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Traditional Design Principles of a Groundwater Irrigation System in the Foothills of the Western Ghats of Southwest India

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This paper presents the traditional design principles of the suranga water-harvesting system found in an area of semicritical groundwater scarcity in the Dakshin Kannada district of Karnataka and Kasaragod

district in the state of Kerala, India. This region is situated in the foothills of the Western Ghats of southern India. Data were derived from a mixed-methods approach that analyzed the structure, technology, governance, organization, and hydrological principles of a little-known and little-understood irrigation system. The main body of this work came from a survey of 215 households that identified 700 suranga over a core area of $\sim 6850 \text{ km}^2$. The total number when added to other inventories puts the figure at closer to 3000 suranga overall. The suranga system was identified, relative to other traditional water-harvesting systems in mountains, as a gallery filtration tunnel system that is exclusively constructed

in laterite substrate. These laterites have a sound internal structure that does not require support structures. Many suranga are found in cascading hydrological networks on more extensive farm units linked to a storage network of small ponds and check dams. The main sources of water come from either perched or shallow aquifer groundwaters that are variable in their discharge rates, such that some systems are perennial, and others are seasonal. Discharges from suranga range from $0.005 \text{ m}^3/\text{s}$ in the dry season to $0.1 \text{ m}^3/\text{s}$ in the period immediately after monsoon. Organizational principles are simple, and nearly all systems are privately owned. Access to water is usually private with just a few usufruct arrangements prevalent that come in the form of the sharing of water. The immediate future of suranga is under threat from unregulated bore well construction and use.

Keywords: gallery filtration tunnel systems; suranga; traditional knowledge; water harvesting; Western Ghats foothills.

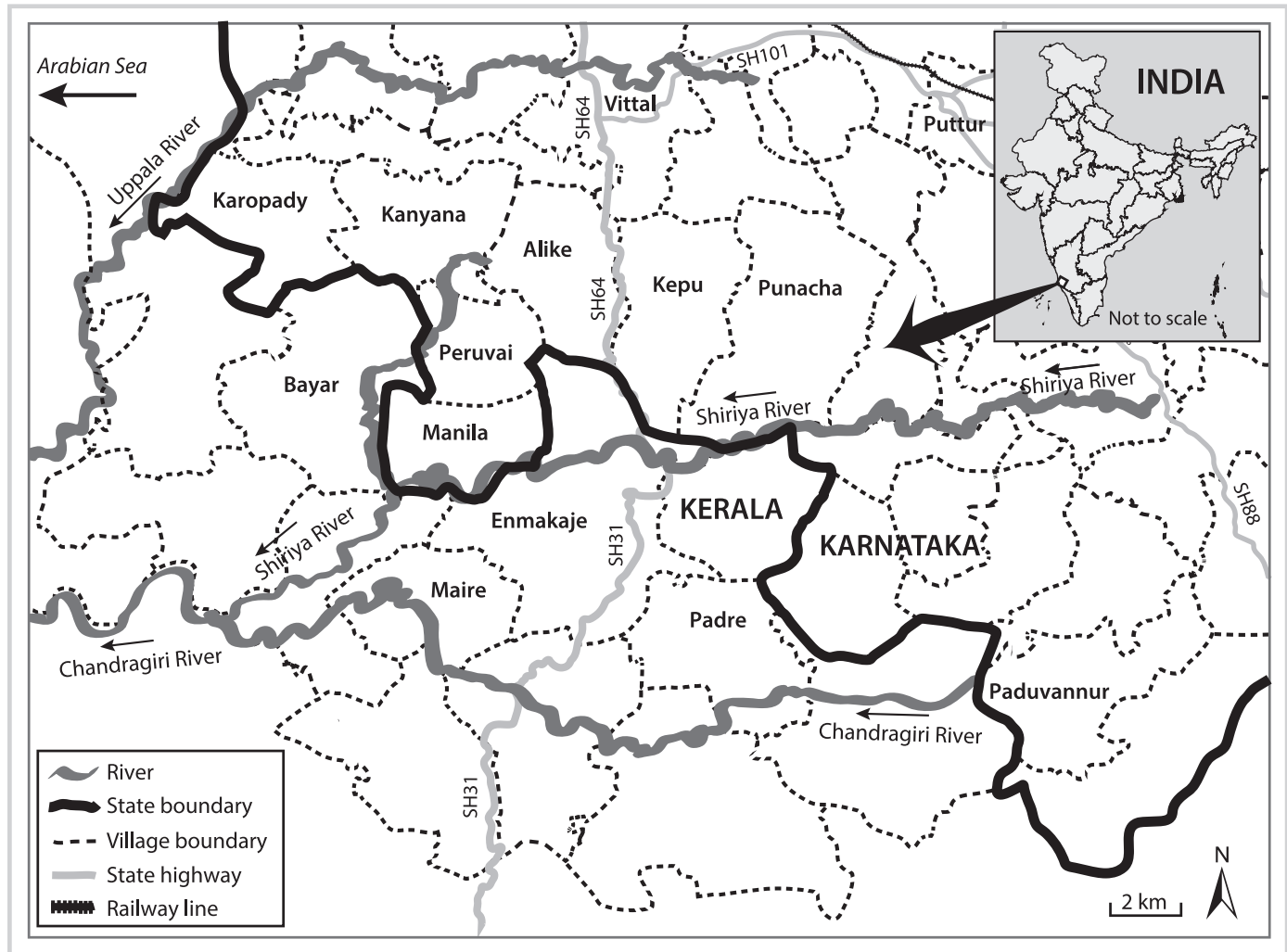
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Introduction

The Western Ghats of southern India act as a water tower (Viviroli et al 2007; Fisher 2018) for adjacent foothill areas and provide a crucial recharge area for groundwaters. They are also important in delineating the scale, location, onset, and variation of the southwesterly Indian monsoon for southern India. Unfortunately, water scarcity has become a major concern in southern India because of a complex array of pressures. Population increases (Cincotta et al 2000; Jain 2011) and climate changes (IPCC 2014; Kattumuri et al 2017; Fukushima et al 2019), such as the delay of monsoon onset (Kripalani et al 2007) and periods of drought and flood, result in a decrease in crops (Krishna Kumar et al 2011; Kumar et al 2011) and forest productivity (Chaturvedi et al 2011) and cause seasonal water scarcity (Jain 2011). Thus, there is a call for an increased focus on traditional water-harvesting techniques on the Indian subcontinent (Kokkal 2002; Agarwal and Narain 2005; Jacob 2008), due in part to their greater sustainability in comparison to large-scale irrigation systems (Christensen 1998) and their ability at times to provide drinking water. Only 28% of the rural

population have access to an official drinking water supply, which is below the national average of 67% (Aayog 2018). Those without these supplies are reliant on buying water or finding sources outside of government supplies. This is the situation in southern Karnataka and northern Kerala. According to the Centre for Water Resources Development and Management, groundwater resources are overexploited in the district of Kasaragod in Kerala (Kokkal 2002; Balakrishnan and Saritha 2007), while the Central Groundwater Board notes that Dakshin Kannada in Karnataka regularly experiences a groundwater resource crisis (Dhiman 2012; Ramaiah et al 2017), which disproportionately impacts small farmers (Anantha 2013). In response to this water crisis, the neighboring state of Kerala introduced a Ground Water (Control and Regulation) Act in 2002, and Karnataka introduced the Ground Water (regulation and control of development and management) Act in 2011. Thus, at a local level in southern Karnataka and northern Kerala, farmers face choices about how best to conserve groundwater depending on the topography and geography of their farm unit. These decisions are predicated on their past experiences of water shortage with regular

FIGURE 1 The study area: Dakshin Kannada (Karnataka) and Kasaragod (Kerala). (Map by authors, based on Google Maps India)



drought periods of 5–9 years in the region (Amrit et al 2018). At an individual farm level, as well as worries over water scarcity, farmers must face up to political and economic vacillation that potentially impacts the security of land tenure and leaves them regularly facing uncertain market and labor availability conditions (Balooni et al 2010). This makes individual investment in water-saving technology unlikely and water-saving initiatives run by water companies and local governments hard to implement. Thus, local adaptive responses to water scarcity assume a heightened level of importance. One local response to this issue of water scarcity, first implemented around 100 to 150 years ago, was to construct smallholdings on excavated slope terraces supported by a little-known technology defined as a gallery filtration tunnel irrigation system called *suranga* (Crook et al 2015). *Suranga* are well suited to the undulating and steeply sloped terrain of the foothills of the Western Ghats. This paper provides the first comprehensive outline of the design principles of the *suranga* water-harvesting system.

Study area

The foothills of the Western Ghats are characterized by relatively low, but at times steep, terrain, with a series of

rounded hillocks (Kale 2009) that create a landscape characteristic of a remote upland area (Vincent 1995). This exploratory study was carried out in the districts of Dakshin Kannada in Karnataka State and Kasaragod in Kerala between 2012 and 2014 (Figure 1). The population of the Dakshin Kannada district at the time of the last census was 2,083,625 with a density of 457 people per km²; in Kasaragod it was 1,307,375 with a density of 604 people per km² (ORGCCI 2011). Most people in this region live in rural locations and engage in a mix of subsistence and small-scale commercial farming; for the latter, most rely on producing plantation crops, such as areca nut and rubber. The climate is characterized by high humidity (78%) for the greater part of the year. There are four seasons: June to September when the monsoon occurs, October to November, which is warm and damp, December to February, which is cool and largely dry, and March to May, which is dry with rising temperatures. The average annual rainfall in the Western Ghats is 3000 mm (Dhiman 2012), although rainfall over the 6000 mm isohyet characterizes the escarpment continuing down into Kerala (Putty et al 2000; Putty and Yadupathi 2006). Around 85% of the rainfall occurs during the southwest monsoon (Dhiman 2012). The capacity of soils to absorb or store water is thus important in ensuring reliable

year-round water availability for farmers. The tropical and monsoonal climate is responsible for laterite soil profiles (Persons 1970) that are a residual deposit characteristic of the region, produced by intense weathering.

Research methods

Using a snowball survey technique, started by liaising with one key gatekeeper, 215 households were interviewed to contribute to an inventory revealing *suranga* systems in Dakshin Kannada and Kasaragod (~720 km²). These farmers were interviewed over 2 field seasons, in 2012 and 2013, but regular discussions with the gatekeeper have been maintained up to present. The main language and culture of the villages surveyed is Kannada, but Tulu is also widely spoken. A translator/facilitator was employed to facilitate access to family testimonies and their farm units. Interviews were also used to collect information about the state of water resources and socioeconomic status (scheduled caste/tribal group) determined according to where families fell above or below the poverty line. The social survey was approved by the University of Hertfordshire School of Life Sciences ethics committee, and the protocol number issued was LS5/7/12SR.

To better understand the provenance of different underground water sources, a suite of 8 range-finder ¹⁴C accelerator mass spectrometry dates were collected to estimate the residence time of water, allowing us to infer the source of the groundwater. The equivalent “apparent” radiocarbon age to the reported percent modern carbon (pMC)/fraction of modern (fMDN) values were analyzed by Beta Analytic on 6 November 2013 and 2 November 2014. These results allow us to infer the speed of recharge of different groundwater sources, which in turn allows some assessment of the *suranga* systems’ vulnerability and resilience to climate change. The second objective was to conduct a survey of *suranga* discharges over the postmonsoon (September–November 2012) and premonsoon (April–May 2013) periods to account for seasonal differences in water availability. Discharges from several accessible *suranga* in Manila village (12°41′22.12″N; 75°4′50.67″E) were considered representative of all the *suranga* surveyed based on their size and flow regimes. These were calculated using a volumetric technique because of the low flows found in most *suranga* conveyance channels (Kokkal and Aswathy 2009). These discharge measurements were taken on 3 separate occasions to find an average discharge figure. Discharge measurements were also taken monthly over 2 calendar years to account for seasonality.

Results

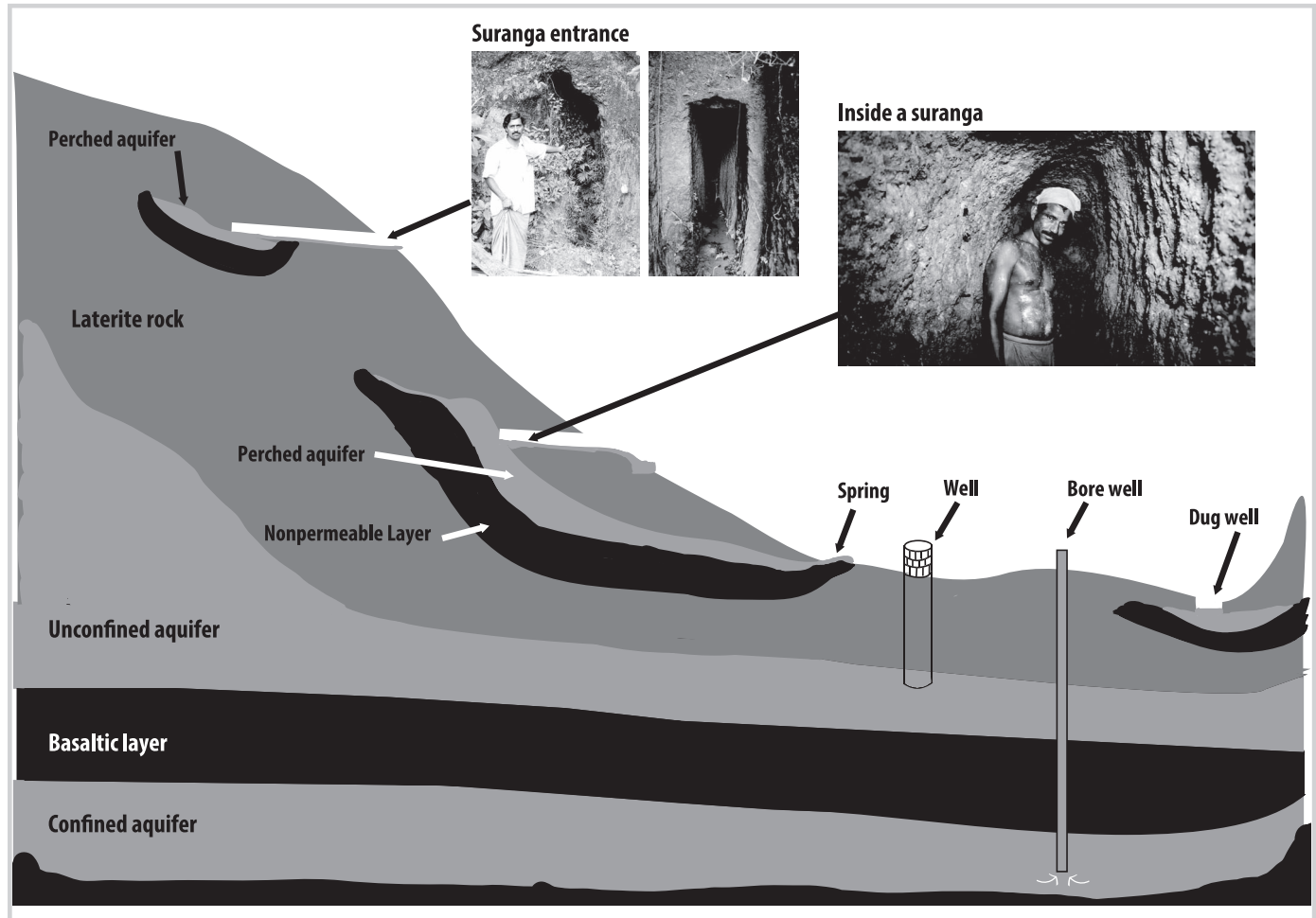
Socioeconomic effects

Suranga were defined as a gallery filtration tunnel system dependent on groundwater recharge found mainly on sloping terrain with laterite soils (Figure 2). We counted 700 *suranga*, which when added to existing partial inventories (Kokkal 2002; Kokkal and Aswathy 2009; Balooni et al 2010) gives an overall figure of at least 3000 *suranga* predominantly in the areas of Dakshin Kannada and Kasaragod. At least 2 extensions of the system had been created by the transfer of the technology to Shivamogga

District in northern Karnataka and Ponda in Goa. There is a large amount of evidence for the use of multiple *suranga* systems on a farm to exploit different microcatchment dynamics (Crook et al 2016). Water supplies from traditional systems, which include *suranga* as a key component, often have a cascading system of hydrological connectivity linked to the use of farm ponds and dug or stepped wells. Crop choices are not influenced by the delivery technology. The system is dynamic, featuring both new construction and abandonment. The percentage of *suranga* found in our survey to have been abandoned as a result of partial collapse or drying up was 18%. *Suranga* are constructed by individual landowners or sometimes by a tenant such that the water rights attached to these are riparian. There is no official regulation of the construction and number of *suranga* on a property. This decision falls squarely on the landowner. It was discovered through multiple correspondence analysis (MCA) of the survey data that *suranga* ownership was almost equally associated with families below and above the poverty line. Poor families may dig the tunnel themselves; those who have sufficient financial resources may hire labor to do this. All *suranga* are privately owned and, in the majority of cases, used individually by small family units. There are just a few instances where water rights are shared between families, usually in a usury or usufructuary arrangement, with water harvested in a rotation that is proportional to the land farmed by each tenant. Several *suranga* were shared by more than 1 family, even though *suranga* ownership always lies with 1 family. This scenario may happen through subdivision of a joint family or the division and sale of property and *suranga* that once belonged to a single owner.

Site designation

There were a few notable elderly *suranga* experts whom farmers asked for advice about where to locate and dig a *suranga*. They were held in esteem and had extensive personal experience of *suranga* building. This spiritual knowledge system appeared to be based on auspicious dates linked to the Hindu calendar. We witnessed families traveling from other areas to seek guidance from these *suranga* elders, although not all *suranga* builders consult elders before attempting to dig *suranga*. We found 2 types of water diviners. They first use their knowledge of water movement and physical characteristics of a hill, such as natural slope, geographical fault, catchment, soil and rock types, and vegetation to find a water-rich area. There appeared to be fairly widespread understanding of key ethnobotanical indicator species on hill slopes, which suggests the existence of an ecological knowledge-based system that probably predates the *suranga* system. The accuracy of water divining can vary according to the logic and experience of a water diviner. The second type of water diviners are people with alleged mystical powers. They usually carry an item with them for the water survey, such as a coconut, twig, metal y-fork, gold chain, or gold watch; wherever the item falls or the diviner senses a movement, water availability is indicated. Water diviners suggest only the location for the construction of a water structure: they are not experts in making water-harvesting structures.

FIGURE 2 Hydrogeology of *suranga*.

Construction

Suranga are typically found on hill slopes, while (dug) wells are in the valleys of these hills. Therefore, farmers usually select one or the other technology according to the type of slope or valley availability in their farmstead. There are several specialized *suranga* builders, but laborers and members of lower scheduled castes and tribes living below the poverty line may do this work themselves. These people are either trained by assisting an experienced *suranga* worker as an apprentice or they simply learn from observation. The removal of hardened laterite and some bedrock is onerous and difficult work and will usually require 2 laborers even when an experienced digger is used. A pickaxe is used, often in poorly lit conditions. The builders of tunnels rarely use candles, preferring to work in the dark, because of the lack of oxygen. An alternative, if weather, time, and aspect align, is to shine light into the tunnel by reflecting it off a mirror or shiny metal sheet. When hard rock or harder laterite is encountered, a chisel is often driven into the substrate using a hammer to help loosen it. Occasionally, a *suranga* is used as a horizontal connecting tunnel between two dug wells. Support structures are rarely used in the tunnels. If they are used, then they tend to be wooden slats made from hard wood. Tunneling often continues even under conditions of partial collapse. The excavated terrain is removed using either a head pan or a wooden sledge made from a wild

fishtail palm (*Caryota urens* L.) trunk that has rope attached to it. The sledge is filled with rubble and is pulled out of the *suranga* by a laborer. Skilled *suranga* constructors search for evidence of a mottled white color in the laterites, indicating a high water content, and look for vertical strata in the laterite for greater structural soundness. Straight tunnels are preferred because they are easier to light, excavate, and maintain. Laborers can dig between 0.3 m and 0.9 m length of tunnel per day depending on the type of laterite and will be paid a typical rate of ~300 INR/m (~4 US\$/m), which can increase for longer tunnels and difficult conditions. There are no standard rates of excavation; some charge by length, whereas others charge a daily rate. In the case of tunnel collapse or insufficient water supply, the digging usually stops after 50–60 m (Balooni et al 2010). The length of time taken to finish a *suranga* can vary according to the length of the *suranga*, soil type, and pace of excavation. Beyond 100 m, the oxygen levels begin to drop (Ajayan 2017). Thus, the construction of channels does have inherent risk, although accidents are rare; our respondents knew of only one accident resulting in death, when a *suranga* worker was killed while removing a stone.

The average length of a *suranga* is 33 m, and the range of lengths is 7–294 m (Crook et al 2016). The widths of the tunnel systems range from 0.45–0.7 m, and heights range from 0.5–2.0 m. There is general agreement that both the

TABLE 1 Provenance of groundwater sources using radiocarbon dates from different locations in Manila village collected in 2013/2014.

Water sample	Source	Elevation (masl)	Approx. depth of water from sea level (m)	Radiocarbon age ^{a)}	Probable groundwater source
1	Seminatural <i>suranga</i>	180	180	Post-1950	Rainwater recharge and perched aquifer
2	<i>Suranga</i> , Manimoole	120	120	1830 ± 30 BP	Perched aquifer and/or unconfined aquifer
3	Community bore well, Adka	132	26	8030 ± 40 BP	Confined aquifer
4	Spring (<i>suranga</i> less than 1 m), Manimoole	150	150	1150 ± 22.5 BP	Perched aquifer and/or unconfined aquifer
5	Dug well	171	145	Post-1950	Rainwater recharge and perched aquifer
6	Bore well, Pakalkunja (90 m depth)	71	-34	8440 ± 21.9 BP	Confined aquifer
7	Dug well with 4 <i>suranga</i> inside	97	95	1150 ± 26.9 BP	Perched aquifer and/or unconfined aquifer
8	Personal bore well, Manimoole	111	35	5460 ± 21.1 BP	Very deep confined aquifer

^{a)} BP, Before present; this means before AD 1950.

width and height of a tunnel usually correspond to the size of the *suranga* digger and their reach with the swing of a pickaxe. The majority of *suranga* are rectangular, although some are arched. Tunnel sides are rarely consistently straight because of differences in the resistance of the laterite to excavation and protruding rocks, so tunnel sides typically widen or contract in places. Bifurcation of tunnel systems always occurs at the proximal end of the dug *suranga* tunnel. There can be multiple divisions, hence they are called the literal translation of fingers, *kai*, and indeed these can also have subdivisions (Crook et al 2016). This is a strategy that is used to enhance water supply within *suranga*. Only 30% of *suranga* were found to have these branches. The low percentage of *suranga* with branches indicates that in most cases enough water was found in the straight *suranga*. Tunnel planimetry is not homogeneous. Sometimes the excavation of the main tunnel may be diverted at an angle to overcome rock barriers; this can happen multiple times to create zig-zag patterns in some of these tunnel systems. We found 5 types of *suranga* in this study: classical excavated, classical seminatural, plateau systems with air shafts, dug-well systems, and syphon systems (see Crook et al 2016). The first of these includes the vast majority of the observed *suranga*. A very small number of *suranga* originated in a natural cave system. To date, we have found only 3 *suranga* with a small number of air shafts, and all of these are in upland plateau areas or very gently sloping terrain. Syphon systems are a relatively recent development used where initial digging of the *suranga* revealed a natural dendritic cave system with groundwater at lower levels, such as on Posadigumpe hill near Bayar village. They tend to have very secure water supplies.

In structurally sound *suranga*, maintenance may happen only once every 4–5 years from November to December, before the main irrigation season starts. According to Balooni et al (2010), the total cost of desilting can range from 50–5000 INR (~0.68–68 US\$). Bat species regularly roost in *suranga* that have no entrance protection, so those used for drinking water have their entrances blocked to avoid contamination of the water source. Sometimes crabs inhabit *suranga*; these are considered a problem because their burrowing activities destabilize the walls, so they are

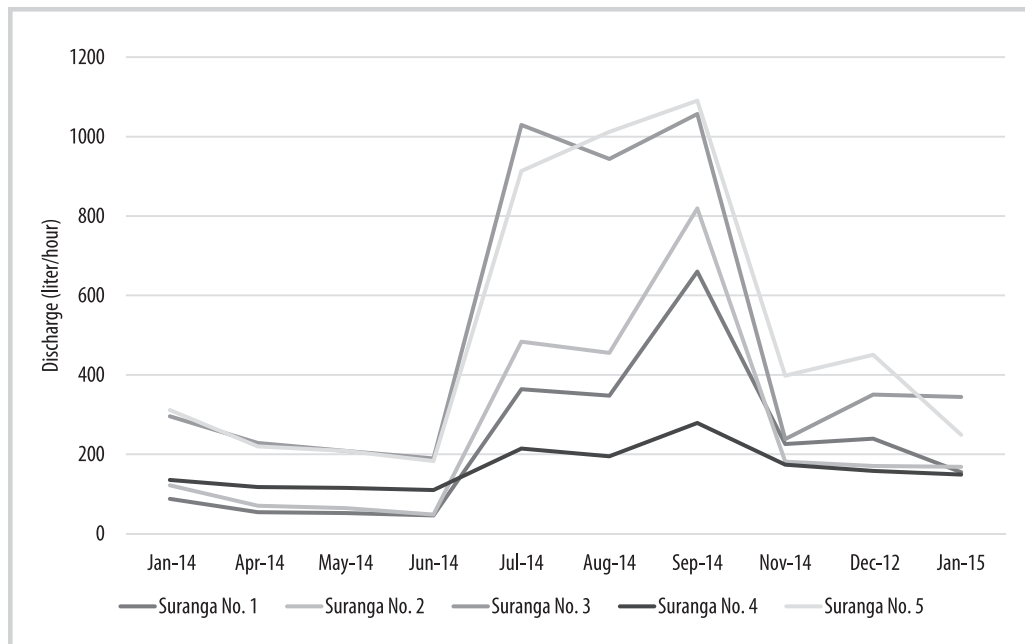
removed and killed. Partial or total tunnel collapse and/or drying up of water supplies can occur. Abandonment of *suranga* is rare, but it does happen when a *suranga* completely dries. Sometimes a *suranga* may function in a moribund status, with the threat of future collapse preventing reentry and maintenance, but if water can still be retrieved a family will continue to use it.

Water sources

On average, 35% of the irrigated area is covered by micro-irrigation systems in Karnataka (Aayog 2018). Water harvesting accounted for ~47% of the irrigated area in Kasarogod in 2007 (Balakrishnan and Saritha 2007). Most of the farmers (65%) in this survey adopted a multiple source strategy of water harvesting using a combination of traditional techniques for their water supplies, including dug wells and occasionally river sources. In terms of combinations, the MCA indicated that only 8.5% of farmers were dependent on both bore wells and *suranga*. In contrast, most *suranga* were found in conjunction with dug wells, which suggests that demand is linked spatially to marginality. Sole reliance on *suranga* in a farm unit was rare, but where this happened multiple *suranga* were typically used.

Groundwater dating results gave a better understanding of the provenance of the possible water sources for *suranga*. Table 1 presents the equivalent “apparent” radiocarbon age to the reported pMC/fMDN value dates derived from *suranga* water sources as analyzed by Beta Analytic on 6 November 2013 and 2 November 2014. Based on these results, both *suranga* in Manilla village that were analyzed are most likely to be extracting water from a suspended phreatic aquifer found within the laterites. Gumpe *suranga*, which is part of a natural cave system and an open well on the other side of the hill from Manila village, has a rapid hydrogeological system that is more vulnerable to changes in weather patterns because of the rapid recharge rates in this system. Bore wells are clearly taking water from deeper semi- or totally confined aquifers.

Water availability: Discharges from *suranga* in this survey ranged from 0.005 m³/s in the dry season to 0.1 m³/s in the wet season (Figure 3). In contrast Balooni et al (2010)

FIGURE 3 Typical discharges from 5 *suranga*.

calculated a larger range of discharges from 0.003 m³/s to 11.6 m³/s. Thus, groundwater availability varies significantly by season. No irrigation is required between the onset of the monsoon (late May) and late November because of an excess of water. Overexploitation of water is avoided as farmers show compunction on use during the dry season as less water flows out of the *suranga*. In the groundwater recharge catchment area for a *suranga*, afforestation, rainwater conservation, and groundwater recharge trenches or pits at the upper levels of hills can increase water availability inside a *suranga* (Malhotra et al 2007). Local government has funded these groundwater recharge initiatives (Shree Padre, water journalist, oral communication, 2014; Kelkar-Khambete 2012), not least because two-thirds of the rural population Karnataka still have no full access to water (Aayog 2018).

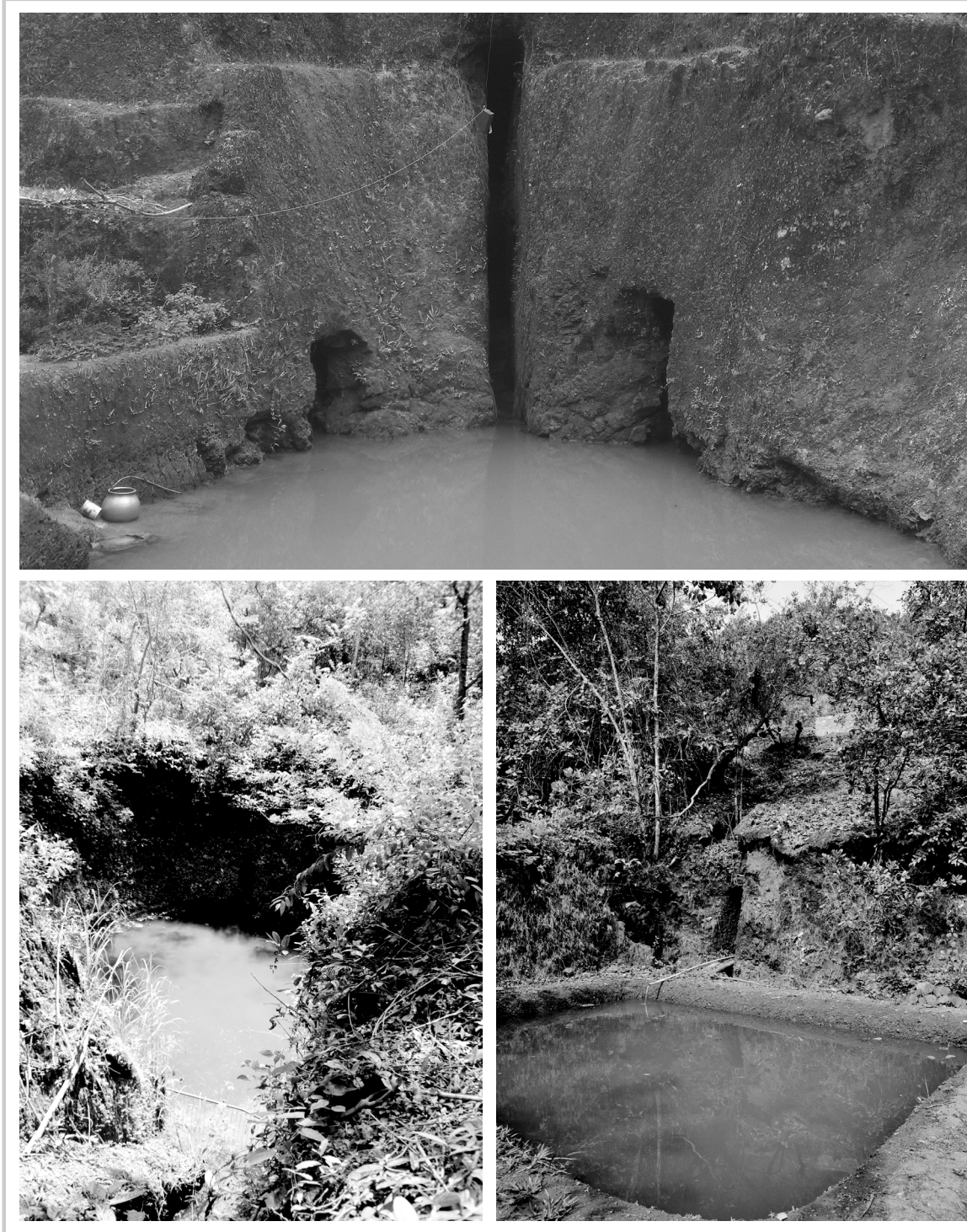
Conveyance and storage: *Suranga* are used for both drinking water and irrigation. Farmers typically create a small earthen dam a few meters into the *adit*/tunnel to create a small pool of water. They then run a pipe of 2.5–5 cm in diameter, usually plastic or PVC, through the dam to collect a low but constant flow of water. This practice has the benefit of reducing the chances of contamination from around the entrance to the *suranga*, where it is most disturbed by mammals and reptiles. This becomes particularly important when the end use is drinking water, as bacterial infections, such as *Escherichia coli*, clearly need to be avoided. As far as irrigation is concerned, farmers typically adopt and integrate new irrigation technology, where appropriate, to improve the distribution efficiency of water (Crook et al 2016). This could include using drip irrigation, sprinkler systems, and hybrid micro-irrigation techniques, such as dripper, fogger, and bubbler systems. The natural pressure gradients created by steeply sloped fields facilitate the use of small spray irrigation networks or foggers. These devices can typically provide water at a rate of >10–12 L/h (Govind Bhat, *suranga* expert, oral communication, 2015). Drip-irrigation pipes are also used in conjunction with microcatchment

techniques. At the opposite end of the spectrum, depending on the water availability, large hoses are sometimes used for short periods to irrigate tree crops. These are used in conjunction with small ponds and storage tanks that are found on most farms located on different terraces in the farm unit (Figure 4). Typically, storage ponds are built from earth and range in size but could store up to 21,600 L of water. From these, water is transferred under gravity either via open channels, but more typically via a small rubber or plastic pipe down the slope, with a maximum discharge rate (during monsoon) of 900 L/h and a minimum discharge rate (during summer) of 90 L/h.

Discussion

The design principles of *suranga* are unique, but the technology fits within a long history of water control on the Indian subcontinent (Agarwal and Narain 2005). Regionally, water-harvesting systems in Dakshin Kannada and Kasaragod have been well documented (Kokkal 2002; Balakrishnan and Saritha 2007; Halemane 2007; Balooni et al 2008, 2010; Kokkal and Aswathy 2009; Suseelan 2009), and several traditional vernacular systems of capturing water have been identified in the foothills of the Western Ghats. Hill *suranga* are used alongside other techniques of water harvesting found throughout India, such as wells, and storage techniques, such as small farm ponds; however, the hill topography negates the use of large tank systems (Shah 2003; Voudouris et al 2019). Only at the margins of the inhabitable area, usually near the tops of hills, where the poorest and most vulnerable farmers are concentrated, was there a greater dependency on *suranga* water because it is the only water supply. *Suranga* are dug only in these marginal zones. The government could promote *suranga* as an alternative to bore wells and to promote diversity in the use of different water resources as provenanced by the radiocarbon dates, but they have not done this, despite the pressures of increasing water scarcity under climate change (IPCC 2014;

FIGURE 4 Storage ponds typically associated with *suranga*.



Fukushima et al 2019). To date, the provincial water authorities of Kerala and Karnataka typically only offer supportive funding for more efficient distribution techniques, such as drip irrigation. One farmer in Karnataka has accessed funds for labor costs to build a *suranga* from the Mahatma Gandhi National Rural Employment Guarantee Act, 2005, but this is atypical, and government authorities tend to overlook the system. The farmers, almost universally, were highly suspicious of government support and were

content to remain autonomous and unregulated by government. Because conflict is so rare under private ownership of *suranga*, it is unsurprising that there are no formal conflict resolution systems in place. The same is not true for bore well use, which can lead to over-abstraction. Both the provincial and national government have been very slow to regulate bore well use through any centralized licensing scheme and have ignored their unregulated impact on the water supplies of traditional techniques like *suranga*.

The National Green Tribunal (NGT) has not yet adjudicated on any environmental issues related to *suranga*, but recent NGT judgements such as Original Application No. 176/2015 from North India, recommending the protection, conservation, and augmentation of traditional water-retaining structures, could point to the possibility of future NGT interventions on over-abstraction from bore wells. To date, the promotion of the sustainable properties of *suranga* technology have been championed only by local water journalists who report through the Indian Water Portal (including our work), and small nongovernmental organization (NGO) research units, like the Varanashi Research Centre, which operates in the foothills of the Western Ghats. Some large-scale national NGOs, like the Development of Humane Action, have started to show interest in the sustainable credentials of *suranga*, and these may prove to be a more efficient conduit for getting information to the central government. The identification of perched aquifers as the predominant water source for *suranga* could point to this relatively new technology being resilient to the pressures of an unregulated expansion of bore wells that threaten the carrying capacity of groundwater supplies only when there is overlap of different water-harvesting techniques, which is rare. Thus, it becomes prudent to examine how the *suranga* system sits in relation to similar traditional and older groundwater-harvesting techniques as a sustainable technology.

Many authors have compared the design principles of *suranga* with ancient *qanat* technology. The scale of *suranga* better fits what Ward-English (1968) referred to as those smaller *qanats* found in mountainous areas that are usually short, shallow tunnels only tens of meters long and several meters deep, which draw surface water from small patches of alluvium. Work in Israel also points to smaller-scale spring systems known as *niqba'* (Ron 1985; Yechezkel and Frumkin 2016) being similar in design and scale to *suranga* (Yechezkel, oral communication, 2019). Some early Hellenic aqueducts in places like Polyrrenia are also of a similar design and scale as *suranga* (Voudouris et al 2013). Both these cases are spring-fed systems in karstic environments. The geomorphological determinant of *suranga* is very different with all systems exclusively tunneled in laterites. Many systems appear from the carbon dating to be supplied from perched aquifers, which is unique for a groundwater-fed irrigation system. The starting point for *suranga* building, like that for *niqba'*, is typically from the entrance and not from a mother well. There is no evidence of aboveground leveling and the use of refraction techniques that were typically used during *qanat* construction (Stiros 2006) and, therefore, the internal construction techniques in *suranga* are different. A technique of constructing hybrid wells in deep wells in the Middle East to increase the capacity of the well (Helweg 1973) is similar to enhancing water supplies in dug- and stepped-well *suranga*. *Qanat* draw water from mountainous areas and transfer this to lowlands and plains, whereas the *suranga* system is found exclusively in hilly areas. *Suranga* take from a couple of months to a year to construct, which is in marked contrast to larger-scale *qanat* that can typically take 20–30 years to construct (Esfandiari 2007). The levels of maintenance of *qanat* and *suranga* are diametrically opposite in scale, commitment, and cost (Esfandiari 2007). At no stage has a *suranga* become a hazard to other people, unlike some *qanat* that pass under built environments

(Abbasnejad 2017). *Suranga* have branches (*kai*) at the proximal end of the structure, which is near the water source; in contrast, *qanat* will usually branch only at the distal end of the system to aid distribution of the water (see Remini 2018). Thus there are morphological differences between the two tunneling systems. Likewise, the shape of the tunnel or gallery can be much more variable for a *qanat* (see Remini 2016: 52) than it is for a *suranga*, which is molded to the shape of the main digger. The etymology of *qanat* system structures and practices found as far west as the Maghreb and the Canary Islands (Lightfoot 2000; Esfandiari 2007; Boualem et al 2014; Dahmen and Kassab 2017) and as far east as China (Mächtle et al 2009) and possibly Japan (Takamura 2018) share similarities, but the language of *suranga* is nontechnical. Overall, *qanat* are a good example of a successful transferable technology; the question remains whether *suranga* could be the same. *Suranga* technology has spread through word of mouth to other parts of India, where similar laterites and hydrological conditions have been found. There is nothing in principle stopping *suranga* from being transferred to other hilly regions of the world with similar types of laterite, topography, and hydrological regimes. A preliminary search has identified Ethiopia as a possible hilly country with laterites that may have the potential for transfer where a water resource need can be identified.

Conclusion

Overall, the use of *suranga* in a multisource strategy is a sensible risk aversion strategy under conditions of climate change, as by drawing on different sources of groundwater farmers minimize the risk of running out of water during the dry season. There are signs of an adaptive response among most farmers to water scarcity, regardless of their level of security of tenure, caste, or level of poverty, and of adopting new conveyance and distribution techniques in conjunction with traditional postmonsoon storage of water in farm ponds for irrigation. By prioritizing some *suranga* systems for drinking and others for irrigation, farmers from all backgrounds can mitigate these problems. In terms of existing extension services, the Kerala State Ground Water Department (KSGWD) provides technical expertise to local government agencies, quasi-government agencies, farmers, and individuals, and it identifies sites for tube wells, bore wells, filter-point wells, hand-pump wells, open wells, and other types of wells, but not *suranga* (Balakrishnan and Saritha 2007). Heavy subsidies are also provided by the KSGWD to marginal and poor farmers for survey, drilling, and electricity charges for pump sets that remain fixed at a low rate despite the rate of use (Balooni et al 2010). This imbalance in local government/water authority support is not generally viewed as a problem for farmers, even those below the poverty line, as they can build their own *suranga* at a lower cost than other groundwater abstraction techniques. Thus, there is a pressing need for better understanding of perched aquifer water supplies that mainly supply *suranga*, as they provide an alternative to scarce water supplies in deeper, more slowly recharging, or confined aquifers supplying most bore wells, and thus they potentially offer a more sustainable use of water. There is a clear need for more government intervention toward regulating bore well

digging and groundwater abstraction. Where there is potential for both bore wells and *suranga*, farmers are opting for the former and so shaping a future where *suranga* become less valued, even though the technology is comparatively more sustainable. Finally, it is argued that minimal external intervention in *suranga* construction should occur, as the antecedents for their historic success lie in individual self-determination. This work therefore warns against ubiquitously applying communal responses to water resource management in mountain environments as best practice.

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