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TANK IRRIGATION IN SEMI-ARID TROPICAL INDIA

PART I : Historical Development and Spatial Distribution

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INTRODUCTION

Small, water reservoirs behind earthen dams are called tanks in India. Tanks supply many villages with drinking water, but their primary purpose is to provide water for irrigation. Tank irrigation is an old, established practice in most of the semi-arid tropical parts of India. Here the monsoon rains fall erratically during a few months in the year, and irrigation tanks serve to store and regulate the flow of water for agricultural use. In the southern states of India this is primarily for the production of rice.

The present study was undertaken to gain a better understanding of the historical and institutional influences, the economic forces, and the technical conditions that have interacted to bring about tank irrigation in India as it is practiced today. An understanding of these forces will be valuable to ICRISAT in its efforts to improve the water-soil management systems in the semi-arid tropics of the world, which is one of its mandates.

The study is presented in three parts. The first part, presented here, gives a brief review of historical records documenting the development of tank irrigation over time, and discusses the relationship of population density and physical factors to the development of tank irrigation. The

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second part (forthcoming) is an attempt to determine the economic performance of irrigation tanks. The third part (forthcoming) discusses the drawbacks in terms of instability and low water use efficiency of tank irrigation as it is practiced today. Suggestions are made for improvements through better water control and reorganization of tank management. An approach for judging the possibilities and limitations of transferring India's tank technology to other places in the SAT is proposed.

1. HISTORICAL RECORDS ON TANK IRRIGATION

In the southern states of semi-arid tropical India, tank irrigation systems have existed since Vedic times. Two tanks are mentioned in the Ramayana : namely, the Lake of Five Nymphs (Panchapraratataka), associated with Madakarni or Satkarni; and the Pampasaras, apparently the same as Pampasagar, the name of a tank in Huvimothadagalli taluk, Bellary District, on the Tungabhadra river (Yazdani, 1960). Further, there are references to irrigation tank practices in the early records of people of India, dating back to many centuries before the commencement of the Christian Era. Many of the tanks which are found in southern India have been in existence for several generations, two in Chingleput District are referred to in inscriptions of the 8th and 9th centuries (Harris, 1923).

Telengana has been termed a land of rice and tanks, where tank irrigation has been developed extensively beginning in ancient times. The districts of Warangal and Karimnagar have some quite old instances of tank irrigation; the lakes of Pakhal, Ramappa, Laknavaram, and Sanigaram were constructed in the 12th and 13th centuries by kings of the period (All India Economic Conference, 1937). There is a system of tanks at Kattagiri referred to in inscriptions of 1096 AD. This system demonstrates the technique or practice

of constructing tanks in a series at different levels of a watershed. In 1108 AD, a merchant named Dasi-Setti renovated and increased the size of a tank at Bhanvur. In 1201-2 AD, after a famine in Tirunvannamalai village two persons built a tank in memory of their mother (Appadorai, 1936). The Somavaram inscription dated 1213 AD states that Racherla Beti Reddi constructed two tanks.

Various kings were active in constructing tanks. Kesari-Tatakam Tank was built by Prola I: of the Kakatiyas, Beta II constructed two tanks: Setti--Kerayan and Kesari-Samudra; and Prola II built two tanks. The Pratapa-Charitra states that the ruler Ganapatideva built tanks at Nellore, Gangapuram, Ellore, Ganapapuram and Ekasilapuri (Appadorai, 1936).

A rock inscription dated 1030 AD praises the many tanks built by the local ruler Kota Gonka (Vaidehi Krishnamurty). Fresh land was brought under cultivation by digging a new Tank, Settikere, as mentioned in an inscription of 1071 AD from Sorali Taluk in Shimoga District (Department of Information and Public Relations, Hyderabad, 1953). Tanks were donated to temples as pious acts and for their upkeep. A number of inscriptions dated around the 11th and 12th centuries describe tank construction activities in Warangal (Gopal Reddy, 1973).

While studying the cultural economy of irrigation in southern Tamil Nadu, (Ludden) observed that tank construction in the past played a key role in the ritual-based system of entitlement to control land resources; through the construction of a tank the local chief generated resources for gifts to temples, which in turn enhanced Brahman ritual powers useful for his support. "The irrigation system as a whole grew in a cellular segmented manner: similar, allied but staunchly independent units were merely added on as population

and irrigated acreage increased. It was this system - within which irrigation facilities were constructed, maintained and regulated by the same organizational units that controlled cultivation processes as a whole-that confronted British administrators in the nineteenth century (Ludden).

The British were highly impressed by the extent of tank irrigation they found in the country.

In 1853, R. Baird Smith wrote:

> "The extent to which the tank irrigation has been carried throughout all the irrigation region of the Madras Presidency is truly extraordinary. An imperfect record of the number of tanks in the 14 districts shows them to amount to not less than 43,000 in repair and 10,000 out of repair or 53,000 in all." (Smith, 1856).

Some 30 years later, statistics of tank irrigation were assembled, and a list of tank irrigated areas[1] (Manual of Administration of the Madras Presidency) in the districts of the Madras Presidency from 1882-1883 gave a figure of 32,000 nonprivate tanks.[2] When comparing the net areas irrigated by these tanks in 1882-1883 with areas irrigated by all tanks (i.e., including the formerly private tanks) in 1969-1972 (Table 1) we find that, for all the districts taken together for which this

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[1] "Apart from the rivers, the rainfed tanks which exist in vast numbers of small and large tanks throughout Madras, play a most important part. Most of these are of old native construction although a few of them have been enlarged by the British Government and their systematic improvement is being carried out year by year as far as money and establishment are available." (Manual of Administration of the Madras Presidency) vol.1(A), p.319.

[2] "In addition to the works included in this statement, there are a large number of private tanks and zamindari tanks, with which the irrigation branch have no concern." (Manual of Administration of the Madras Presidency) vol.1(A), p.406.

Table 1. Area irrigated by tanks and total cropped area in the region of the old Madras Presidency in the year of 1883 and at present

(Area in 000' acres)

District	1882-83		Avg. for 1969-72		(3)/ (1)	(4)/ (2)
	Total cropped area	Net area irrigated by tanks	Total cropped area	Net area irrigated by tanks		
	1	2	3	4		
Anantapur	114	89	2249	78	19.8	0.9
Cuddapah	240	188	1142	42	4.7	0.2
Kurnool	72	39	3220	33	44.5	0.8
Bellary	72	53	1507	20	21.0	0.4
Krishna	287	39	1661	88	5.8	2.3
Nellore	225	151	1646	227	7.3	1.5
Vizag	48	30	1307	221	27.4	7.3
Salem	185	97	2283	80	12.3	0.8
Coimbatore	142	44	2068	12	14.6	0.3
Madurai	233	158	1601	130	6.9	0.8
Chinglepet	430	315	1070	405	2.5	1.3
North Arcot	338	201	1589	260	4.7	1.3
South Arcot	397	213	1786	268	4.5	1.3
Thanjavur	104	46	2162	73	20.8	1.6
Tirunelveli	377	145	1376	189	3.6	1.3
Tirichirapalli	247	132	2031	196	8.2	1.5
All Districts	3511	1940	28698	2320	8.2	1.2

Source: Tamil Nadu, Season and Crop Reports, 1969-72.

information is available, the extent of tank irrigation today is about the same as it was a century ago. Tank irrigated area has decreased in two regions including the districts of (i) Anantapur, Kurnool, Cuddapah, and Bellary, and (ii) Salem, Coimbatore, and Madurai. On the other hand tank irrigation has increased in two other regions, i.e. (i) Vizag, Krishna, and Nellore, and (ii) Chinglepet, North Arcot, South Arcot, Thanjavur, Tirunelveli and Tiruchirapalli.

The overall area under nonprivate tank irrigation was reported to be 1.9 million acres in 1882-1883, while the area irrigated from all tanks in 1969-72 was 2.3 million acres. This difference is not very large and if the private tanks, excluded from the earlier figures, could be accounted for as the present figures include all tanks, the conclusion that emerges is that in the area of the former Madras Presidency there has hardly been any change in the overall extent of tank irrigation during the last 100 years.

In contrast to the marginal change (if any) of tank irrigated area in the former Madras Presidency, it is interesting to note that total cropped area in the region increased about 8 times during the last century. Thus, while tank irrigation was available for over 50 percent of the total cropped area in the past, now less than 10 percent of the total cropped area is irrigated from tanks. Eventhough other sources of irrigation have become available now, so that canals and wells irrigate approximately another 10 percent each in this area, the overall irrigation of cropped area has fallen from 50 percent to about 30 percent.

In contrast to the above facts about the old Madras Presidency area, there is evidence that tank irrigation in old Hyderabad State is of more recent origin. The area irrigated from tanks considerably increased only during the first half of the past 100 years under the rule of the Nizams of Hyderabad. Table 2 shows that from 10000 acres in 1895-96 the Public Works Department (PWD) of the Hyderabad State had arrived at around 100000 acres of tank irrigated area around the turn of the century, and between 800 to 900 thousand acres some 40 years later. No estimate is made in the sources of these statistics about the amount of private tanks that surely must have existed. The fact that the PWD of the State of Hyderabad expanded the tank

irrigated area during the earlier half of the last 100 years, while the British Government in the Presidency of Madras did not do so, provides an indication that the intensity of tank irrigation in different areas was to some extent influenced by the respective governments and their emphases on certain types of capital development programs. However, as is shown below, in the long run not institutional factors alone but population density together with the institutional set up are important variables explaining these differences in development of tank irrigation over time.

Table 2. Tank irrigation provided by the Public Works Department, and net sown area in Hyderabad State from 1895-96 to 1949-50.

Year	HYDERABAD STATE		
	Tank irrigated area 000' acres (1)	Net sown area 000' acres (2)	$\frac{(1)}{(2)} \times 100$
1895-96	10	n.a.	n.a.
1905-06	135	n.a.	n.a.
1915-16	209	n.a.	n.a.
1925-26	581	26874	2.2
1930-31	634	29455	2.2
1935-36	930	29133	3.2
1939-40	840	28433	3.0
1944-45	855	26475	3.2
1949-50	834	24064	3.5

n.a. : not available

Source: H.E.H. The Nizam's Government, Hyderabad District Gazetteers, Mahbubnagar District vol. 1340-1345 F(1931-1936 AD) with comparative statistics from 1331 Fasli, Hyderabad, 1940.

2. POPULATION DENSITY AND TANK DEVELOPMENT

It is logical to assume a relationship between the density of population and the intensity of tank irrigation. Where physically feasible and economically attractive, tank irrigation systems are expanded when the population growth crosses a certain minimum level: tanks and population increase in

mutual support to another upper limit of population density, beyond which further population pressure may tend to adversely affect the existing tank irrigation systems, and special measures may be required to preserve the capital of irrigation tanks[3] (Ludden).

Before a tank is built, a need for more intensive land use must be felt, i.e., traditional forms of extensive land use must have become insufficient to support the growing population. Moreover, a minimum number of people are required to do the work, and a political force capable of organizing the people for this effort must be available. Our hypothesis is that population has to reach a critical density of about 50 to 60 persons per km^2 before these conditions are met and tank construction begins.

Table 3 presents data on rural population densities between 1901 and the present for the Indian States of Andhra Pradesh and Tamil Nadu. It is interesting to note that rural population densities in Andhra Pradesh, about half the area of which is made up of regions of the former Hyderabad State, went up from 60 persons/km^2 to over 130 persons/km^2 between 1901 and today. On the other hand, within the present Tamil Nadu State which includes much of the former Madras Presidency, rural population densities were already at 134 persons/km^2 in 1901, and are presently about 240 persons/km^2. Unfortunately, the data on population before 1900 are not available. It may be safe to

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[3]Ludden also points out the "dialect... between population and the intensification of land use." He emphasizes that "over time, intensification (of land use) and increasing density (of population) place demands on agrarian organization" (p.4). In our study, population density is regarded as an independent variable, constituting one of the most important environmental conditions that determine the existence of tanks. The obvious link between population and agrarian organization is not investigated here. However, the institutional environment as expressed in British versus princely rule and its influence on tank irrigation will be analyzed later.

assume, however, that during the 50 years prior to 1900, i.e., from around 1850, population in both regions was only marginally below the 1900 levels. If this were true, then in 1850 the Tamil Nadu region might have had a rural population density of perhaps 120 persons/km^2, while in the Andhra Pradesh region rural population would have been below 60 persons/km^2. If these population figures are any indication, it would appear that tank building in Tamil Nadu, which started much earlier than in Andhra Pradesh, was more or less "completed" in 1880; population growth did not work as an incentive to build additional tanks after that time. In comparison, in Andhra Pradesh massive public tank building activity did not even start until 1900, and it reached its climax sometime around 1960, when rural population density had reached levels of 100 to 120 persons/km^2. Given the assumptions above on

Table 3. Rural population densities in selected states of India

Year	Andhra Pradesh**		Tamil Nadu**		All India**	
	Rural population (1000 persons)	Rural population density[a]	Rural population (1000 persons)	Rural population density[a]	Rural population (1000 persons)	Rural population density[a]
1901	16703	60	17449	134	212700	65
1911	18586	67	18327	141	221684	67
1921	18360	66	18316	141	217801	66
1931	20517	74	19192	148	238203	72
1941	22875	83	20701	159	268029	82
1951	25695	93	22785	175	295000	90
1961	29709	107	24696	190	359772	109
1971	35103	127	28732	221	439076	133
1981*	40991	148	32481	250	522779	159

*Estimated population: a: persons/km^2
**Geographical area in Andhra Pradesh = 276 800 km^2; in Tamil Nadu = 130 100 km^2; and All India = 3280000 km^2
Sources: Indian Agriculture in Brief 15th edition; Bulletin on Food Statistics, 1968 and 1977; Census of India 1971, paper 1, p.52.
NOTE: Data on rural and total population are available only for the years 1951, 1961 and 1971. Trends of the percentage of rural population in total population for these years were extrapolated to derive estimates for the other years, for which information is available only on total population.

population levels in 1850, these differences in construction activity can be explained if the density of rural population, critical to trigger tank construction, lies somewhere around 50 to 60 persons/km^2.

At population levels of over 120 persons/km^2, additional tank construction may be less attractive, perhaps partly because the most favorable sites are already taken, and partly because the land required for tanks is more and more difficult to acquire as at this stage it is already taken for dryland cultivation. Further reasons for a decline in tank irrigation capacities could be the stripping of vegetative cover on catchments leading to erosion and siltation, and encroachment of tank beds. These and other processes can reduce tank efficiency and are directly attributable to higher population densities.

Thus we have reasons to believe that population density imposes not only a lower but also an upper limit constraint on tank irrigation. At the all-India level as well, the upper limit density of about 120 persons/km^2 might have restricted development of tank irrigation. In India as a whole the absolute area irrigated by tanks increased from about 3.5 million ha around 1945-50 to over 4.5 million ha between 1960 to 1970, and subsequently it fell to less than 4 million ha in 1973 (Table 4). It was between 1960 and 1970 that the rural population density in India crossed 120 persons/km^2 (Table 3). Population growth continues while tank irrigation decreases; at the same time canal irrigation and especially irrigation from wells has expanded rapidly after independence.

The development of tank irrigation in India after independence was subject also to a number of forces which may not be directly attributed to population density although these are related. The abolition of ownership

Table 4. All India growth of tank irrigation

Year	Total cropped area	Net irrigated area	Well irrigated area	Tank irrigated area	Tank irrigated area to total cropped area (%)	Tank irrigated area to net irrigated area (%)	Well irrigated area to net irrigated area (%)
	(----In million hectares-)						
1950-51	131.9	20.9	5.9	3.6	2.7	17.2	28.2
-52	133.4	21.0	6.5	3.4	2.5	16.2	30.9
-53	137.5	21.2	6.6	3.2	2.3	15.1	31.1
-54	142.3	21.7	6.7	4.1	2.9	18.9	30.9
-55	144.0	21.9	6.7	4.0	2.8	18.3	30.6
-56	146.7	22.8	6.7	4.4	3.0	19.3	29.4
-57	149.1	22.5	6.2	4.5	3.0	20.0	27.6
-58	145.4	23.2	6.8	4.5	3.1	19.4	29.3
-59	150.8	23.4	6.7	4.8	3.2	20.5	28.6
-60	152.1	23.8	6.9	4.7	3.1	19.7	29.0
-61	152.3	24.6	7.3	4.6	3.0	18.7	29.7
-62	156.2	24.9	7.3	4.6	2.9	18.5	29.3
-63	156.8	25.7	7.6	4.8	3.1	18.7	29.6
-64	157.0	25.9	7.8	4.6	2.9	17.8	30.1
-65	159.3	26.6	8.1	4.8	3.0	18.0	30.4
-66	155.3	26.7	8.7	4.4	2.8	16.5	32.6
-67	156.8	27.1	9.2	4.6	2.9	17.0	33.9
-68	163.0	27.5	9.3	4.6	2.8	16.7	33.8
-69	159.7	29.0	10.8	4.0	2.5	13.8	37.2
-70	163.9	30.3	11.1	4.4	2.7	14.5	36.6
.71	167.4	31.4	11.9	4.5	2.7	14.3	37.9
-72	164.2	31.9	12.2	4.1	2.5	12.3	38.2
-73	161.5	32.0	13.0	3.6	2.2	11.2	40.6
Compound growth rates for the period 1951-71	1.01	1.94	3.04	1.08	-	-	-

Sources: Irrigation Statistics and Statistical Abstracts of India

rights for private tanks stopped private investment into tank irrigation soon after independence. This also decreased the efficiency in water control and tank management. On the other hand public campaigns were launched to increase food production and tank building was one of the activities which were vigorously pursued in these campaigns until the late 1950's. Subsequently, the availability of diesel and electricity-powered pumps made well water more

attractive as an alternative, and privately controlled source for irrigation. Resources were shifted from the development of tanks towards wells, leading to a massive expansion of well irrigation. Further, problems connected with raising the water rates made it more and more difficult for the PWD to receive the funds for covering the increases in costs of maintenance and repairs. Tank irrigation, basically an economically productive and profitable undertaking (see Part II), thus, began to be looked down upon, and was only halfheartedly supported by policymakers and planners. The resulting decreases in efficiency and in reliability of the performance of irrigation tanks tended to promote the erroneous notion of tank irrigation being notoriously inferior to other types of irrigation (see Part III).

3. REGIONAL DISTRIBUTION OF IRRIGATION TANKS

Although runoff collection tanks exist in nearly every district of India, the density of tank irrigation varies considerably from district to district. Presently, in the semi-arid tropical region of India (Fig. 1), tanks are concentrated in South and Central India, i.e., in the coastal districts of Tamil Nadu and Andhra Pradesh, in South-Central Karnataka, in Telengana and in East Vidarbha. In North India, there are two pockets which show a high density of tank irrigation: north-east Uttar Pradesh in the area of the former kingdom of Oudh, and in Rajasthan, east of the Arvalli mountain range.

Generally it appears from Table 5 that tank sizes increase from North to South; based on information on number of tanks and irrigated area, the average size of tank command areas is around 2 ha in Gujarat and Madhya Pradesh, 7 ha in Maharashtra, 15 ha in Andhra Pradesh, and 30 ha in Tamil Nadu. Within Andhra Pradesh a similar pattern of smaller

Figure 1. Density of Tank Irrigation in SAT India

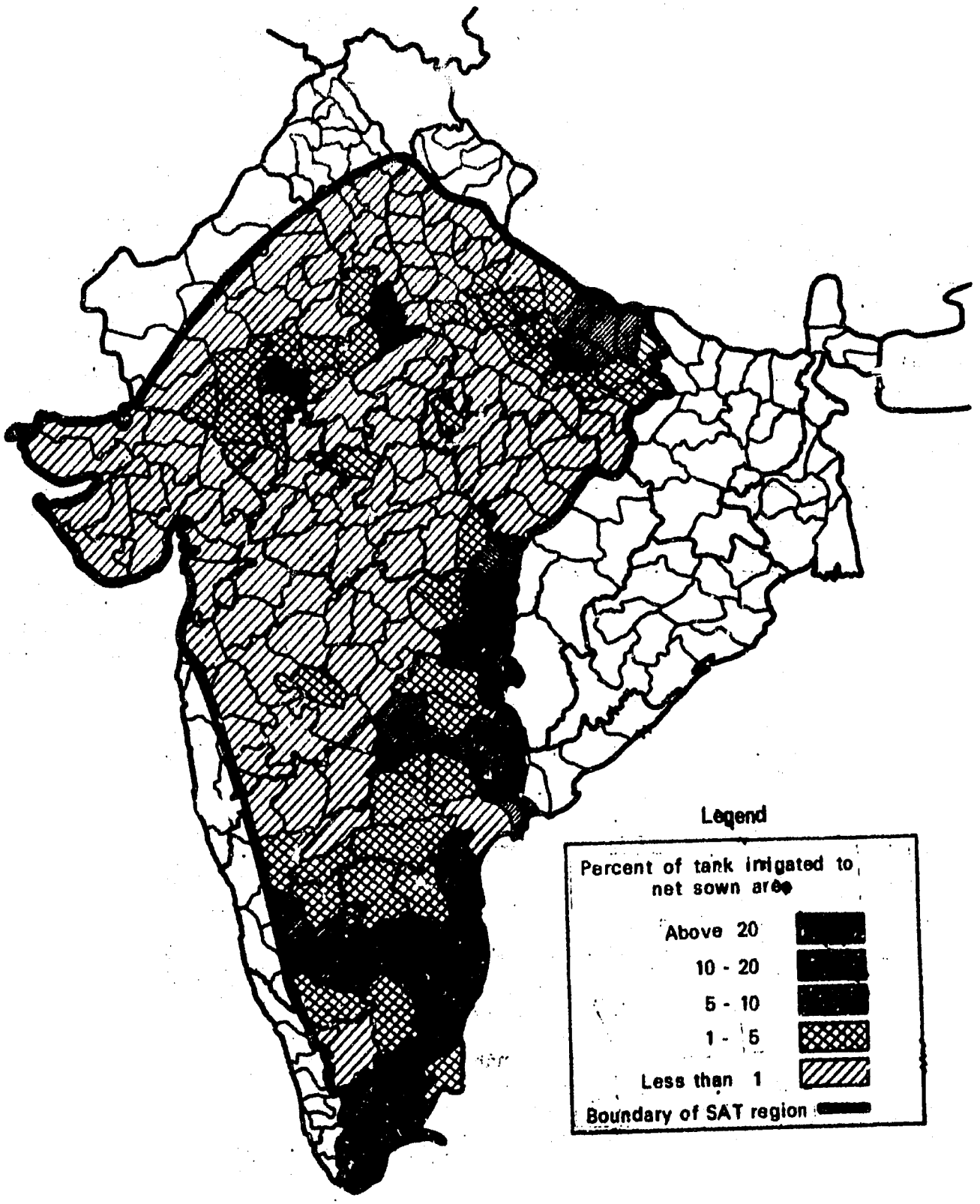

Table 5. Tank irrigation in selected states and districts in India

State Region District	Area irrigated by tanks: Gross	Area irrigated by tanks: More than once	Total cropped area	Total gross irrigated area by all sources	No. of tanks: >40 ha	No. of tanks: ≤40 ha	Gross tank irrigated area to total irrigated area	Gross tank irrigated area to total cropped area	Average size of tanks (ha)
	(1000 ha)								
Rajasthan	270*	-	16729	2136*	-	-	13	1.6	-
Gujarat	35	1	10420	1166	271	20022	3	0.3	1.7
Madhya Pradesh	131	-	20561	1523	-	-	9	0.6	2.2
Maharashtra	208	3	18737	1570	1348	27857	13	1.1	7.1
Andhra Pradesh	1110	160	13283	4423	7395	66114	25	8.4	15.1
Tamil Nadu	1084	205	7161	3272	8726	27019	35	12.3	30.3
Karnataka	373	-	11079	1144*	-	-	13	1.6	-
Coastal A.P.	467	21	4820	2479	2739	26381	19	9.7	16.0
Telengana	458	102	5387	1246	3681	30647	37	8.5	13.4
Rayalaseema	185	36	3075	698	975	9086	26	6.0	18.4
Medak	77	15	522	131	512	4423	59	14.8	15.6
Mahbubnagar	63	13	1041	145	498	5624	43	6.1	10.3
Kurnool	14	2	1091	147	78	297	10	1.3	38.4
Anantapur	56	15	991	194	244	893	29	5.6	49.1

* Net Irrigated Area.

Sources: Indian Agriculture in Brief, 12th Edition, Government of India;
Season and Crop Report of Andhra Pradesh, 1975;
Bureau of Economics and Statistics, Government of Andhra Pradesh.

tank sizes in the north as compared to the south can be observed. The average size of tanks in the northern districts of Mahbubnagar and Medak is between 10 to 15 ha, which is significantly below the average size of tanks in southern districts such as Kurnool and Anantapur with 40 to 50 ha.

In view of the regional variation in density of tank irrigation and considering the need to make full use of the scanty rainfall in semi-arid India, the following questions arise: Why do we find much more tank irrigation in coastal Tamil Nadu than in coastal Andhra? Why are there so many tanks in Telengana and so few in Maharashtra? Is it possible that some of the areas with less tank irrigation have a potential which simply has not yet been

exploited? If they had more tank irrigation earlier which has disappeared subsequently (e.g., Anantapur, Kurnool, Cuddapah, and Bellary), was this perhaps because institutional structures did not support collective action at critical periods?

HYPOTHESIS

Distribution of Indian territory between British and princely rule in 1800 gives rise to an impression that perhaps princely rule was more conducive than colonial rule to the promotion of tank irrigation (Fig. 2). This hypothesis appears plausible for the following reasons:

1. Tank irrigation systems require a strong local authority (a) to generate collective action for tank building, (b) to efficiently distribute water by optimally allocating it among beneficiaries and over seasons, and (c) to properly maintain the irrigation system. It would seem that under princely rule, local authority was likely to have been stronger than under British rule.

2. Regarding agriculture and irrigation, British emphasis was on development of large-scale irrigation schemes to promote production of export crops, rather than on local food production (Whitecombe, 1971).

3. There might also have been a causality, to the effect that wherever tanks were physically more easily established, princely rule would have been comparatively stronger to hold out against the British claim for territory: and thus tanks and princely rule would complement each other (Wittvogel, 1957).

In the literature on development and change, the dispute continues on the importance of institutional factors on the one hand, and economic payoffs and relative resource endowments on the other, as primary causal determinants of change (Binswanger and Ruttan, 1974).[4] The above hypothesis, if accepted, would indeed strengthen the argument of those who maintain that the institutional framework, as expressed in the differences between British and princely rule, dominates natural conditions.

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[4]For a review of the controversy between institutional and economic or technological determinism, see V.W. Ruttan: Induced Institutional Change, Ch.12, in H.P. Binswanger and V.W. Ruttan, Induced Innovation : Technology, Institutions and Development, Baltimore, Johns Hopkins University Press, 1978; and Nathan Rosenberg, 'Karl Marx on the Economic Role of Science,' Journal of Political Economy vol.82, no.4, July-August, 1974, pp 713-728.

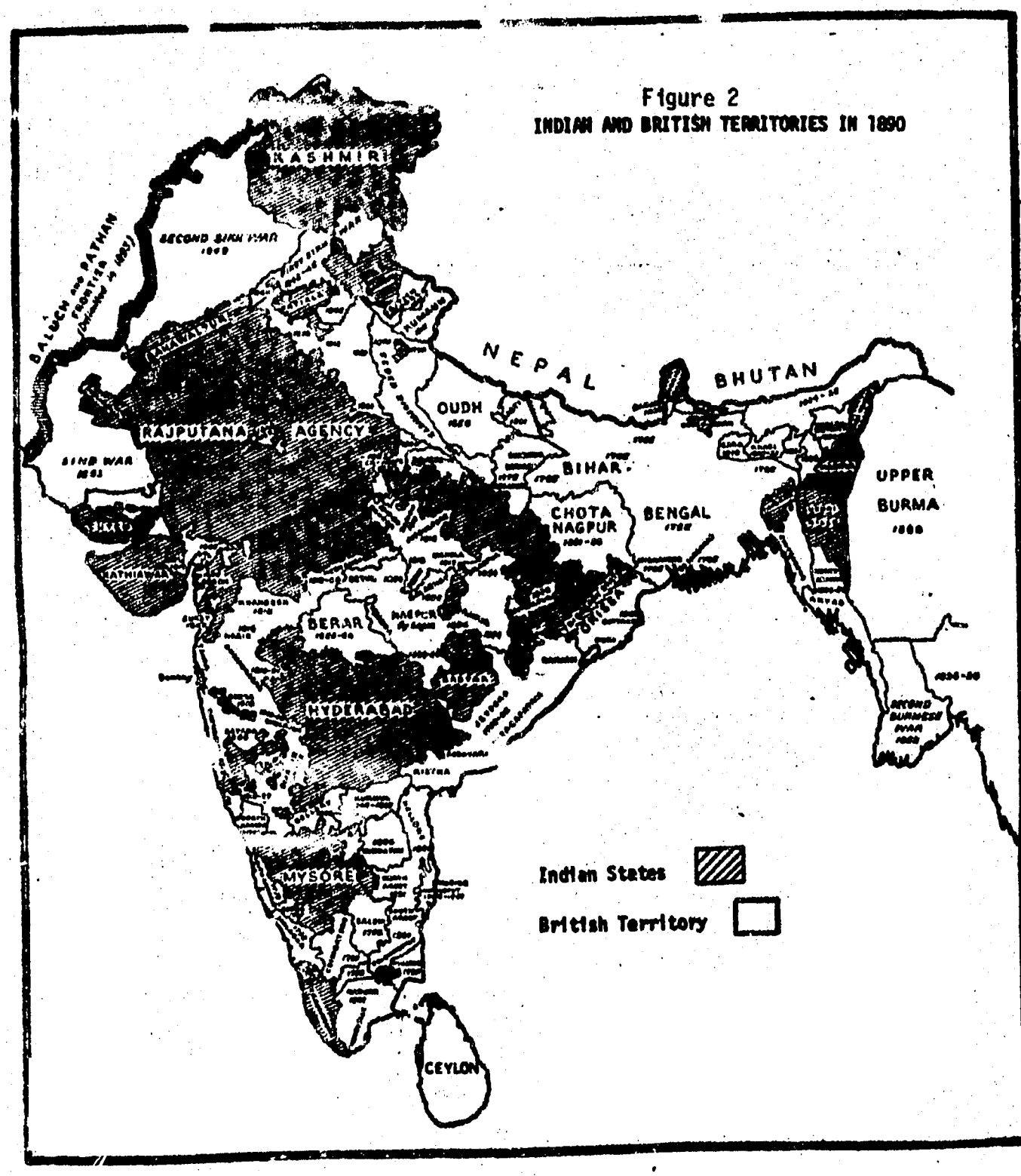

Figure 2
INDIAN AND BRITISH TERRITORIES IN 1890

Source: C. Collin Davies, *An Historical Atlas of the Indian Peninsula.* Second Edition, Oxford University Press, Madras 1976, p. 73.

On the other hand, if it was not true that princely rule had a strong impact on the creation of tank irrigation systems, then environmental factors such as population density over time and physical conditions should be the major determinants. The test of the above hypothesis thus had to be set up so as to measure the degree to which these environmental conditions were related to density of tank irrigation, and to test whether the influence of these factors differed significantly between areas under British rule and princely rule.

METHODOLOGY AND DATA

Areas under British and princely rule were identified from a map (Davies, 1976), depicting Indian and British territories in 1890. The year 1890 appeared to be appropriate for differentiating British and non-British areas, because in the later years very few territorial changes took place until independence. Also as shown above, tank construction under princely rule (as in Hyderabad State) experienced its major spurt only after the turn of the century and slowed down significantly after independence. At the same time no major effort was made in the Madras Presidency under British rule to expand the already existing tank irrigation capacity.

Any differentiating influence on frequency of tank construction arising from differences in legal and administrative structures under British versus princely rule would have manifested itself during the period after 1890 and would still be measurable today, and thus might explain average tank density at present. Also, if there was a casual relationship of tanks supporting princely states, this was likely to have been reflected in the division of the territory as it was in 1890.

Data on 165 districts with semi-arid climates were collected and the following variables, representing physical determinants of tank irrigation as explained in parentheses were generated.

1. GEOG: Geology of subsoils with granite underground using dummy variable (granitic underground prevents percolation and is conducive to tank building).

2. VAPR: Average vapor pressure over the year (high vapor pressure implies high humidity and therefore low evaporation losses; thus high vapor pressure would be conducive to water storage in open tanks).

3. POST: Average amount of post-monsoon rainfall (the more rain, on the average, falling after the normal end of the monsoon, the higher is the probability of having a full tank at the end of the rainy season, and therefore the higher the payoff to irrigation).

4. TOTR: Average total rainfall per year (the greater the rainfall, the less the payoff from water storage and therefore the fewer the tanks).

5. SIND: Weighted average of soil moisture retention capacity (the higher the retention capacity, the more water can be stored in the soil and the lower is the runoff; thus the lower the payoffs from building artificial storage devices).

6. INTR: Average intensity of rainfall (average rainfall divided by average number of rainy days: high rainfall per rainy day implies runoff and therefore supports efficiency of water-storage systems).

7. POPD: Total population density in 1971 in linear and squared form (number of persons per hectare of geographical area: the linear term is expected to be positive and the squared term 'SPOP' negative).

8. TIME: Year in which density of rural population is estimated to have passed the level of 100 persons per square kilometer (setting year 1900 = 0). These estimates could be derived from data available statewise; only adjustments at the district level could not be made for lack of data.

The choice of the aforesaid variables as major environmental factors affecting tank irrigation was made in line with results emerging from related studies presently underway at ICRISAT. Statistical analysis of rainfall runoff data indicates that, with equal rainfall, there is more runoff from red soils than from black soils (Ryan and Pereira, 1978). A survey of farmers operating in the command areas of different irrigation tanks shows that in red-soil areas tank irrigation is more profitable than in black-soil areas

(see Part II), and experimental evidence on large-and small-scale plots indicates that there are no economic payoffs from supplementary irrigation in medium to deepblack soils. Unfortunately, lack of data made it impossible to include a variable measureing the topography of the districts.

The inclusion of population density in 1971 (earlier data on districts as presently delineated were not available) implies that we expect to observe the population effect on tank density across regions expressing itself as it was hypothesized to do over time: i.e., tank irrigation should increase with population density at a rate up to a maximum, beyond which tank irrigation falls as population rises. Since population in different parts of the country passed through these stages -- critical for tank construction -- at different times over the past century or more, a variable was needed which would permit at least to approximately assess the effect of this time dimension.[5] Therefore, estimates derived from statewise data on rural population densities were included.

As a dependent variable, the gross irrigated area from tanks (TDENS) as percent of total area cultivated was computed. For this, the average of 4 years (1968-69 to 1971-72) was chosen, because the generally good rainfall during these years permits the assumption that all of the tank irrigation facilities available were actually in use. A regression model was specified:

$$TDENS = a + b_1\ (GEOG) + b_2\ (VAPR) + b_3\ (POST) + b_4\ (TOTR) + b_5\ (SIND) + b_6\ (INTR) + b_7\ (POPD) + b_8\ (SPOP) + b_9\ (TIME)$$

This model was applied on three different sets of the above data. (1) Combined set of all 165 districts, (2) British subset of 70 districts under British rule, and (3) Princely subset of 95 districts under princely rule.

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[5] Ideally, time series data on tank irrigation and population, covering say 100 years for a cross section of several districts in different regions would be required, for a proper statistical measure of the population effect on tank irrigation.

RESULTS

Table 6 summarizes the coefficients and the results of this statistical exercise to explain differences in the density in tank irrigation in the semi-arid tropical states of India.

The hypothesis that there is a difference in tank irrigation between British and princely districts had to be accepted.[6] The appropriate F test comparing the error sum of squares shows that the intercepts and the slope coefficients for the two data subsets differ significantly. Thus, it is organization and legal conditions, as far as they differed between British and princely rule, together with physical and geographic conditions, that determined the allocation of tank irrigation in the past.

In the British as well as the princely states, physical variables included into this model explain about 50 percent of the variability of tank density for both areas the coefficients for the most important factors, geology and postmonsoon rainfall, are remarkably close in magnitude, indicating the similarity between the two regions in response to natural factors when allocating tank irrigation facilities.

Population density and time are highly significant only in the case of the non-British data set. However, the coefficients of all the three data sets indicate that tank density is maximum at total population densities of 220 to

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[6] To readers of earlier versions of this paper (M. von Oppen, Binswanger, H.P., Institutional and Physical factors affecting tank irrigation density in India, December 1979, Mimeo.) this finding may appear contradictory. The explanation is that only after including the two variables of population density together with time as specified above, did the significant difference between the British and the non-British data sets become apparent. Inclusion of these two variables increased the R^2 of the non-British set from .48 to .69, while it did not affect the British data set: i.e., only in the non-British districts did population density over time have a very significant impact on tank density today (Table 6). This finding was confirmed by a test, in which a dummy variable (British Set = 1) was found to be significant and interaction terms between population density and this dummy were not significant.

Table 6. Variables and coefficients explaining variation in tank densities

Data Set	GEOG	VAPR	POST	TOTR	SIND	INTR	POPD	SPOP	TIME	DUM[1]	DPOPD[2]	DSPOP[3]	DTIME[4]	Inter-cept	R^2	ESS	DF
Combined	4.78*	0.60*	0.026**	-0.002**	-0.54	0.06	0.96	-0.21	-0.014					-9.101	0.503	3225.7	155
	(5.45)	(4.04)	(2.20)	(1.98)	(1.39)	(0.53)	(0.90)	(1.15)	(1.09)								
British	6.38*	0.56**	0.056*	-0.002	-0.29	0.19	4.46	-0.98	0.007					-17.526	0.579	1903.0	60
	(3.63)	(2.11)	(3.00)	(1.35)	(0.34)	(0.65)	(1.20)	(1.22)	(0.34)								
Non British	3.40*	-0.18	-0.046*	-0.0004	-0.88*	0.003	2.73*	-0.62*	-0.161*					18.742	0.694	709.3	85
	(4.37)	(0.94)	(2.56)	(0.26)	(2.67)	(0.02)	(3.29)	(4.43)	(7.55)								
Combined	4.54*	0.45*	0.033*	-0.002**	-0.86**	0.146	1.42	-0.43	-0.095*	-9.41**	2.09	-0.30	0.095*	-0.494	0.541	2981.5	151
	(5.22)	(2.89)	(2.69)	(2.31)	(2.15)	(1.16)	(1.15)	(2.06)	(3.52)	(2.44)	(0.60)	(0.46)	(3.23)				

Figures in parentheses are t-values
* Significant at 1% level
** Significant at 5% level

[1]DUM = Dummy variable: British set = 1, Non-British = 0

[2]DPOPD = Interaction variable = DUM x POPD

[3]DSPOP = Interaction variable = DUM x SPOP

[4]DTIME = Interaction variable = DUM x TIME

F test of significance between British and Non-British data subsets:

$$F_{(10,\ 145)} = 2.43 \text{ (at 1\% level)} \qquad \frac{\dfrac{3225.7 - (1903 + 709.8)}{155 - (60+85)}}{\dfrac{1903 + 709.8}{60+85}} = 3.40.$$

Therefore the difference is significant

230 persons/km^2, which corresponds to rural population densities of around 170 persons/km^2.

4. SUMMARY AND CONCLUSIONS

Historical records give ample evidence of tank irrigation having been practiced for centuries in many parts of India. Statistical analysis of district data on tank irrigation densities in former British and princely territories in semi-arid India indicates that spatial distribution of tank irrigation has been determined primarily by physical conditions -- such as granite underground, vapor pressure, and late rains -- and by population density. The data reveal significant differences between formerly British districts and princely states in this respect.

The tank irrigation capacity which we find today in the country was created during different periods in different regions. For instance, the area under tank irrigation in the former Madras Presidency a century ago was about the same as today, while in the former State of Hyderabad considerable public tank-building activity developed only during the first 40 years of this century. Such regional differences in the timing of tank construction may be explained by differences in population density: there appears to be reason to postulate a minimum density of population of about 50 persons/km^2 above which tank construction begins and population and tanks increase in mutual support of each other up to an upper limit of abotu 120 to 170 persons/km^2, the point when population pressure in rural areas tends to cause effects that reduce operational efficiency and extent of tank irrigation systems.

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