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Morphodynamic Setting and Nature of Bank Erosion of the Ichamati River in Swarupnagar and Baduria Blocks, 24 Parganasz(N), West Bengal

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A B S T R A C T

River banks are multifaceted earth-forms where different geomorphic processes act together in a complex manner. River bank erosion is an episodic event by which an unstable bank tries to reach into a stable one. This is very common in deltaic meandering river systems. The River Ichamati, located in the eastern part of the Ganga delta region, is susceptible to severe bank erosion. This is because of its diurnal and seasonal fluctuation in the tide-dominated discharge, which is favoured by its channel geometry and local land use. The present paper is based on filed level observations and measurements followed by analysis with reference to theoretical perspectives of channel morphometry as provided by renowned scholars in the field. A set of relevant morphodynamic variables like rainfall, discharge, groundwater, geology and soil, and also human factors have been considered for understanding the nature of river bank erosion.

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Introduction

River bank areas are the upper parts in any of its cross sections, and it may or may not consist of man-made structures to have an influence on the natural morphodynamic system of the channel. After the bed, bank is the second most important component of the river channel, and it is a transverse vector of the channel. The river banks gradually descend up to the river bed and the cross-profile may consist of different slope elements. The nature of these cross-profiles may differ at different stretches of a river, and thereby may put significant influence on the morphological equilibrium of the channel in relation to its ambient environmental set up. The bank area of a deltaic river channel is highly influenced by tidal conditions. When the river is in low tidal level, the bank of river channel is further exposed, but a high tide situation, when the river is full to its brim, much of its bank area is inundated. The present paper is an attempt to study the morphodynamic setting and erosion status of the river banks of the Ichamati, a decaying river located in the eastern part of the Ganga delta region of West Bengal.

The study area includes a selected portion of the Ichamati river channel under the police station of Swarupnagar and Baduria in the eastern portion of the district of North 24 Parganas, West Bengal, and it covers an area of about 419.16 sq. km. Geographically, the study area is located between 88˚48'18" E to 88˚51'16" E, and 22˚ 42' 22" N to 22˚ 47'24" N (Fig-1).

The study area is located in the south-western part of the Bengal basin and is situated within the Bhagirathi (Hugli)-Padma interfluves. The Bengal basin comprises an essentially complete Tertiary sedimentary succession concealed under the Quaternary alluvium of the Ganga-Brahmaputra river system in West Bengal, India (Ganguly, 1997). The Quaternary formation deposited in the environs of Bengal delta broadly range in age from Middle Pleistocene to Recent (Roy and Chattopadhyay, 1997). The deltaic rivers are now trying to adjust with the local environmental conditions including human intervention through bank erosion, sedimentation and meander formation (Basu, 2005).

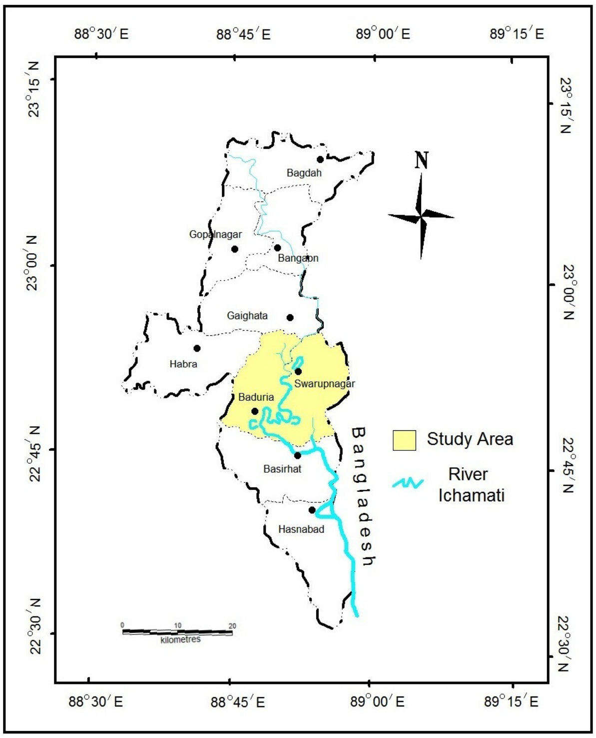

Fig-1: Location of the Study Area

General Mechanism of Bank Failure

River bank is a multifaceted zone where different type of geomorphic processes act together in a complex manner. In the deltaic alluvial region a channel tries to adjust and readjust for the distribution of energy, under some seasonally characterized hydro-mechanical and channel-geometric conditions. Bank erosion, in the form of mass wasting, is one of the tools of this adjustment. This is probably an 'episodic event', because an unstable bank reaches to a stable condition after a short or long silence period.

The weakening process of the bank is subject to large variety of processes, and as the time goes on, the external force (P) exceeds the elastic point of the shear stress of the bank material, and the bank breaks down. Breaking-point of the bank is treated as threshold. When the instability of an erosive bank reaches its maximum, it tries to achieve the stability (a newer one) by breaking itself (that is threshold). At the moment of breaking, the stability of the newer one is the maximum. As the time goes on the new bank becomes unstable due to external or internal forces. During this period, it resembles that the bank is taking rest and, therefore, this time period is called relaxation time (Fig-2).

All the mechanisms are treated as dynamic-metastable equilibrium. Stable equilibrium exists until some incremental change (i.e. a trigger mechanism) pushes the system across a threshold into a new equilibrium and dynamic means balanced fluctuations about a mean value that itself has a trending, non-repetitive, mean value (Thorn and Welford, 1994). The intensity of bank erosion is measured based on the 'time distance' between two thresholds. This time distance may be a fraction of a unit of time or year. The 'time distance' is called 'recurrence interval'.

River bank erosion is a form of slope failure. The general mechanism is described in

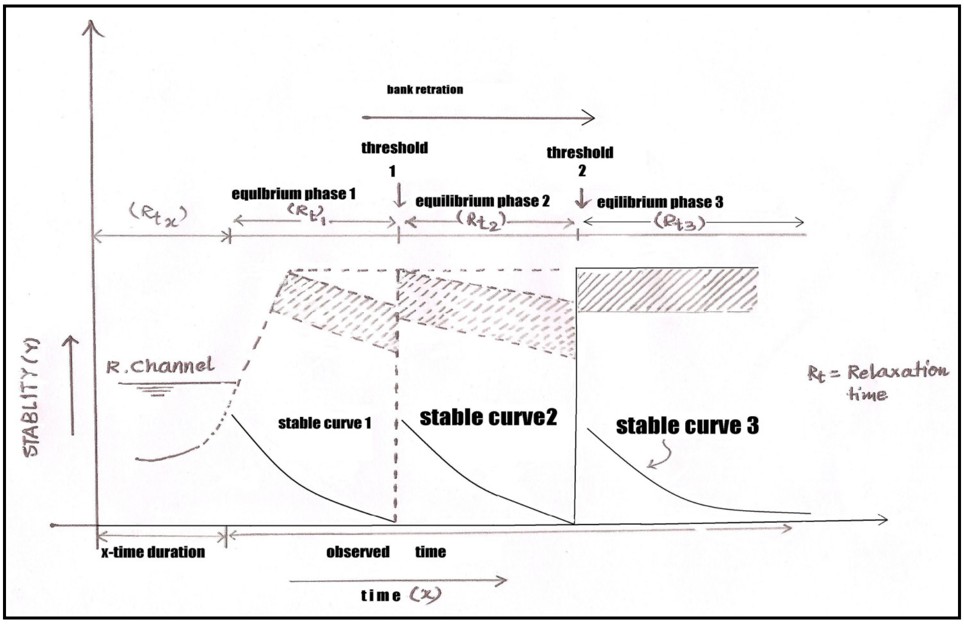

Fig-2: The Equilibrium Scenario of a Channel Process (after Chorley *et al*, 1984)

the following figure (Fig. 3). When a mass (m) is on the inclined slope (AC), its weight (W) is acting downward. There are two component vectors of W, such as, W.sin θ and W.cosθ. W.sinθ is driving force for the material going downward along the inclined plane (Dasgupta, 1994). When the material begins to move downward along the slope, it has to overcome an opposite force applied by the slope as the frictional force (F). Thus, when the material is in equilibrium on the slope,

$F + P.\cos\alpha = W.\sin\theta$ .... (1)

$R + P.\sin\alpha = W.\cos\theta$.................. (2)

As $F = \mu R$, where μ is the frictional coefficient,

$\mu R + P.\cos\alpha = W.\sin\theta$................ (3)

Solving Eqns – 1, 2 and 3,

$P = W.\sin\theta - \mu.\cos\theta / \cos\alpha - \sin\alpha$

Now, if the angle of friction is λ,

Then, $\mu = \tan\lambda$ and

$P = W. \sin(\theta - \lambda) / \cos(\alpha + \lambda)$.

But when the bank material is in motion on slope, the model is different. In that case, the angle of slope is greater than the angle of friction. The downward component of the weight being parallel to the slope is given by: W= mg. sinθ and the component of weight perpendicular to the slope is given by: R = mg. cosθ.

As mg. sinθ > F, and (mg. sinθ) – F´ = mf´

Therefore, $mf' = mg.\sin\theta - \mu' R$

or, $mf' = mg.(\sin\theta - \mu'\cos\theta)$

Hence, $f = g.(\sin\theta - \mu'\cos\theta)$ (Dasgupta, 1994).

If the inclined plane (slope) is completely smooth, i.e., $\mu' = 0$

then, $f = g.\sin\theta$.

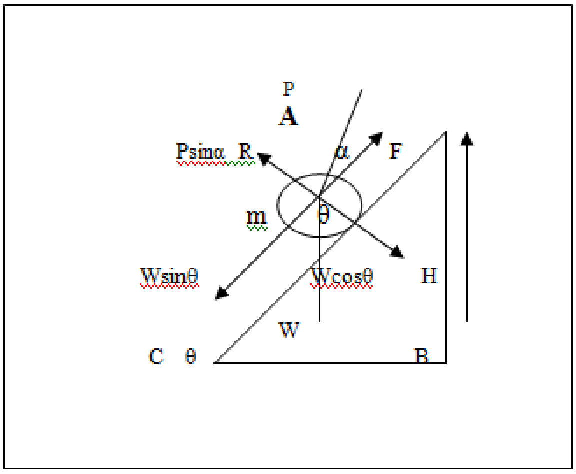

Fig-3: The geometry of slope failure

So, it is clear that the downward movement of material depends on the angle of bank and coefficient of friction (μ) (Dasgupta, 1994). The factors affecting the bank angle and coefficient of friction are rainfall, discharge, groundwater, channel geometry, biological activities etc. because an alluvial channel, particularly in deltaic landscape with imperceptible slope constantly adjust and readjusts with the available slope, discharge, length, cross-section geometry and other fluvial and hydrological variables. These are briefly discussed as follows:

(i) ***Rainfall, Discharge & Groundwater***

The role of water is to reduce the shear stress of the surface of the inclined plane and increase the mobility of the materials. Rainfall use to increase the discharge that enhances eddies in the flow, and the resultant turbulence excavates the material from the toe of the bank and increases the bank angle. "..the more active tidal inlets and inter-connections of the Sunderban (in case of the Ichamati river) with complex motions, great speed and enormous energy is naturally followed by an equally forceful ebb flux so that the upper part of the soil mantle above the permanently moist zone undergoes a diurnally alternating soil-moisture regime. The hydraulic impact of the covering in-flux and diverging out-flux undercuts the base of the bank profile leading to bank failure and bank erosion' (Sarkar, 2004: 87). Therefore, the intensity of bank erosion usually becomes greater in the monsoon and the post-monsoon seasons. Several villages of Aturia Gram Panchayet of Baduria CD Block were severely affected due to the heavy monsoon rainfall of the years 2000 and 2001. Liquefaction of bank materials due to effluent groundwater during high discharge from monsoon accentuates the bank erosion rates as well as volume.

(ii) ***Bank Material***

Observations from the field visits revel that the soil of the study area is predominantly sand. It is further noticed that the areas where the bank erosion is more are characterized by sandy soil. The cohesiveness of sand is very low, so it is susceptible to easy removal by running water. It has been found that the sandy bank materials simply coagulate with river water. During ebb period, the exposed bank profiles of the river Ichamati in the study area reveals that, the soil is composed of medium to coarse sand, and partly composed of sandy silt. The upper 1 to 2 metre portion of the profile is characterized by unconsolidated sand, silt and occasionally by clay. The lower portion is formed by more cohesive materials, i.e. older clay-mud formations with occasional laminar structures.

(iii) ***Channel Geometry***

There is a profound effect of channel geometry on bank erosion of the river Ichamati in the present study area. The elements of the channel geometry are *width* (w), *depth* (d), *height of the bank* (H), *angle of the bank*, *radius of curvature* (R_c), *meander weave length* (λ) etc. When the ratio between R_c and w equals to 2, the channel is considered to be stable or is in equilibrium (Hickin, 1974). Most of the data which are collected from the Ichamati river show that the ratio between R_c and w is below 2 (Table-1). So, the Ichamati river is unstable in character in its lower course specially Swarupnagar, Baduria. The bank profile of each station shows that there are several segments of slope elements on both side of bank profile. These segments ultimately form an irregular bank profile on both sides of the river channel, and these irregular slope angles create turbulences in the flow at local level. The turbulences enhance the river bank erosion. Because it is noticed generally that the current of water flows parallel to a straight river bank, the molecules of water roll over the surface of the river bank in the same manner as a wheel, the velocity of the rim of the molecule in touch with the surface of the bank being for that movement zero. So, there can be no erosion of the bank material. When there are inequalities on the bank surface, the local turbulence or eddies are formed (Roy, 1954).

Eroding Banks along the Lower Ichamati Channel

Lateral erosion is a natural tendency of a meandering channel system (Lawler, 1993). Lateral erosion is noticed more or less throughout the Ichhamoti channel within the study area. But the intensity the lateral erosion is not same everywhere. On the basis of observation for a period of six (2004-2010) years, the river course may be divided into three zones according to the intensity of the bank erosion. These are: Zone-A with the rate of bank erosion is 6-7m/year), Zone-B with the rate of bank erosion is 3-6m per year, and Zone-C with the rate of bank erosion being less than 1m (Fig.-4a). Locations of the zones are as follows:

<u>Zone-A:</u> (1) Kabilpur (40, L/B - 600m), Swarupnagar P.S., (2) Media, Raimonitala (28, R/B - 595m), (3) Punra kheyaghat (89, L/B - 482m), (4) Fatullapur (88, L/B 400m), (5) Sarfarajpur (L/B -790m), 6 Magurati Srirampur (87, L/B 600m) Baduria P.S

<u>Zone-B:</u> (1) Swarupnagar Bhattacharjee Para (L/B - 439m), (2) Katabagan, Sarapul (36, L/B - 500m), (3) Kulia (26, R/B - 509m), (4) Ramchandrapur (25, R/B - 467m.) (Baduria P.S.), (5) Durgapur (L/B 1200m), (6) Bhekutia (24, R/B 600m), (7) Nalbara (22, L/B1500m)

<u>Zone-C:</u> (1) Ghola (28, R/B-800m), (2) Srirampur (27, R/B - 560), (3) Gobra (18, L/B - 850m). Saguna (15, R/B - 2000m), (5) Sakdaha (R/B - 2500m), (6) Srirampur (27. R/B - 500m), (7) Tentulia (L/B - 400m), (8) Taranipur (17, L/B - 2642m), (9) Tipi (31, R/B-4532m) Swarupnagar P.S. [Note: R/B means *right bank* and L/B means *left bank*]

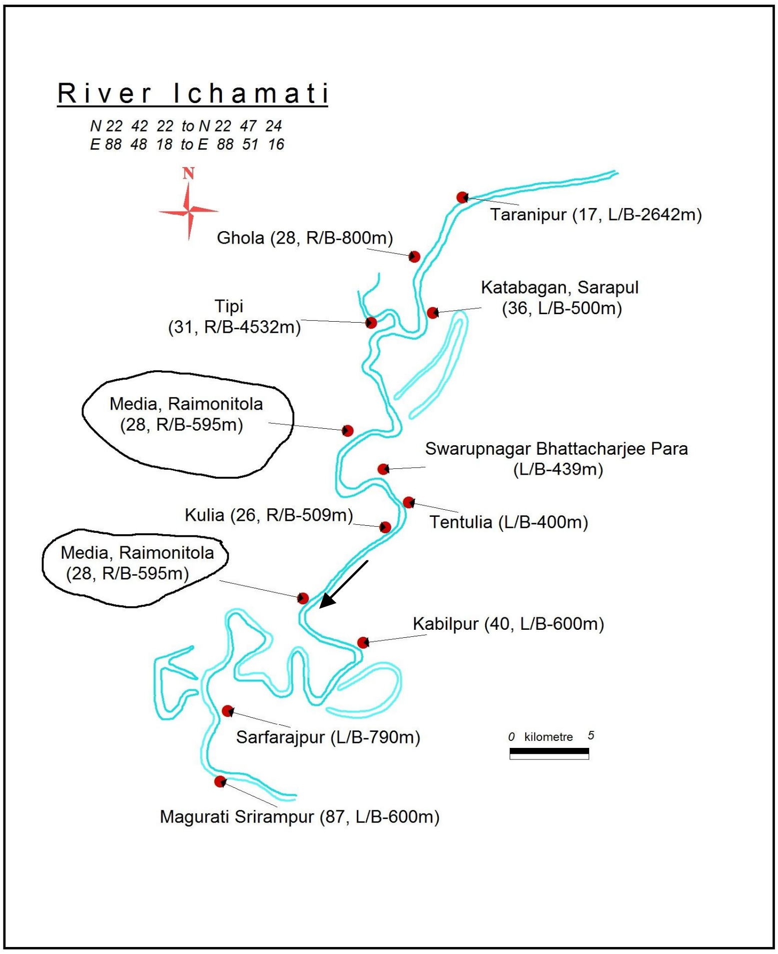

Fig. 4

Table-1: Channel Geometry of the Lower Ichamati River

Locations Swarupnagar P.S.-1 Baduria P.S.-2	Width (W) in m	Height of Concave Bank (H) in m	Angle of Bank		R_C (m)	R_C: W
			Concave	Convex		
Kabilpur 1 (Mouza No. 40) RB-600m	109	10	1st segment 80° 2nd segment 45°	6° 3°	167	1.5
Media 1 (Mouza No.28) RB-590m	200	10	1st segment 56° B.O.S. 90° 2nd segment 45°	3° 2°	192	1.04
Polta 2 (Mouza No.99) LB-500m	100	9.5	1st segment 80° 2nd segment 2° 3rd segment 75°	2°	-	-
Safarajpur 2 LB-790m	270	14	Broken	3°	288	0.8

Note: P.S.- Police station, RB.- right bank, LB.- left bank, B.O.S.- break of slope, R_c = Radius of curvature.
Source: Calculated by the authors based on SOI maps and field survey, 2004-10.

Nature of Bank Erosion in the Study Area

From the above discussion, it is observed that most of the study stations of A-zone belong to Baduria Block. Furthermore, the Ichamati river, within the present study area, can be divided into two segments: (1) *the reach of flat gradient* in between Kalanchi and Tentulia, where the gradient is very low often reverse towards the upstream and this does not follow the 'law of stream slope' (Strahler, 1969: 494); and (2) *the reach of steep gradient* in between Tentulia and Basirhat, where the gradient is steep and the slope is abrupt in the downstream direction. This is because a meander cut off has taken place near Swarupnagar (Fig. 4b). Besides, the form and component of cross profile change from place to place on the basis of the hydraulic character of the river. The cross profiles of the river Ichamati can be divided into three zones. These are as follows. (1) *The less unstable zone* in between Kalanchi and Tentulia, where the velocity is relatively greater than that of the upper portion, and both the sides of the channel are characterized by slight bank erosion.

Here the bank profile is asymmetrical, the river width is greater than the upper section, and the river bed is formed mostly by sand. (2) *The most unstable zone* in between Tentulia and Basirhat, where the river is very dynamic. Here the concave portion of the cross profile is characterized by bank erosion, and there is a point bar deposition on the convex side of the channel. There are well developed pools and riffles on the concave side and also in the straight section of the river channel. The depth and width of this section are much greater than those at the upper sections. It is worthy to mention here that, not only the channel characteristics change but hydraulic characters such as velocity, Froude Number ($v/\sqrt{g.d}$), and Specific Energy (E_s) {$v^2/2g+d$}(Morisawa, 1995:26 & 28) also change in these two zones.

Anthropogenic intervention to the river hydraulics is also noticeable to affect the river. A river bridge, called Tentulia Bridge at Swarupnagar area has been constructed using a numbers of pillars on the river bed. These masonry structures are obstructions to the free flow of tidal currents, the velocity of which is significantly reduced. Thus, rapid siltation has been taking place on both up-stream and down-stream sides of these columns. As a result the river is becoming shallower and narrower gradually towards upstream.

Though the river Ichamati within the area under the present study is undergoing severe bank erosion, the rate of erosion is not same throughout the year. Usually, the maximum erosion is taken place during monsoon and early post-monsoon periods. The area receives highest rainfall during the monsoon season, and for this reason discharge of the river becomes more, e.g. at Tentulia Bridge the discharges (in m^3/s) 64.5, 203.8 and 96 during pre-monsoon, monsoon and post-monsoon seasons respectively. The cross profile of river channel is asymmetrical and pools are found at the concave side of the channel. So, there is a strong helical flow or turbulence at the concave side. The concave bank profile consists of different slope segments which create local eddies and change the flow direction. These eddies scour deep holes on the river bed, into which the material from the river bank continues to slide downwards, and therefore, cracks appear on the top surface of the river bank. This type of bank erosion predominates at Kabilpur, Polta, Ramchandrapur villages, where the bank heights are about 1.5 to 2m. Here the erosion is mainly in the form of small slides and cantilever type.

The other important factor is the rapid change of water level. As the Ichamati is a tidal river, there is rapid fall of water during ebb period and the receding water removes soil particles from the banks also. The highly saturated sediments liquefy and move toward the channel through thread like pathways, and sheet like erosion is taken place. This type of erosion is noticed at Sarfarajpur. There is another effect of fluctuating discharge on bank erosion. During the high tide, the water is forced into the sediment increasing the pore-pressure. During the low tidal period, the rapid fall of water releases the pressure from the bank wall, and as a consequence, there is lateral flow of sand and silt into the channel. This type of erosion produces bowl-shaped or semi-circular cavities of different magnitude with rotational slumping.

In land use pattern also enhances the local level bank erosion. There are numerous brick-fields and fisheries along both sides of the river. These pools/ water bodies are directly joined with the river through inlets/outlets. The pools/ water bodies get water and silts during H.T.L. as per their requirements. Water is released from these water bodies during L.T.L. through the outlets disturbing the natural environment of the river banks. As the time goes on, the mouth of the outlet becomes progressively bigger, and severe bank erosion starts at these outlet points. This type of bank erosion is found mainly at Baduria C. D. Block. The number of brickfields and fisheries gradually decreases towards Swarupnagar, where this type of erosion is seldom noticed.

The highest rate of retreat of river banks occurs as a result of high flow during prolonged wet period. As increase of moisture in the soil decreases the inter-molecular unity between the soil particles and thereby frictional force (F) becomes lesser than the downward component of the weight ($mg.\sin\theta$). Thus, a devastating 'erosion episode' took place in September 11-24, 2002. In this year the lower Ichamati basin received huge rainfall successively in May (169 mm), June (492 mm), July (250 mm), August (251 mm) and September (387 mm). The discharge of the river during the aforesaid time became the maximum (350.03 cumec). The bank materials were already saturated leading to massive bank erosion in this period. At Swarupnagr area the rate of bank erosion is not much most probably due to lack of water. Besides, in this section the sinuosity index of the Ichamati channel is lesser (2.13) than Baduria area (3.56), where the length of the erosive bank is more but the rate of erosion is significantly less.

Conclusion

River Ichamati in Swarupnagar and Baduria Blocks of North 24 Parganas, West Bengal is decaying very fast due to natural changes and human interventions on the river system. Very high fluctuation of seasonal as well as diurnal flow of water, tidal ingression, and river geometry itself are responsible for frequent change in the river course to adjust the river system through a constant erosion-sedimentation scenario. The river is now trying to reach a stable equilibrium condition shedding its earlier meta-stable balance under the active deltaic environment of South Bengal.

Table-2: Specific Energy and Froude No. at Bhattacherjee para, Swarupnagar

Station	Depth(m)	Mean Velocity (m/s)	Froude No. (f_d)	Specific Energy(E_s)
1	1	0.10	0.0387	1.00
2	1	0.10	0.0387	1.00
3	1	0.10	0.0387	1.00
4	1	0.15	0.0580	1.00
	2	0.15	0.0290	1.00
	3	0.15	0.0190	1.00
5	1	0.23	0.0880	1.00
	2	0.23	0.0440	2.00
	3	0.23	0.0290	3.00
	4	0.23	0.0220	4.00
6	1	0.40	0.1547	1.01
	2	0.40	0.0770	2.01
	3	0.40	0.0515	3.01
	4	0.40	0.0386	4.01
	5	0.40	0.0309	5.01
	6	0.40	0.0257	6.01
	7	0.40	0.0221	7.01
7	1	0.50	0.1934	1.01
	2	0.50	0.0967	2.01
	3	0.50	0.0644	3.01
	4	0.50	0.0483	4.01
	5	0.50	0.0386	5.01
	6	0.50	0.0322	6.01
8	1	0.30	0.1160	1.00
	2	0.30	0.0580	2.00
	3	0.30	0.0386	3.00

Source: Calculated by the authors based on field observations, 2004-2010

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