The decrease in water supply from tunnel wells and their abandonment in the Enmakaje panchayat have been accompanied by a decreasing trend in the construction of tunnel wells. In our sample, construction follows an inverted U-curve, reaching its maximum in the 1950s (Fig. 6). Only one-fifth of the tunnel wells were constructed within the last decade. This decline continues even while attempts are being made to reduce the construction cost. In contrast, earlier studies by Prasad et al. (1991) and Nazimuddin and Kokkal (2002) report an increasing trend of construction of tunnel wells in this region. Prasad et al. (1991) notes that residents are increasingly becoming aware of the importance of tunnel wells. However, Nazimuddin and Kokkal (2002) also caution that development of new tunnel wells is inadvisable, given the decreasing groundwater level, and recommended the maintenance of existing tunnel wells.

4.5. Ownership and management in changing agricultural landscape

Owners of tunnel wells use most of the developed water, as the wells are constructed on private land. When the land is sold, the rights to use groundwater are also implicitly transferred. The technology of constructing tunnel wells is indigenous knowledge, and anyone can design and construct a tunnel well while freely making use of this common knowledge. However, there is no collective decision-making regarding the location of a new well to avoid negative externalities on others. Nor is there any panchayat or government intervention (Nazimuddin and Kokkal, 2002), even though such water harvesting systems reduce the government's burden of providing drinking water.

The effect of fragmentation of landholdings on ownership and management of tunnel wells also warrants study. As discussed earlier, the landholding pattern of the sample farmers, as in the entire agricultural landscape of this region, has been increasingly dominated by marginal and small landholdings. When fragmentation occurs, each of the new smallholders has legal claim to the groundwater structure and its extensions that were spread over the un-fragmented landholding. This may give rise to conflicts over ownership of water tunnels, lack of maintenance or abandonment, or construction of new tunnels, reducing the water supply of the existing ones. Rarely, a formal (or informal) equitable water sharing arrangement amongst new holders arrived at. However, such a collective mode of water sharing may or may not be sustainable in the long-run, as we discuss below.

We have observed a few instances of owners of tunnel wells allowing neighbours to use water for domestic purposes on humanitarian grounds; and two cases of formal arrangements for water sharing by rotation, with legal documentation. One arrangement has worked well, but in the second case, the maintenance of the common storage tank, collectively undertaken by the three families involved, has been neglected, resulting in reduced water supply. Though these two cases show mixed outcomes, it may not be wrong to hypothesize that with the increasing trend of private bore wells, such joint usage of water from tunnel wells may fade. Attaching water rights to property rights acts provides an impediment to the collective management of water.

Generally, collective action is absent in the construction and management of tunnel wells. While the idea of developing tunnel wells on private land through community participation has not found favour with residents, panchayat authorities have cited problems such as the difficulty in locating good sites, a shortage of construction workers, and maintenance problems as major impediments to constructing tunnel wells on public land (Nazimuddin and Kokkal, 2002). Policy makers might consider the experience of *qanats*, which are collectively managed by groups of users. Each household has an irrigation share measured in time, which are attached to the land and can be traded among the users (Wessels and Hoogeveen, 2002).

Our findings do not imply that there are no collective efforts by local residents in managing water resources in this region. Balooni et al. (2008) have analyzed the community initiatives in building and managing temporary check-dams across seasonal streams in Kumbadaje panchayat in Kasargod district and found this traditional system to be fairly successful in overcoming the water scarcity faced by farmers during the summer irrigation season. Given this experience, an effort to assist farmers in overcoming some of the challenges in constructing tunnel wells might be beneficial.

5. Concluding remarks

Farmers in the study area, the majority of whom are smallholders, depend on tunnel wells to meet their water requirements. This indigenous knowledge-based water harvesting system has been shaped by agro-ecological conditions in this region. However, the significance of tunnel wells has declined in recent years. The system is endangered by the state-subsidised exploitation of groundwater through bore wells in this region, which has seen a gradual shift in cropping pattern toward perennial cash crops that require timely and reliable irrigation. This shift is occurring even though the region has been declared a semi-critical area requiring cautious groundwater development.

Another concern is the dwindling supply of workers skilled in tunnel well construction. This increases the construction cost and reduces the quality of construction, threatening the long-term sustainability of this indigenous knowledge. The increasing fragmentation of landholdings in the agricultural landscape is a further threat to the system. Legal agreements are needed to support collective sharing among farmers of tunnel wells, the water they provide, and the annual maintenance.

Additional policy measures that might enhance tunnel well maintenance and promote wise water management, more generally, include promoting water conservation and management at the farm level, promoting groundwater recharge to enhance traditional water harvesting systems, and implementing watershed management programmes consistent with hydro-geological conditions. This essentially requires effective use of local institutions, given the devolution of power and decentralization of decision-making in India. Local institutions should also be made guardians of the indigenous knowledge and technology in their region. The Iranian experience of reviving *qanats* carries many valuable lessons for the preservation of traditional water harvesting systems in India.

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