Balinese Subak Irrigation System

Last Updated: November 2025

Part I: Static Analysis - Collective Action

The rice paddies and irrigation system of this case are near Thingan village, in the Klungkung district of Bali, Indonesia - 45 km northeast of Denpasar. The original case spans from 1957 to 1959, and it catalogues an action situation involving 455 rice farmers who are members of an organization that regulates irrigation and planting cycles (a *subak*). The *subak* system in Bali represents a longstanding tradition for irrigation, dating back to at least the 12th century (some estimates suggest as far back as the 9th century). The data was extracted from a chapter by Geertz (1967) in a book about irrigation systems in South Asia (ed. Coward, 1980), and additional information can be found in Lansing (2007).

The key resources (natural infrastructure) in the system are the watershed and its associated ecology, which includes both land (private) and water (shared). The key resource relevant to the commons dilemma faced by the community is water for irrigation (common-pool). It should be noted that water dictates crop cycles, which are managed to mitigate pests and require coordination of crop following techniques.

1.1 The Commons Dilemma

- **Potential over-appropriation / poor coordination of appropriation:**

  The water temples are where decisions about cropping and irrigation patterns are made, taking into consideration the trade-off between two constraints: water sharing and pest control. If everyone plants and harvests at the same time, a widespread fallow period may be required to reduce pest populations by depriving them of food and/or habitat. In addition, if everyone plants the same rice variety at the same time to coordinate their harvests and fallow periods, then irrigation demand cannot be staggered. Furthermore, cropping choices made by upstream farmers strongly affects the amount of water that reaches the weir in the dry season, upon which their downstream neighbors depend. Asymmetric water access has led to conflicts between head-end and tail-end farmers.

- **Potential under-provisioning of public infrastructure:**

  All farmers in the *subak* contribute to the maintenance of the hard infrastructure (field canals) by contributing: (1) labor for large projects, and (2) a tax payment to fund a subset of members who carry out smaller projects related to water regulation and the general upkeep of the irrigation system (members of this subset are called *pekaseh*). All users also contribute to aspects of the soft infrastructure (e.g., guarding against theft in harvest). There is no mention of under-provisioning of public infrastructure in the original case (pre-Green Revolution).

1.2 Biophysical Context (IAD)

- **Natural Infrastructure:**

  Water in Bali flows down deep river gorges from the top of a volcano in the center of the island to the sea, creating a series of natural watersheds. In the absence of hard and soft human made infrastructure, villages at higher elevations may have access to a more consistent source of water. This causes an asymmetry from upstream to downstream in terms of water supply. Irrigation is dependent on both controlling the volume of water during the rainy season (November to April) and storing water in irrigation systems for provisioning during the dry season. The wet and dry cycles are important in maintaining biogeochemical cycles essential for good rice yields. Controlled changes in water levels create pulses that alter soil pH, release potassium (when draining) and phosphorus (when submerged), increase nitrogen fixation through algae, stabilize soil temperature, and more. A delicate ecological balance is crucial to mitigating pests. Viruses, bacteria, grasshoppers, rats, and other pests can destroy rice crops. However, farmers can burn rice fields (losing nutrients) or flood fields to kill pests, which is only effective through coordinated action of all fields in a large area. If only one farmer attempts to control pests, it will be useless because pests can migrate from field to field. Collective action is required to keep pests at bay.

- **Hard Human-made Infrastructure:**

  Most Balinese irrigation systems begin at a weir (diversionary dam) across a river, which diverts part of the flow into a tunnel. The tunnel may emerge as much as a kilometer or more downstream, at a lower elevation, where the water is routed through a system of canals and aqueducts to the summit of a terraced hillside. In the regions where rice cultivation is oldest in Bali, irrigation systems can be extraordinarily complex, with a maze of tunnels and canals shunting water through blocks of rice terraces. The weir in the river that provides the water for the main canals is usually made of earth, logs, and stones, and may be easily washed away by flash floods. Therefore, these must be kept in good condition in order to regulate water to prevent flooding or water scarcity. In addition to the tunnel and canal systems, water temples have been constructed to coincide with the weirs. The locations and hierarchy of temples, thus, follow the flow of water and support rich religious and spiritual traditions and narratives while acting as meeting places for the leaders of all associated *subak* for a given watershed. The private infrastructure used for farming is not described in either Lansing (2007) or Geertz (1967).

1.3 Attributes of the Community (IAD)

- **Social Infrastructure:**

  The community is more than just an irrigation society because of the co-existence of: (1) multiple autonomous units for agricultural planning and management (*subak*); (2) a communal legal institution for other civil, public, and social matters (*bandjar*); and (3) an influential religious authority (Hinduism and associated temples, festivals, and rituals). Each of these three types of social infrastructure have their own governance structure and set of rules; and while they influence each other, they never fuse. This criss-crossing of social relations across the countryside forms a complex web of relationships. For instance, each citizen may be a member of various *subak* (depending on where they own plots of land for rice farming), while being a member of just one *bandjar* (depending on where their home is physically located).

  Social norms for compliance rely on a dense social network created by these governance systems with overlapping members and shared infrastructure (such as water, roads, and temples). Overlapping group membership requires a household or farmer to contribute to the social, hard human-made, and soft human-made infrastructure in a myriad of ways – such as through taxes, attending meetings at regular time intervals (e.g., head of a household must attend each *bandjar* meeting every 35 days or be fined), or participating in the preparations and rituals for a variety of religious festivals and temple offerings. In addition, all *subak* strictly follow rules set by the water temple, and farmers follow rules set by the *subak*. This compliance is due in part to effective monitoring systems, where the *pekaseh* of each *subak* can fine members.

  Balinese share a common religion and village life revolving around ritual and festivals. Temples regulate both holy and secular life. The various festivals at each temple throughout the year are essential to developing social ties. Geertz (1967) calls this “the linchpin of the entire system” (p. 89).

- **Human Infrastructure:**

  There is no mention of formal education in the case studies. However, indications are that the human infrastructure in the system is incredibly high. The depth of river gorges and absence of reservoirs requires complex engineering and ingenuity to construct the correct series of tunnels, width of canals, placement of weirs, and more to regulate the water system with pure gravity. In addition, the ability of leaders in the water temples to successfully regulate pests by making correct cropping and fallowing decisions among the many *subak* requires in-depth local knowledge.

1.4 Rules in Use (IAD)

The rules in use, i.e., soft human-made infrastructure, are provided by Geertz (1967) and Lansing (2007) (see System Representation). Based on the study, the following specific rules are relevant for this case:

1. **Position Rules:**
    - *Jero Gde* (described in Lansing 2007) is a high priest who is head of all 45 *subak* in the region, and selected for this role through ancient religious ritual and tradition.
    - There is one leader/elder (*klian*) for each *subak* and 5 *klian* for each *bandjar*. *Subak* are further divided into smaller administrative units called *tempek* and elect *klian tempek*.
    - In Subak A, there are 4 *tempek*, 455 farmers/members, and 160 *pekaseh* (a subset of members who are paid to carry out smaller projects and maintenance of the irrigation system).
2. **Boundary Rules:**
    - Geertz (1967) defines the boundaries of a *subak* as "all the rice terraces irrigated from a single dam and major canal" (p.79). Furthermore, all *subak* whose canal's headwaters flow from a single upstream weir will belong to the water temple associated with that weir.
    - A farmer must own a plot of land in a *subak* to be a member. A farmer may own plots of land within multiple *subak*, and therefore be a member of more than one *subak*. Each citizen belongs to the *bandjar* where he or she lives, and may only belong to one *bandjar*.
3. **Choice Rules:**
    - Farmers must pay taxes and obey *subak* regulations (to plant rice, vegetables, or lay field fallow). This taxation is based on the number of *tenah* owned for the services of the proceeds of which are applied to the *subak* needs and then distributed.
    - There are four sharecropping systems under which a tenant can receive 1/2, 2/5, 1/3, or 1/4 of the crop based on location and quality of land, crop type, source of seeds and cattle, etc. The 1/3 sharecropping system is standard in the Klungkung district, but may vary case by case.
    - There are three other systems for regulating access to land: 1) *gade* - a pawning system where owners surrender their land for cash (while maintaining the title) and regain ownership once the cash can be repaid; 2) *plais* - a tenancy system where prospective tenants can offer to "loan" a fixed sum to owners for use of the land, and owners have the ability to kick old tenants off when they find a higher bidder; or 3) *melanjain* - a "labor-hire" system where tenants plant dry crops and receive half the harvest, but must also prepare the owner's field for rice planting and receive no share of the rice crop.
4. **Aggregation Rules:**
    - All types of leaders/elders (*klian*) are elected by members of the respective *subak*, *bandjar*, or *tempek*. Each member has one vote in each election, regardless of proportion of land ownership or any other basis of social or economic status.
    - *Subak*: All members elect a *klian subak*, who represents the local *subak* in inter-*subak* governance, such that all *subak* that are in the same watershed coordinate at the level of a regional water temple. Each temple (which can hold 10-15 *subak*) meets once a year to determine planting and irrigation schedules. This coordination is regulated by *adat*, a code of customary law, to which all *subak* in the watershed adhere. For large tasks, like repairing a main dam, the whole *subak* may be mobilized.
    - *Bandjar*: All households elect the members of the *klian bandjar*. The *klian bandjar* are chosen by consensus and nominate their successors every 5 years.
5. **Payoff Rules:**
    - Each farmer pays a percentage fee (varies by *subak*) based on how many *tenah* (a complex measure simultaneously accounting for total water supply, land area, rice seed demands, and rice production) their land represents in the *subak*.
    - *Pekaseh* receive a portion of this for the maintenance and monitoring of the hard human-made infrastructure irrigation system.
    - Farmers pay fines if they fail to comply with *subak* regulations.
6. **Scope Rules:**

- The specific timing of the crop planting cycle is based on a timing system (*masa*) that follows the Balinese months and accounts for the relative position of the *subak* compared to its up- and down-stream neighbors (e.g., higher *subak* plant earlier to stagger peak water requirements).

7. **Information Rules:**

- *Kilan subak* tell members of each *tempek* the crop type and cycle they will plant (both for rice and other dry crops). This information is acquired through inter-*subak* coordination and collective bargaining among the various *subak* as well as intra-*subak* rituals and ceremonies that mirror the flow of agricultural activity. However, it is possible that the *kilan subak* are primarily ensuring the maintenance of the cropping patterns and crop type.

1.5 Summary

The history of irrigation in Bali reflects the development of a decentralized, complex governance network that has effectively regulated sustainable rice yield, reduced inequality, and minimized the effects of disturbances from pests, droughts, and floods on livelihoods of the Balinese for many centuries. Through sophisticated public hard and soft infrastructure, such as well-defined position and boundary rules and deep religious tradition, the system effectively reduced variability from shock and coordinated asymmetries in water supply in the watershed. Until the 1970s, the Balinese *subak* irrigation system would have been considered an incredible success story of a robust, decentralized, and context-specific coordination solution to a potential commons dilemma. However, major shocks to the system during the Green Revolution destroyed the soft human-made infrastructure, with serious consequences that seem to have altered the system permanently (see Dynamic Analysis).

Part II. Dynamic Analysis - Robustness

Lansing (2007) wrote about a major shock and temporary suspension of the *subak* system and its implications during the Green Revolution in the 1980s. The system was reinstated in the 1990s, but suffers from new exogenous pressures of tourism and subsequent land use change. Additional information on the current state of the *subak* system is provided by documentation from UNESCO (2025), SEI (Salamanca et al 2015), and Dharmiasih and Lansing (2014). Since a selection of 20 *subak* that "exemplified natural, religious, and cultural components" became a World Heritage Cultural Landscape in 2012, UNESCO provides annual reports on threats to the conservation of the *subak* system. In-text parentheses indicate corresponding links in the System Representation found in the SES Library.

2.1 Update on the Commons Dilemma

The Green Revolution temporarily suspended the *subak* system, which impacted the resource system by disrupting the balance of pests (Lansing 2007). The Indonesian government and Asian Development Bank installed policies to encourage farmers to achieve maximum rice yield production by growing rice continuously throughout the year and using chemical fertilizers. The *Jero Gde* and *subak* heads no longer dictated rice-cropping patterns, and this soft human-made infrastructure was replaced with hard human-made infrastructure of high yield rice seeds, specialized fertilizers, and pesticides. This proved to be less robust than the combination of public infrastructure and soft human infrastructure in the Balinese *subak* system. While control of irrigation and crop cycles returned to the *subak* in the 1990s, new threats to the commons came from tourism and land use development. UNESCO reports note that land is highly valued for tourism, and some *subak* heads sell their land to developers. The resulting deforestation may impact the hydrologic balance on which the irrigation system depends (UNESCO 2015). Dharmiasih and Lansing (2014) assert that the robustness of this system hinges on the ability of UNESCO to support local governance and regulate tourism and land use. Salamanca et al (2015) speculate the *subak* will only remain in Bali as a tourist attraction but not as a livelihood strategy for farmers. Conflicts about which *subak* receive tourism money and water for tourist infrastructure represents a new social dilemma. Since many farmers now use pesticides, the role of the *subak* in mediating crop schedules for pest control has become less of an issue.

2.2 Shocks, Capacities, Vulnerabilities

...to and of the Resource (link 7 to R):

The Green Revolution imposed a fine on farmers for failing to crop rice two to three times a year, which destroyed the ability of water temples to regulate crop fallow cycles and appropriate water. This caused pest outbreaks and chaos among farmers who no longer had reliable access to the water in the dry season their *subak* previously provided (Lansing 2007). This decrease in soil fertility remains a problem to the present day (Trigunasih et al, 2022; Salamanca et al 2015). Returning control to the *subak* and designating their practices as part of a UNESCO cultural landscape has returned some ecological balance to the system. However, new pressures of land conversion for tourism, lack of support for traditional farming, water scarcity, and housing development demand cause some farmers to sell land for development (UNESCO periodic cycle report 2023), compromising the hydrologic balance of the system. As water is increasingly allocated for tourism, less remains for the *subak* (Salamanca et al 2015). Biophysical changes across Bali indicate subsidence, groundwater level falling, and salt instruction (Cole 2012). This provides a vicious feedback cycle, because as water scarcity increases, pressures to sell and convert land are greater, and water supply becomes ever more variable.

...to and of the Public Infrastructure (link 7 to PI):

The value of the soft human-made infrastructure came to light during the Green Revolution, when water temples lost power to regulate cropping cycles. The hard human-made infrastructure of the Green Revolution (specialized seeds and fertilizers) could not regulate pests and prevent rice harvest destruction. Lansing (2007) does not comment on the impacts of the Green Revolution on hard human-made infrastructure. Recent UNESCO documents note with high concern that conversion of land use may disrupt the hydrologic system. Deforestation in upper parts of the watershed could cause scarcity which would make it difficult to reliably grow rice; or it could cause floods which might destroy the irrigation infrastructure. UNESCO has recommended catchment management plans to regulate land use and require impact assessments for construction permits for tourism. A lack of coherent water policy means there are no rules in use to regulate how water for tourist infrastructure affects the hydrologic system. Farmers note that water directed toward tourism (e.g., hotels) is not monitored; and *subak* are concerned about increasing non-agricultural uses of water and the impact of tourists hiking on delicate paddy bunds and sacred shrines, destroying the productive and symbolic function of rice cultivation (Salamanca et al 2015).

...to and of the Public Infrastructure Providers (link 8 to PIP):

The Green Revolution weakened the role of *subak* and temple heads as public infrastructure providers, because they no longer regulated crops or water. Now, many farmers rely on agricultural extensionists from the Indonesian state, who only know how to give support for high yield rice varieties (*padi baru*) with short crop times and intensive input requirements. The local variety, *padi lokal*, is unfamiliar to these extension agents (Salamanca et al 2015).

The UNESCO world heritage site included *subak* heads in a governance assembly, but did not include the *Gde* (temple priest). UNESCO supports public infrastructure providers with capacity building efforts that teach *subak* leaders to read and create irrigation maps, allowing them to better articulate problems to government agencies. However, according to Salamanca et al (2015) some farmers feel uninvolved with the UNESCO process.

...to and of the Resource Users (link 8 to RU):

During the Green Revolution, farmers had to pay fines for farming with their low yield rice varieties. Many farmers also converted to chemical fertilizers during this time. Organic fertilizer is expensive, and only becomes cheap to produce if enough farmers get involved, which is a challenge as more farmers exit the *subak* system. Expensive inputs, high land taxes, and water scarcity make it difficult to make a profit from rice cultivation. This causes farmers to sell land. Darmiahsih and Lansing (2014) note that 1000 hectares of rice are converted every year. In addition, youth are less interested in farming. Salamanca et al (2015) found that women feel the knowledge of rice farming and the *subak* system should be taught in schools so the knowledge is not lost.

2.3 Robustness Summary

The *subak* system overcame one major external shock: The Green Revolution. The Green Revolution was a *panacea*. The Indonesian government and the Asian Development Bank attempted to impose a panacea—"high-yield seeds + chemical inputs + continuous cropping"—on Bali. The fact that the *subak* system, the anti-thesis of a panacea; highly context-specific and fine-tuned over centuries to the specific "plant" of the Baliese watersheds, survived despite the introduction of new hard human-made infrastructure and the temporary suspension of the authority of water regulation and crop cycles is remarkable (link 7 to PI). However, the legacy of the Green Revolution continues to impact the system. Knowledge of some traditional rice farming was lost, and government extensionists can only give support for high yield rice varieties that require large expensive inputs (link 8 to RU). However, new shocks of tourism and the difficulty of profit from rice farming increases land conversion, which in turn diminishes hydrologic robustness of the resource system (link 7 to R). Efforts to include 20 *subak* in a World Heritage Cultural Landscape in 2012 spurred financial support and governance structures that persist to date and are helping mediate current problems, and provide a source of economic support in the form of tourism. However, tourism has also created trade-offs within the *subak* system in the form of increased development pressures. Additionally, concerns with the governance system, including failure to include temple priests and efforts from the Indonesian government to take control, means that continued conflicts in water allocation and conversion of rice paddies remain. Darmiahsih and Lansing (2014) note that UNESCO could remove Bali *subak* from the World Heritage List if these conflicts remain unresolved. Has the UNESCO world heritage status strengthened the system by providing global prestige and funding, or has it led to commodification and a "museumification" of the *subaks*?

Finally, if the *subak* system is preserved due to tourism and its nature as an emblematic Cultural Landscape but not due to its ability to support livelihoods of Indonesian farmers, this transformation from farming to tourism represents the robustness-fragility trade-off To what extent is the system being subsidized by its labeled status or its rice paddy and irrigation system of preserving livelihood?

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