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Monsoons, rice production, and urban growth: The microscale management of 'too much' water

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Abstract

In discussions of human-environmental dynamics and climate change, treatments of water usually focus on the problem of drought. Monsoon environments constitute a different set of parameters for landscape interactions because of seasonal episodes of water abundance. In this paper, we evaluate the microscale management of routine and anticipated high-water events for the ancient Indian subcontinent, where people used the monsoon cycle to engage in rice farming that in turn supported the growth of cities. Rice production would have encompassed two fluctuating inputs: rural labor, which may have become scarce when villagers left farmlands to become city dwellers; and water, the quantity of which varies dramatically on both a seasonal basis because of the monsoon and on an occasional basis because of tropical cyclones. The abundance of water (even with its risks of overabundance) encompassed numerous logistical challenges but also permitted high productivity within short distances of urban centers. The case study of the ancient city of Sisupalgarh in eastern India illustrates that high levels of productivity per land area enabled city residents to engage in short-distance economies for food production, while maintaining regional contacts through durable-goods trade to mitigate occasional episodes of crop failure in times of major flooding.

Keywords

archaeology, flooding, rice, urbanism, water

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Introduction

In much of the literature on both modern and ancient food production, water is considered a limited resource the absence or scarcity of which results in environmental stress, food shortages, and famine. The monsoon belt of Asia presents an interesting oppositional case study, in which food production, consumption, and distribution are often marked by conditions of *too much* water. The strength and impact of monsoons have fluctuated over geologic time; monsoons also fluctuate in onset, duration, and intensity from year to year (Kingwell-Banham, 2015; Parthasarathy, 1984; Webster and Yang, 1992). Nonetheless, the primary experience and effect of the monsoon comes in the form of seasonally abundant rainfall, a process that B.K. Paul (1984: 3) characterizes as 'normal floods'.[1] Studies of water management and agricultural cycles in a world of 'normal floods' are an important corrective to the global discourse of water extremes characterized by unpredictable oscillations of drought and catastrophic inundation.

In the watery world of the Asian monsoon environment, rice farming is an ideal solution to both the realities of 'normal floods' and the challenge of sustaining increasingly large populations. Rice requires significant amounts of labor investment and planning, however. Rice cultivation has more bottlenecks in the production process than other grains because of the multiple inputs per growing season ranging from field preparation and seeding to transplanting, weeding, and harvesting, all in response to the fluctuating availability of water. In both the past and in the present, the growth of urbanism has resulted in a changing balance of labor availability as more people relinquish full-time farming to become city dwellers. In the ancient cities of the Asian monsoon belt, the mutual dependence of farmers who required an on-again, off-again labor supply and urban dwellers who required grain might have kept cities more strongly tied to rural agricultural endeavors than might have been the case for urban systems elsewhere in the world that relied on cereals such as wheat, barley, and maize.

Archaeologists and historians have long noted that the emergence of cities resulted in the simultaneous creation of rural hinterlands as an economic and social counterbalance (e.g. Adams, 1972; Smith, 2014; Taylor, 2013: 26; Yoffee, 1995: 284). Yet, in comparison to the focus on cities themselves, hinterlands have been undertheorized despite the essential role played by rural households in the provisioning of urban centers. In village economies prior to the emergence of urbanism, each household would have needed to generate sufficient resources to feed its own members as well as generating enough resources to contribute to community pursuits and religious activities. Farmers are known to have engaged in elaborate strategies of risk management for crop

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production from the beginnings of agriculture, resulting in what Winterhalder and Goland (1997: 123) characterize as 'localized decisions about resource selection' (see also Halstead and O'Shea, 1989; Marston, 2011). With the emergence of proximate urban centers, those localized decisions would have been informed by the additional need to account for the production of food for the city, whether through exchange or in direct support of urban-based family members. In addition to considering the economic impact of agriculture on the development of urban centers, we also should consider the effect of cultivated resources on the lived level of human experience, in which the energetics of physical production are interwoven with perceptions of food preference, social obligations, and individualized assessments of seasonality and weather (Erickson and Walker, 2009: 249; Smith, 2006; Weiss, 1997: 167). Even simple, received environmental phenomena such as rainfall, over which people have no direct control, become culturally encoded, structurally planned for, and consciously mitigated (Guyer, 2015; Quintus et al., 2016).

A focus on the adaptive, flexible, and agentive approach to the microscale is a productive contrast to much of the existing archaeological discussion of the Anthropocene, which has tended to focus on large-scale and longitudinal effects of deleterious human actions such as extinction (e.g. Braje and Erlandson, 2013), human-produced methane (Fuller et al., 2011), and industrial pollutants (Rosman et al., 1997). The advent of cities provided a particularly dynamic environment for decision-making and resource provisioning that would have enabled people to integrate their knowledge of agricultural ecosystems with the expanded production and consumption opportunities provided by growing urban centers in ways that resulted in new ecosystem configurations. Researchers working on other global cases of early urbanism, for example, in Mesopotamia, have noted that sites were linked in networks of trade across environmental zones (Wilkinson et al., 2014: 46). In the Maya region, the use of tropical plants and dispersed settlement patterns resulted in 'garden cities' in which agricultural productivity would have been integrated into the urban experience (Stark and Ossa, 2007: 387). In the monsoon belt of Asia, urban–rural labor coordination would have been a structural necessity that linked agricultural strategies with urban labor pools on an ongoing basis.

A particularly salient place to examine the effects of rainfall and the concomitant mutualistic dependencies of rural to urban dwellers is the Indian subcontinent, which first developed cities in the Indus period from 2500 to 1900 BC primarily reliant on wheat, barley, and millet (Weber, 1999). Urbanism was subsequently absent from the subcontinent for more than a thousand years until the Early Historic period starting around the 4th century BC, when there was a near-simultaneous development of urban centers, Buddhist and Jain monastic institutions, writing, state-level territorial integrations, and organized warfare (Figure 1). Within a short period of time, nearly a hundred sites of urban size developed in the subcontinent along with evidence for intensive rice consumption as seen in both texts and archaeological remains, where rice was celebrated as a preferred food and its cultivation served as a metaphor for social cohesion and moral uplift (Singh, 2008; Smith, 2006).

Figure 1. Map of Indian subcontinent showing cities of the Early Historic period (*c.* 3rd century BC–AD 4th century) with inset of rivers in study area and sites mentioned in text.

Rice

Rice was domesticated by around 6500–6000 years ago in China and around 4000 years ago in India (Fuller, 2011) and is among the world's most productive domesticated food plants. Like other grains, rice has a high caloric and carbohydrate content while also being storable. It can be prepared for consumption in both whole grain and milled form including boiling, steaming, dry-roasting, and fermenting. From the consumer perspective, rice is a preferred food even when globalized trade flows enable the consumption of other foods (Papademitriou, 2000). Factors of productivity and preference propelled rice to become the fortuitous element in the development of high population densities in monsoon environments, and rice became the basis for the support of complex societies in South, Southeast, and East Asia in a mutually reinforcing pattern of increased population, increased productivity, and increased labor requirements that are still evident today (see, e.g. Fuller, 2011: 79, 84; Fuller and Qin, 2009; Greenland, 1997).

Rice can be grown in a variety of environments, from uplands to deep submergence (Khush, 1997; Weisskopf et al., 2014). Within rice-growing areas, farmers select from rice varietals suited to different microtopographies and soil types, with different lengths of growing season, and having different output characteristics of taste and texture and different qualities of byproducts such as straw for thatching and animal fodder (Kshirsagar et al., 2002). Farmers also calculate the projected availability of labor for field preparation, planting, weeding, and harvesting. Interspersed with these cultural approaches to agriculture are the natural parameters of production, in which 'water rather than soil is the more important factor in deciding on the suitability of an area for growing the rice crop' (Framji, 1977: 266; Greenland, 1997: 44). The relationship of rice with water is distinct in a number of ways: rice has the highest water requirement of any cereal crop (Greenland, 1997: 141 citing Bhuiyan, 1992), it is the only major cereal crop whose seeds can germinate in anaerobic (e.g. underwater) conditions (summarized in Jackson and Ismail, 2015), and it is the only major cereal crop that can be waterlogged (Setter and Waters, 2003).[2]

Even under conditions of 'normal flooding', the monsoon season has landscape-level effects from year to year that include not only an abundance of water but an associated abundance of silt and nutrients. Silt depositions have been measured in South Asia as a 20-fold difference in different years (Greenland, 1997: 105, citing Whitton and Rother, 1988). Flooding brings nutrients down from higher elevations (Greenland, 1997: 104), but high water levels also dilute the chemical composition of the soil (Roger, 1996: 12). Farmers address the variability of water abundance in numerous ways, including through the construction of field bunds which reduce the velocity of water across a landscape (Chapagain and Hoekstra, 2011: 756); once built, bunds are continually managed as farmers alternatively build and breach bunds to keep water at desired levels throughout the growing season. This is necessary even with rainfed rice because the onset and intensity of rain are variable within the parameters of 'normal' years, and because the timing of water affects plants differently at different times in the growth cycle. Rice seedlings are adversely affected by submergence, and benefit from germination in seedbeds where farmers

Figure 2. Rice cultivation strategies in the eastern Indian monsoon belt (clockwise from top left): plowing before rains; broadcast rice seeds, fallow field, and recently harvested field; plowing after rain; transplantation of seedlings.

can control the water level that involves water removal as well as water augmentation (Greenland, 1997: 30). Water availability also has an effect on ancillary processes such as weed growth: some weeds such as *Echinochloa* spp. germinate poorly in flood conditions (Estioko et al., 2014), but other weeds thrive in high water levels and can physically suffocate rice plants (Roger, 1996: 56); moreover, some weeds are 'mimics' in morphology that can be difficult to distinguish in the weeding process (Kingwell-Banham, 2015: 91). The logistics of human labor inputs and field access also are adversely affected by rain variability. For example, 'incessant drizzling for days just after the emergence of both rice and weeds, makes weeding difficult resulting in complete failure of the crop' (Sattar, 2000: 61).

Different opportunities and constraints are evident during periods of irregular and unpredictable 'abnormal floods' resulting from unusually heavy annual monsoon rains as well as rain from cyclonic storms (Murty et al., 1986). Rice does not have unlimited tolerance to water and can be damaged through excessive submergence, with losses ranging up to 100% of the crop (Ismail et al., 2013 cited in Kato et al., 2014; see also Framji, 1977: 289).[3] Abnormal flooding can overwhelm the many incremental adjustments that are used to maximize gain and mitigate loss in times of 'normal' flooding. When faced with excessive rainfall, households instead must focus on quickly saving themselves as well as their livestock and household goods (Paul, 1984; cf. Douglas et al., 2008). The speed at which abnormal flooding occurs illustrates that the problem of 'too much' water is fundamentally different from the mitigation of drought. Whereas in drought, there is the potential for a life-giving rainstorm, or at least the saving of some plants through stopgap irrigation, an overabundance of water presents a condition in which there is no feasible way to dry out the landscape.

Labor investment, water abundance, and rice agriculture

The parameters of rice cultivation vary according to the availability of labor. Field preparation can reflect variable levels of investment, ranging from little to no preparation, to the creation of field bunds through buildup or downcutting of the soil, to multiple sessions of harrowing and flattening within individual fields to facilitate uniform water distribution, to the terraforming of entire landscapes to render flat surfaces within terraces (Figure 2). After field preparation, rice is either broadcast or transplanted from seed beds, with significant tradeoffs between labor input and eventual yields. Framji (1977: 267–268) reports that transplanted rice has a 15–30% greater yield than broadcast rice; this may in part be because of the simultaneous germination and growth of weeds in broadcast rice, in which 'yield losses due to weed competition have been reported to be 3-fold greater in direct-seeded rice than in transplanted rice' (Estioko et al., 2014: 2 citing Hill et al., 1990). The practice of transplanting also provides greater control over field timing because the seedlings can be growing in a seedbed while the farmer prepares the main fields, which can include plowing 4–6 times at 4- to 5-day intervals (Framji, 1977: 268).[4] The direct tradeoff of labor availability and cultivation practices is evident even today, as seen in the increase in direct broadcast of seeds compared with transplantation as increasing numbers of rural dwellers migrate to cities (see Estioko et al., 2014, citing Ismail et al., 2012).

Because rainfall can vary in both amplitude and frequency even within anticipated seasonal water abundance, farmers must be ready to adjust workloads and expectations throughout the growth cycle. Observations of modern cultivation practices illustrate that labor shortages can be found at even the smallest scale of production when fields are all being planted or harvested at the same time (e.g. the near-subsistence Odisha villages investigated by Mishra, 2015: 21). Labor shortages are also keyed to specific weather conditions, with more labor invested in field preparation if the onset of the monsoon is delayed, and more labor required for harvest if there is a bumper crop. Labor is differentiated not only by factors of gross production output such as yield, but also by the selection of varietals that have different growth cycles and have specific processing needs related to their uses for grain, fodder, and thatch (Kshirsagar et al., 2002: 1240). Such labor bottlenecks would have scaled up whenever rural farmers were growing

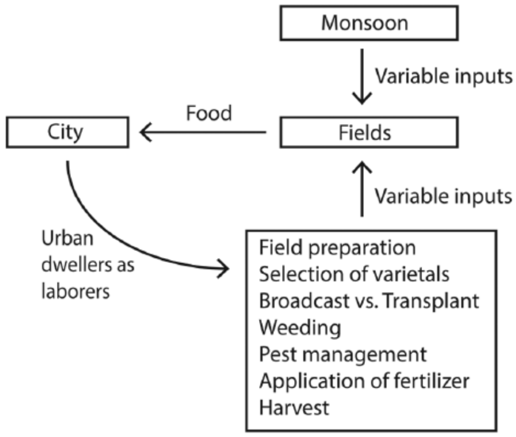

Figure 3. Variable human and natural inputs in rice fields.

food to supply urban consumers. In addition, the simultaneous emergence of a 'market' for grain (in the sense of indirect provisioning mechanisms, whether they involved institutional redistributions, urban/rural mutualisms, or monetized transactions) and the migration to urban centers would have resulted in a potential for labor competition and a need to communicate labor needs quickly in order to recruit sufficient numbers of people to address the needs of different farmers, each of whom could evaluate and institute labor inputs along a sliding scale of strategies (Figure 3).

Where would labor have come from? One answer is, from the cities themselves. In her study of historic-period London, Margaret Grieco (1995) provides a model of seasonal outmigration from urban areas at times of labor bottlenecks for the harvest season in the surrounding countryside. This labor pattern was fluid and individualized, yet resulted in whole neighborhoods (primarily of women and children) relocating themselves to the fields at times of hops-picking and apple-picking, producing a circumstance in which the 'casual sources of rural employment [became] a routine part of household earning and budgetary practice' (Grieco, 1995: 201). Grieco's work illustrates the extent to which urban dwellers can remain engaged with the agricultural hinterland, and the ways that individuals and households make agentive decisions about labor allocation depending on rural opportunities. 'Circular' migration is a phenomenon not limited to those from the rural areas who come into the city, but characterizes the changes of labor that occur throughout an urbanizing hinterland on a timetable that can include daily commutes as well as seasonal returns to farmland (e.g. Oluwasola et al., 2008).

Labor, rice, and water at Sisupalgarh

As in other global regions, urbanism in the eastern Indian coastal plain was preceded by a phase of small village settlements that relied on domesticated plants and animals. Research confirms the presence of rainfed rice agriculture by 1000 BC at village sites such as Golbai Sasan and Gopalpur (Harvey et al., 2006; Weisskopf et al., 2014: 50). By the subsequent Early Historic period, regional villages were seemingly abandoned as populations shifted to urban settlements such as Sisupalgarh, located in the monsoon area of the Mahanadi River Delta 45-km inland from the Bay of Bengal. The site of Sisupalgarh, which is marked by an encircling rampart and monolithic stone columns within the core of the ancient city, is the most thoroughly investigated of the Early Historic urban settlements in eastern India, with surface survey, geophysical survey, and excavations providing data for the evaluation of both domestic activity and monumental architecture (Lal, 1949, 1991; Mohanty and Smith, 2008; Smith and

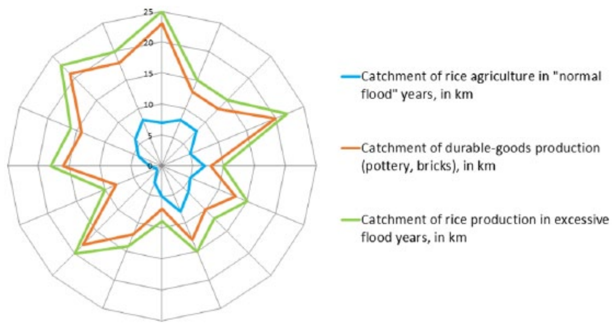

Figure 4. Sisupalgarh at the center of a hypothetical catchment area that encompasses both years of 'regular flood' agriculture and the extended network of rice provisioning that called upon regional exchange networks for durable goods to mitigate shortfalls during abnormal floods. Note that the location of the town-sized site of Talapada, which is 40 km southwest of Sisupalgarh, is outside of the range of all of these networks.

Mohanty, 2016). Archaeological investigations confirm that the totality of the area within the rampart wall, measuring 134 ha, was occupied in the Early Historic period and that there was substantial occupation outside of the rampart as well. At Sisupalgarh, excavations included deep soundings that reached natural soil in three areas of the site inside of the rampart. In each case, the remains of charred grains were recovered throughout the waterlogged lower deposits, suggesting the presence of rice from the very earliest period of habitation in the 6th century BC (Smith and Mohanty, 2016). Fish remains also were recovered in these deposits; although analysis is still in progress, the presence of fish and rice together suggests a high dependence on a watery environment that may have included deliberate pisciculture as a component of rice farming.[5]

The density and spread of occupational deposits at Sisupalgarh suggest a population size of 25,000 in the Early Historic period that serves as a basis for calculating total rice intake using statistics from contemporary traditional rice production and consumption. Although rice alone would not have comprised 100% of the diet, it serves as a proxy measure for the minimum surface area needed to support the population with staple grain. Rice consumption is listed for coastal rural Odisha today at 0.4319 kg/person/day (Mishra, 2015: 8). Odisha's average productivity of paddy (rice in the husk) is an average of 1626 kg/ha (Mishra, 2015), a calculation that is within the range for traditional rice reported by Mackill et al. (2012; cited in Kato et al., 2014; see also Kshirsagar et al., 2002: 1241).[6] Paddy must be milled to produce edible grain, with a range of 55–72 kg of rice per 100 kg of paddy (Araullo et al., 1976: 351; Womach, 2005: 166). With a population of 25,000 and a milling yield of 60 kg of edible product per 100 kg of paddy, the total hectares required for this rate of consumption at Sisupalgarh even at a reduced productivity level of 1000 kg/ha of paddy would have been 6566 ha (65.66 km^2). Taking into account local topography (including a laterite upland to the west and the Daya River to the east that would have been unsuitable for cultivation), Sisupalgarh's carbohydrate footprint nonetheless could have been maintained within a 10-km radius of the site to the north, south, and east (Figure 4).

Ancient farmers' planning would have taken into account the interconnected effects of seasonally abundant rain, uncertain labor availability, and demand for staple carbohydrates within culturally determined parameters of quality and taste. Given the demonstrated productivity of transplanted rice compared with broadcast seed, it is likely that farmers living in the vicinity of Sisupalgarh would have been interested in maximizing their yields through the use of transplanted rice. Labor bottlenecks for rice production would have been at three distinct intervals, all of which could have been predicted and foreseen once other processes were in place: preparation of fields (in the dry season prior to the onset of the summer monsoon); transplantation of seedlings (which could be projected as a specific date after the initial planting of seeds in a seedbed); and the harvest (which could be projected toward the end of the growing cycle on the basis of the rate of maturation of the plants). In addition to these specific bottlenecks, there were other variable inputs of labor that could be exercised as and when excess labor became available, for example, pest management, weeding, and the construction of elevated embankments and field boundaries (bunds). Bunds, which were prepared in advance of the rainy season, constituted a form of what Dillehay and Kolata (2004: 4328) have called 'anticipatory agricultural infrastructure' that constituted a demonstration of authority and planning capacity in advance of actual production.[7]

From both consumer and producer perspectives, the acquisition of rice and the provision of labor in years of 'normal floods' could have been managed by the presence of fields within walking distance from the city of Sisupalgarh, with communication between rural and urban areas enabling the provision of 'just-in-time' labor calls. Urban inhabitants might have expected there to be some type of field work consistently available, although the specific type of labor might vary from year to year, depending on farmers' perceptions of the relative amounts of workers needed for field preparation, transplantation, weeding, or pest management in any given season. In addition, the vagaries of the weather would have made labor call-ups particularly urgent to capitalize on quick-changing conditions ranging from beneficial early-onset monsoons to damaging rains at harvest time, all of which would have required immediate attention to crops in the field. Labor investments also would have demonstrated social and economic capacities beyond the physical output of rice agriculture, with bunds as a demonstrable form of landscape delineation and property ownership that transcended the rice-growing season.

Both farmers and urban residents would have continually negotiated the migratory flows of labor from rural to urban areas and back again to enable optimal production even in years of 'normal' floods. Additional changes would have been required when landscapes became flooded through extraordinary events such as cyclones that inundated or destroyed rice crops and that would have disproportionately affected the cities of the coastal regions of the subcontinent compared with the more climatologically stable regions of the Gangetic Plain. Murty et al. (1986) provide a historical study of storm surges along the shoreline of the Bay of Bengal, with a tally of 68 such surges between 1912 and 1982 as the result of oceanic storms. The chronological spacing of these surges is also instructive, as they occur at an unpredictable frequency: in some cases multiple storms in the same year (e.g. 5–7 May 1970, 22–23 October 1970, and 8–13 November 1970 or 16–18 November 1973 and again in 6–9 December 1973) and with a maximum gap of 14 years between major recorded storms in the 20th century. It is important to note that such storms, although destructive, have gradations of impact upon a landscape. While areas within the path of the storm can suffer severe consequences, successive outer bands produce progressively less rainfall. The effects of catastrophic floods are thus not universal, and destruction in one region can be mitigated by the movement of food and other necessities from less-affected areas.

In the Early Historic period, medium- and long-distance networks of provisioning are evident in the presence of goods such as pottery, terracotta ornaments, and sandstone that also represent durable proxies for a diversity of other items such as textiles and fuelwood that are not preserved in the archaeological record (Smith, 2002). Interestingly, both the surface survey and the excavations at Sisupalgarh indicate a near-total absence of any kind of production debris within the ancient city itself, suggesting that the urban residents relied on rural producers for daily-use goods as well as for food (this lack of production debris also gives rise to the question of how the ancient city-dwellers were occupying their time; the presence of significant monumental architecture such as earthen ramparts and formal gateways suggests that at least some of the population was engaged in manual labor but the realities of the monsoon environment meant that such tasks were likely to have been curtailed during the monsoon, precisely when agricultural activities were at their peak). Far from being victimized by the localized effects of catastrophic flooding, urban residents were able to survive disruptions in the food supply because of the presence of multiple and overlapping trade networks that could be mobilized to ship food instead of (or in addition to) consumer durables. Trade networks needed to be widely distributed in all directions because of the variability of rainfall across the landscape. Greenland (1997: 61) observes that there is a significant variation in rainfed rice yield from year to year and from site to site, an observation upheld by Mishra's (2015) study of villages in Nuapada and Koraput districts of Odisha and by the variability in rainfall reported from the two topographically similar locations of Bhubaneswar and Khorda located only 25 km apart (Figure 5). Thus, the reliance on just one single source of backup supply for the city of Sisupalgarh would have been insufficient given the unpredictability of rainfall and agricultural production in any given area. Reliance on existing trade networks for durable goods, which already were distributed across different natural resource zones, thus provided an effective strategy of information flow and grain supply along established communication and transportation corridors.

Discussion

The potential for food shortfalls is inherent to any agricultural production system even when crops are highly suited to their environments. The most serious food shortfalls are characterized as famines, a circumstance that may at first glance be a considerable risk for urban populations both modern and ancient. The textual record of the Early Historic period does acknowledge the phenomenon of individual hunger (Chelliah, 1985: 155) and the *potential* for shortfall (see, e.g. the Mahasthan and Soghaura inscriptions dated to Mauryan times; i.e. *c.* 3rd century BC; Bühler, 1896; Thapar, 1997 [1961]: 7–8, 17, 68). Yet famine as a widespread and catastrophic occurrence appears not to have been as great a problem in the Early Historic period as it was to become in the subsequent medieval era (Srivastava, 1968; summary in Smith, 2013). In the Early Historic period, skillful, 'low-level' (sensu B. Smith, 2001) management of rainfed agriculture within short distances of urban centers resulted in a flexibility of production that not only provided a steady source of food (and kept otherwise underemployed urban labor pools engaged), but also eliminated the need for more complex strategies of centralized production across larger territories. 'Normal' floods and other variations in annual rainfall were mitigated through communication and labor-mobility strategies for agricultural production. 'Abnormal' floods were addressed by bringing food in from beyond the usual distance of local production through already-established trade networks.

In the Early Historic period, cities along with religious institutions (see Liu, 1988; Ray, 1986; Shaw, 2007) were robust anchors of localized production. Although primarily controlled at the local level by individual farmers, political leaders also took an interest in agricultural productivity and occasionally made contributions to local water management by sponsoring the construction of wells, dams, and other infrastructure (Gokhale, 2006). At Sisupalgarh, there is an inscription at the nearby Khandagiri cave that provides a list of activities of the 1st-century BC ruler Kharavela. The inscription notes that the ruler's activities included raising armies and repairing the city

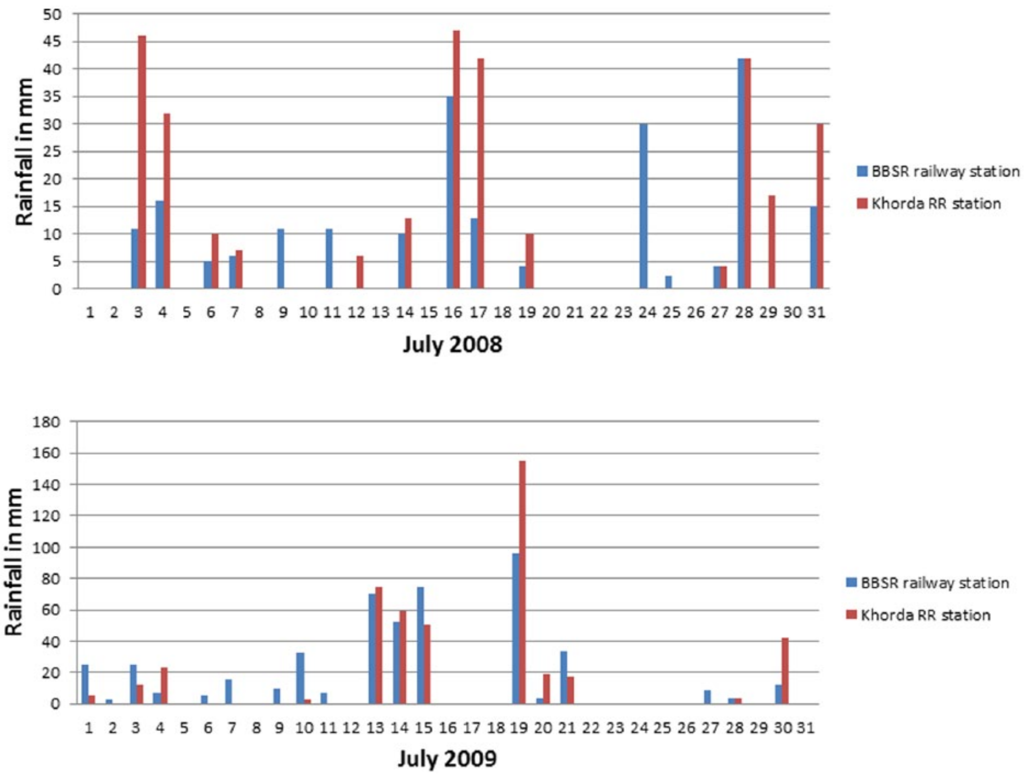

Figure 5. Sample of rainfall variability in sequential rainfall years in Bhubaneswar (adjacent to Sisupalgarh) and Khorda (closest weather station to Talapada). Note the difference in amplitude and frequency from one year to the next, with rainfall in July 2009 being as much as three times greater than equivalent days in July 2008 (note that the peaks in the 2009 rainfall data are not because of a cyclonic storm; see Special Relief Commissioner, 2009–2010). Rainfall data downloaded from http://as.ori.nic.in/balangir/rainfall, accessed 3 August 2015.

gateway which had been damaged by storm, as well as extending a canal built by one of his predecessors (Sahu, 1984). Given the lack of taxation or revenue documents from this era, it appears that landscape management probably did not extend to the monitoring of actual infrastructure use, as long as demand could be met by entrepreneurial networks of production and distribution (cf. Zeder, 2003: 159).

Short-distance production networks and regional trading networks at Sisupalgarh would not therefore have depended on explicit leadership directives and direct political control, but the lack of comprehensive centralized managerial efforts in the hinterlands was probably a good thing given that imperfect top–down efforts may be less adaptive and successful than individualized and opportunistic mitigation strategies. Even today, state-level management of subsistence food production often is associated with unintended negative consequences (see, e.g. Blaikie and Brookfield, 1987 for general assessments, and Mishra, 2015 for Odisha in particular). Famine is a much more visible part of the historical record starting in the medieval period when states became more robust, a factor that may be more directly linked to political configurations of local management than to the inevitable vagaries of seasonal monsoons and occasional catastrophic storms given Amartya Sen's (1981) assessment that famines result from political failures rather than environmental ones.

The discovery of smaller, town-sized sites with artifacts and architecture identical to Sisupalgarh indicates the extent to which there was decisive contact between Sisupalgarh and its larger regional hinterlands (Thakuria et al., 2013), but those contacts were more ephemeral than appearances might suggest and confirm a relatively disconnected political landscape. Investigations at the site of Talapada, located 40 km to the southwest of Sisupalgarh, reveals that the town was laid out with the same types of formal ramparts and gateways as Sisupalgarh. However, Talapada has a comparatively thin occupational deposit and appears not to have been as densely occupied in either chronological or spatial terms; the ramparts also are quite low and have little evidence for augmentation. These archaeological indicators suggest that the town was never fully occupied (Mohanty et al., 2014, 2016). Although located in what today remains a fertile agricultural area, Talapada appears to have been located beyond the distance of even the failsafe role of bad-year rice production, and lacking any distinct other products, was less attractive to potential settlers compared with areas closer to Sisupalgarh.

Conclusion

Ancient South Asian urban centers were integrated with both nearby and distant hinterlands of food production, in which rice was the optimal choice of carbohydrate staple because of its ability to thrive in the habitually wet environments provided by annual monsoons. Maximization of this resource nonetheless required subtle and constant acts of maintenance through labor management particularly in the stages of field preparation, transplantation, weeding, and harvest. The proximity of urban centers to productive rice agriculture areas would have enabled a close relationship between farmers and urban dwellers for mutual benefit, a factor of labor management that continues to resonate in modern cities of the Asian monsoon belt, in which normal-year relationships of labor investment and provisioning are subject to disruptions on an irregular basis in years of excessive flooding such as those brought on by tropical cyclones and other extraordinary events of rainfall. Mitigation of those destructive events involves the use of extended social and economic networks that allow for flexible provisioning and that increase the resilience of cities through the use of provisioning strategies based on existing regional exchange networks.

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Notes

1. A better phrase for 'normal' flooding might therefore be 'seasonal high water' given that the word 'flood' automatically confers a deleterious image.
2. Despite these unusual characteristics, rice is considered a model crop in cereal breeding (Ahmed et al., 2013: 5). It is also interesting to consider how many of the world's grain crops were domesticated in areas characterized by threat of water scarcity (maize in the New World, wheat/barley in the Near East) and which had to become adapted to different conditions as they were carried into new temperate, tropical, and high-altitude environments.
3. Our field team has lived in the village of Talapada, Odisha, where we have observed dramatic shifts in yields of rain-fed agriculture over the years. For example, farmers lost more than 60% of the rice crop during 2015 because of late-season rains, whereas the return to typical weather conditions during 2016 yielded a bumper harvest.
4. Another ancillary benefit of increased foot traffic in wet-rice paddies is the creation of a 'traffic pan' when underlying sediments are trampled into a denser substrate that enables greater water retention in the field (see Greenland, 1997: 71–72).
5. Another consideration, beyond the scope of this paper, is the extent to which fish constituted the principal animal protein source for the inhabitants of ancient Sisupalgarh, just as it does today in much of the eastern Indian subcontinent. Although mammal bones of both wild and domesticated species have been recovered at the Early Historic settlements of Sisupalgarh and Talapada, the time/labor logic of a mutualistic fish-rice cultivation system, along with the advent of Buddhism and Jainism with their prescriptions against animal slaughter starting in the sixth century BC, all suggest that there were social reinforcements to rice cultivation that went beyond considerations of caloric value and waterlogging tolerance. G.S. Khush (1997) notes that in the present day, 'rice is the only major cereal crop that is consumed almost exclusively by humans' (p. 25). Animals do consume rice bran and chopped straw, but these are both byproducts that cannot be consumed by humans and secondary to the production of rice for human consumption. As a predominantly human-focused grain, therefore, the adoption of rice agriculture may thus have served as an incidental precondition for a fish-based or wholly vegetarian cuisine.
6. For comparative purposes, Edmundson and Edmundson (1988) recorded 1700 kg/ha for rainfed rice in the Deccan region of western India.
7. The investment in rice-field bunds was not strictly necessary in order to grow rice, but indicates yet another series of tradeoffs involved in the agricultural decision-making process. Khush (1997: 31–32) notes that rice that grows without bunding yields about 1.2 tons/ha, while rice with bunding yields about 2–3 tons/ha. The investment in bunding and water entrapment thus represented a tradeoff toward more secure rice production closer to the city, and again may have been done in practical recognition of the needs to keep fields close enough to the urban center for city-based populations to walk to fields and back again.

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