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DEVELOPMENT OF STREAMBED POTHOLES AND THE ROLE OF GRINDING STONES

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Abstract

The largest grinding stone episodically stored in pothole is not only responsible for growth of pothole size but also determines its shape. This paper examines the largest grinding stone found in cylindrical potholes and their role in pothole growth using empirical analysis. The largest grinding stone from 34 randomly selected potholes, developed on the riverbed of Subarnarekha River at Ghatshila, Jharkhand, India, were analyzed to have an insight into 1) their sizes and shapes; 2) controls on grinding stone shape; and 3) roles of largest grinding stone on streambed pothole growth. Strong correlation coefficient between the size and weight of grinding stones reveals their similar specific gravity. The pothole depth was proportional to the diameter of the largest grinding stone in it. Concave pothole-floors developed because of abrasion by grinding stones atop floor. A force applied on largest grinding stone depends upon not only eddy velocity within pothole but also on shape of the stone.

Keywords: potholes, largest grinding stone, shape of grinding stone, eddy velocity

INTRODUCTION

Potholes are the most spectacular features in bedrock river channels. Currently potholes are studied extensively and considered as key factor in bedrock channel development and morphology (Hancock et al., 1998; Whipple et al., 2000). Potholes along with other sculpted forms in bedrock channel can be tied to river hydrology (Blumberg and Curl, 1974; Curl, 1974). Bedrock channels with higher velocity and hydraulic radius (Reynold's number > 2200) are characterized by turbulent type of flow which leads vortex / whirlpool motion and formation and growth of potholes.

Springer et al. (2005) established relationship between average radius ($\bar{r}$) and depth (d) of potholes and expressed the relation as $\bar{r} = kd^{\varepsilon}$. They considered the potholes as radially expanding cylinders and designed a growth-model on geometrical base. Pelletier et al. (2014) also showed that pothole depth (d)increases in proportion to both the mean pothole radius ($\bar{r}$)and the diameter of the largest grinding stone episodically stored in potholes.They also modeled a limit of depth to mean radius ratio (γ) beyond which bed shear stress (τ) become too small for abrasive work atop floor of the pothole and designed formula of minimum water depth for development of pothole of given radius on given slope. Yet numerous questions concerning discrete erosion phenomena remain unanswered (Whipple, 2004). For example, how pothole size related to stream power? How vortex velocity within pothole varies with rising river velocity and increasing $d / \bar{r}$ ratio? With given stream flow velocity, how vortex velocity changes with increasing pothole depths? How long the positive feedback between growth of potholes and vortex velocity (Allen, 1968; 1971; Blumberg and Curl, 1974; Hancock et al., 1998) goes on? Moreover, to entrain stones from bottom of pothole for episodic abrasion (and shaping of stones), Rouse number must be less than 7.5 (Julien, 1998) which increases with increasing $d / \bar{r}$ of a pothole and which in turn reduces the frequency and degree of abrasion by stones. So beyond $\gamma \sim 2$, largest stones remains relatively idle with rough and irregular shape.

The fundamental properties of sediments are size, shape, mineralogical composition, surface texture, and orientation. Sediment shape plays an important role in selective transportation of the particle. Settlement velocity of a sediment particle is again controlled by size, shape, and density of the particle. Thus the shape, along with size and density, shed light not only on the transportation history of the deposit, but also on the immediate conditions at the site of deposition (Knighton, 1998). Pebbles or boulders from various environment are examined by Gregory and Cullingford (1974), Carroll (1951), Carroll et al. (1950), Plumlley (1948), Allen (1949), Krumbein (1940, 1941a, b), Zingg (1935), Luttig (1962), Bluck (1969), Tricart and Schaeffer (1950), Riviere and Ville (1967), Flemming (1964), Lees (1964) and Folk (1972). Using roundness measurement, [(2r/L) × 100], Gregory and Cullingford (1974) distinguished between till and fluvioglacial material and found lateral variation in pebble shape in northwest Yorkshire. Carroll (1951) examined variation in shapes and roundness of pothole pebbles collected from Valley of the Waters, Wentworth Falls, in the Blue Mountains. Experiment done by Rayleigh (1942, 1944) reveals that spherical pebbles are scarce. Pelletier et al. (2014) found relation between the largest grinding stones diameter and pothole depths.

In western India, potholes at Indrayani knick point are studied by Sengupta and Kale (2011), Kale and Gupta (2001) and Kale and Joshi (2004) and established evidence of formation of potholes in bedrock on human timescale. But shapes of grinding stones responsible for shaping those potholes are not examined. So present study illuminated size and shape of the largest grinding stone in potholes and its role in pothole growth.

IMPORTANCE OF GRINDING STONES IN POTHOLE GROWTH

Potholes grow as a result of combined erosion of walls and floors. Efficacy of erosion phenomena (Springer et al., 2005) determines differences in erosion rate of wall and floor of the potholes. All type of sediments sizes stored in potholes and involved in erosion is collectively called stones (Gilbert, 1877). Suspended load-size stones (largely coarse sands) abrade on wall and increase the aperture of potholes. Bed load-size stones like cobbles and boulders (Knighton, 1998) on the other hand works atop floor of potholes are called grinders (Springer et al., 2005). Grinders roll, skip or slide to abrade atop floor of potholes to maintain depths with proportionally increasing radii. Springer at al. (2005) reported small potholes having slightly concave floor and larger potholes having slightly convex floor in the Orange River bed inSouth Africa. By inference, large bed load-size grinders are absent in small hemispherical potholes. As a result, dominant wall erosion gives the potholes hemispherical shape. Grinder on the other hand perceived as largely responsible for pothole growth (Springer at al., 2005). It is also reported that depths of potholes grow faster than radius. And as suspended load-size sediment mainly impacts on wall, they have little contribution in deepening the potholes. Rather, grinders working solely atop floors are largely responsible forpothole deepening. Grinding stones are swept around pothole floors and lower part of pothole walls. Centrifugal force applied on rotating grinders in persistent non-transient vortices abrade more along the circumference than center of the pothole floors. As a result, potholes with central boss (Morgan, 1970) and convex floor (Springer et al., 2005) are intuitively shaped by grinders' erosion phenomena. It was observed in some larger potholes that radius at the bottom are larger than radius of aperture. This larger radius towards bottom is largely because of abrasive works of bed load-size grinding stones.

Present paper examines the largest grinder found in each of the pothole and its role in pothole growth. Pelletier et al. (2014) observed that pothole depths increase in proportion to diameter of largest grinding stones episodically stored in potholes. Therefore, it is inferred that with uniform flow velocity of stream above potholes, vortices velocity increases with increasing depths of potholes and thereby entrapping larger largest-grinder. Largest grinding stone, if too large to move by vortex velocity within pothole, may protect the pothole floors from further erosion causing formation of central boss (Morgan, 1970) and convex floor (Springer et al., 2005).

But efficacy of erosion phenomena by largest stone or its role in shaping potholes depends not only on its size but also on shape. For example, two stones having equal sizes and weights may require different vortices velocity to be entrained if their shapes are different. For abrasion, the stone episodically stored in the potholes is to be entrained and set under eddy type of motion. To entrain a particle of sediment of volume 'V' density 'ρ' and diameter 'D', the force F of flowing water applied on it must equals its submerged weight $w_s = g(\rho_s - \rho_f)$. And this can be expressed as:

$$F = m \times a \tag{1}$$

where m = mass of sediment, a = acceleration.

$$F = \frac{m \times v}{t}$$

[∵a = v/t, v= velocity of water flow in river, t=time]

$$\text{or} \quad F = \frac{V \times d \times v}{t} \; [\because m = Vd]$$

$$\text{or} \quad F = \frac{V \times d \times v}{t} \tag{2}$$

Suppose velocity 'v' of river flow is constant. Volume 'V' and density 'ρ_s' of sediment are also constant. Diameter 'D' of irregular shaped stones is under question because natural grinding stones are seldom spherical in shape. If long axis (L), intermediate axis (I) and short axis (S) of a stone (Fig. 1) of volume 'V' varied, amount of force applied on it also changes.

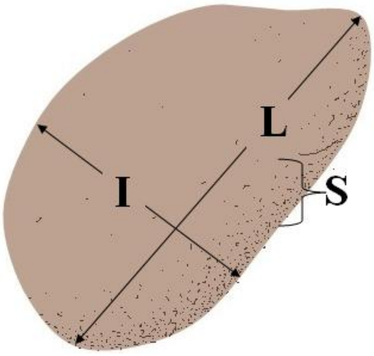

Fig. 1 Dimensions of the largest grinding stones in potholes. L: long axis (length), I: intermediate axis (width), S:short axis (height)

Drag force (Charlton, 2008; Knighton, 1998) applied depends on surface area (A) of the stones exposed to flow direction (Fig. 2). If L, I and S are unequal, then in normal condition, the stones will rest on the river bed with largest surface area (L×I) contact. Therefore if L and I are relatively small, the S will be relatively large causing higher force applied by flow of water on the stones and vice versa. Force applied by given flow velocity 'v' on a surface area 'A= I×S' perpendicular to flow direction (although all the points of the surface of a natural grinding stone are not perpendicular to flow direction) was calculated as:

$$F = \rho A v^2 \tag{3}$$

Therefore, higher the surface area exposed to water flow, higher is the applied force to initiate entrainment of stones (Fig. 2). According to Figure 2 both the grinding stones A and B have same volume, density, mass and therefore equal frictional force against movement. But A is cubical and B is cuboidal in shape. River's uniform flow velocity ‘v’ shown by length of the blue arrows are applying force ‘F’ perpendicularly on surface area (I×S) facing flow direction. As surface area of stone A exposed to river velocity is greater than surface area of stone B exposed to river velocity, force applied on A is also greater than force applied on B. So critical velocity to entrain stone A is much less than critical velocity needed to entrain stone B. Surface area exposed to direction of water flow directly depends upon shape of the stones. It is maximum for spherical stones and minimum for planner and acicular stones (Zingg, 1935).

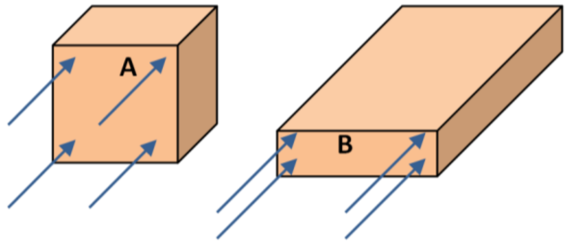

Fig. 2 Different surface areas of the cubical (A) and cuboidal (B) shape grinding stones exposed to flow direction

The shape of stones determines friction angle (Fig. 3) of sediments which in turn determines force applied on it which in turn determines momentum of stones without which carving of pothole is impossible. Therefore in equation (4), shape factor which is most appropriately represented by sphericity ψ was incorporated to find out critical force F_c needed to set a stone in motion. As sphericity of all natural river borne stones are less than 1, it reduces surface area of stones perpendicular to flow direction and in turn reduces drag force applied on stone.

$$F_c = \frac{\mathrm{V}\times \mathrm{d}\times \mathrm{v}}{\psi\times \mathrm{t}} \tag{4}$$

If velocity ‘v’ of the river is known, and if we can derive eddy velocity v_e within pothole with increasing aspect ratio γ (depth to width ratio) and once eddy velocity v_e is known, one can logically guess (using Hjulstrom's 1935 curve) about whether the largest boulder stored in the pothole have ever been entrained to abrade atop floors of pothole or it is lying inactively protecting the floors and giving it convex shape.

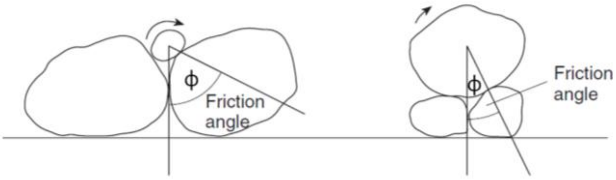

Fig. 3 Stones shape and size control friction angle which in turn determines their entrainment velocity and critical shear stress (Charlton, 2008)

Shear stress is regarded as the most important impelling force to set a sediment particle in motion. When critical shear stress τ_{cr} equals stones shear stress τ_0, stone starts to move. It is defined as:

$$\tau_{cr} = \mathrm{k}(\rho_s - \rho_f) \times \mathrm{D} \times \mathrm{g} \text{ (Knighton, 1998)} \tag{5}$$

where ρ_s = density of sediment, ρ_f = density of water, D = diameter of sediment= $\sqrt[3]{L \times I \times S}$ (Williams, 1965) and g = acceleration due to gravity ($9.81ms^{-2}$).

Putting the value of the given Shields parameters (k = 0.045 (Knighton, 1998) for pebbles and boulders) the equation (6) can be simplified as:

$\tau_{cr} = \mathrm{k}(\rho_s - \rho_f) \times \mathrm{D} \times \mathrm{g}$ (Knighton, 1998)

or, $\tau_{cr} = 0.045\ (2700\mathrm{kgm}^{-3} - 1000\mathrm{kgm}^{-3}) \times \mathrm{D} \times 9.81ms^{-2}$ [average density of dolerite/ granite $2700\mathrm{kgm}^{-3}$]

or, $\tau_{cr} = 0.045\ (1700\mathrm{kgm}^{-3}) \times \mathrm{D} \times 9.81ms^{-2}$

or, $\tau_{cr} = 76.5\mathrm{kgm}^{-3} \times \mathrm{D} \times 9.81ms^{-2}$

or, $\tau_{cr} = 750.46\mathrm{D}$

Incorporating shape factor, the equation is given as:

$$\tau_{cr} = 750.46\,\frac{D}{\psi} \qquad \left[D = \sqrt[3]{L \times I \times S}\right] \tag{6}$$

But submerged sediment weight is not only the resisting force to motion. Degree of packing ‘ɳ’of sediment is of significant importance which in turn, to some extent, controlled by shape of stones (Fig. 3). Shape factor of sediment also exerts its direct influence on critical shear stress.

$$\tau_{cr} = \eta \mathrm{g}(\rho_s - \rho_f) \times \frac{\pi}{6} \times \frac{D}{\psi} \times \tan \phi \tag{7}$$

where ɳ = a measure of grain packing, ϕ = friction angle. Stones shape in pothole therefore is of great significance which determines not only chance and frequency of entrainment of largest stones under given maximum river velocity but also of the smaller stones of different size and shape.

Therefore, sizes and shapes of bed load-size grinding stones (and largest grinder) are given importance because those are [1] determinant of drag force needed to initiate stones motion needed to abrade the floors, [2] restrainer of critical shear stress to set a sediment particle in motion, [3] responsible for increase in potholes depths,[4] responsible for convexity of potholes floors and [5] responsible for overall pothole growth (Springer at al., 2005).

STUDY AREA

In our study potholes in the Subarnarekha river bed downstream of Bhatajhor River confluence at Ghatsila were investigated. Subarnarekha river has a total length of 395 km, covering a drainage area of 18,951 km^2. After origin near Nagri village in Ranchi hill area at an elevation of 600 m (CWC, 2015), the Subarnarekha River traverses through Ranchi, Seraikela, Kharsawan and East Singhbhum districts in the state of Jharkhand, east India (Fig. 4). Thereafter, it flows through Paschim Medinipur district in West Bengal for 83 kilometres and Balasore district of Odisha for 79 kilometers to join the Bay of Bengal near Talsari. There is a small cluster of about 40 potholes in middle Subarnarekha river bed at the immediate downstream of Bhatajhor River confluence at Ghatsila, a town of East

Singhbhum District of Jharkhand in India. For this study, largest grinding stone was collected from each of 34 potholes from there (Fig. 4).

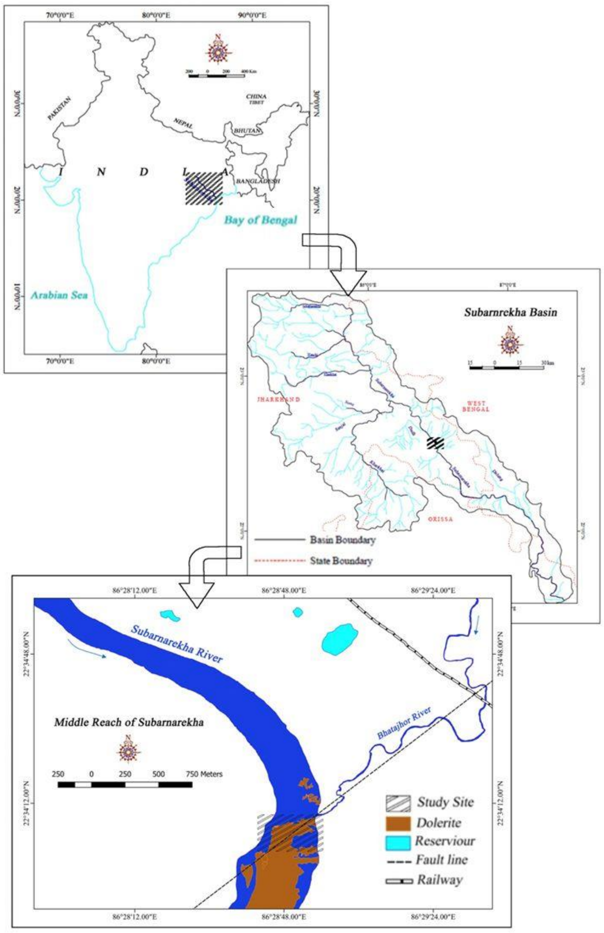

Fig. 4 Location of study area and the sampling site

There is a vast variation in peak water level which varies from 378.9 m to 8.9 m. Zero of the guage of the river Subarnarekha at Ghatshila was 72.00m and peak water level ever recorded was 85.05m recorded on 17.08.1974. Discharge recorded on that day was 9579.59 cumecs. Minimum water level 45.14m was recorded on 20.04.1972 when discharge was only 3.8 cumecs. Highest discharge ever recorded was 10582 cumecs on 06.08.1997 and minimum discharge ever recorded was 0.4 cumecs on 12.03.2010. So there was a high seasonal and annual variation in guage height and discharge. Average sediment load during monsoon months (2182000 metric tones) was 110 times higher than average sediment load during non-monsoon months (19800 metric tones).

Surface exposure of schist / phylite and quartzite of Singhbhum Group of rocks are recorded around Ghatsila, a town of East Singhbhum (Fig. 5) District of Jharkhand of India (GSI, 2006). Foliated mica-schists forms the bed of the river Subarnarekha. Foliations of schists dip 50˚ - 70˚ towards south and south-west. An arc of fault line East-North-West with doleritic intrusion runs across the river Subarnarekha at study site. Outcrop of doleritic dyke is aligned east-west across the river atop which potholes are sculpted. Dolerite substrate are characterized by vertical cross joints and cracks which facilitated potholes formation.

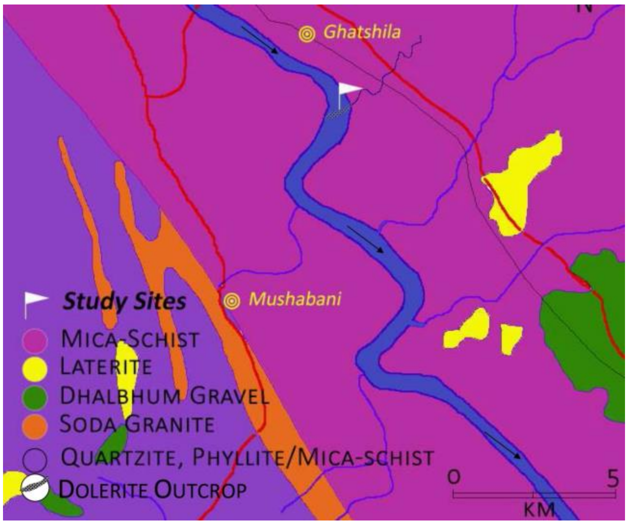

Fig. 5 Geological setup of the study area

MATERIALS AND METHODS

First of all, 34 potholes (more than 80% of the population of the study site) were selected randomly. Then those were numbered serially to avoid overlaping and gaping. Then diameters and depths of potholes were recorded (Fig. 6). Potholes with collapsed walls were not selected because it made difficulty in measuring their dimensions.

As materials for this study are data on different variables of largest grinding stone stored in potholes, Long axis (L) intermediate axis (I) and short axis (S) of stone (Fig. 1); volume, shape, weight, flatness and sphericity of largest grinding stone was recorded from each of the 34 potholes. Weight was measured by electronic balances of 1.0g to 500.0g and 100.0g to 15000.0g. Volumes were measured diping the stone into water and collecting the replaced water by stone in a graduated jar which gives volume of the stone directly. Absorption of water by dry stone affects volume of replaced water. So dry stones were first dipped into water before puting it into water of measuring device. Shape of stones are explained in terms of sphericity and flatness and measured using formulas of Krumbein (1941 a,b) and Cailleux (1945) respectively.

Sphericity (ψ) of the largest grinding stone was determined using the formula by Krumbein (1941). Higher the value ofψ, more spherical is the stone.

$$\psi = \sqrt[3]{(IS/L^2)} \qquad (8)$$

Using ratio of intermediate axis (I) to long axis (L) and short axis (S) to intermediate axis (I) stones were classified (Zingg, 1935) into different sphericity classes.

Cailleux (1945) developed the flatness index ($\mathbb{F}$) based upon the relationship between the particle dimensions along the three principal axes. The index is given by

$$\mathbb{F} = \frac{L+I}{2S} \qquad (9)$$

Theoretically, lowest value is 1.0, the higher the value more flat is the stone. The measure is opposite to the sphericity index. If sphericity of stones is greater, its flatness is less and vice versa. Roughness of pothole stones is the degree of irregularities in shape. It has opposit notion of sphericity. Roughness of stoness was measured using formula $R = \frac{L-S}{L}$. (10)

Fig. 6 A. Pothole where depth is greater when comparing to aparture diameter. B. Dimensions measured with the help of a specially devised instrument. C. Weight measurement of grinding stones D. Pothole almost full of stones quoted with mosses.

Out of the largest 34 grinding stones found in 34 potholes, the largest (amongst the 34 largests) was of diameter 19.89 cm. The stone was rounded and logically assumed that it was entrained by river velocity and was in abrasive action for pothole growth. Entrainment velocity ($1.5\ m^{-s}$) for that largest stone was taken from Hjulstrom's curve (1935). Then forces applied by that given velocity 'v' (v = velocity $1.5\ m^{-s}$ needed to entrain largest D=19.89cm of the 34 grinding stones was derived from Pjulstrom curve) on surface area 'A' (of all other grinding stones) perpendicular to flow direction (although all the points of the surface is not perpendicular) was calculated using equation No. 3.

RESULTS AND DISCUSSION

Potholes

Depths of potholes were from 17cm to 147cm. Average depth was 55.32cm and coefficient of variation of depth was 56.08. Out of 34 potholes, 16 potholes had depths less than 0.5 meters and rest 18 potholes had depths from 0.5 meters to 1.47 meters. Volume of potholes were from $0.005m^3$ to $1.672m^3$. Average volume of 34 potholes was $0.22\ m^3$. Median volume was found $0.081m^3$. 30 potholes had volume less than $0.5\ m^3$ and only 4 potholes had volume above $0.5m^3$. Only one pothole had its volume more than $1.0\ m^3$ and it was $1.672m^3$.

Size, weight and shape of largest stones

Average size (volume) of 34 grinding stones is 1991.28 cm^3. The largest one is of 7873.60 cm^3 and the smallest one is of 83.64 cm^3. The greatest weight of stones (12096 g) does not correspond to the largest size of stone. Lowest weight of stones was recorded 83.3 g and average weight was 2950.48 g. There is a very strong correlation ($R^2 = 0.94$) between stones size and stones weight which indicates homogeneity of stones composition. There are two distinct clusters of stones (Fig. 6): one group of relatively smaller size and light weight having compact association. Perhaps these stones are working for a longer period within potholes and have got more sphericity ($\psi = 0.66$ to 0.88) in shape. Another group of five stones of larger size and heavy weight have relatively dispersed association. This is because larger stones may be the collapsed blocks of the pothole wall and have not experienced long abrasive action to be spherical ($\psi = 0.46$ to 0.62). Moreover, the larger five stones were of varying parent rocks (Dolerite-1, Quartzite-2, Schist-1, Granite-1).

Sphericity (ψ) indicates how long the stone was involved in pothole formation. Longer period the stone is engaged in abrasion of pothols, the stone is more spherical. Sphericity of stones ranges from 0.46 to 0.88. Most irregular stones with low sphericity were found in breached potholes (Richardson and Carling, 2005). Out of 34 grinding stones, 38.24% stones were found to be oblate shaped (Fig. 8), 26.47% stones were recorded as spherical while 23.53% and 11.76% were prolate and blade shaped respectively. Standerd deviation (SD) of ψ of 34 stones was 0.08 and coefficient of variation (CV) was 11.28 %. These imply that there was no significant variation in shape of the largest grinding stones of 34 potholes.

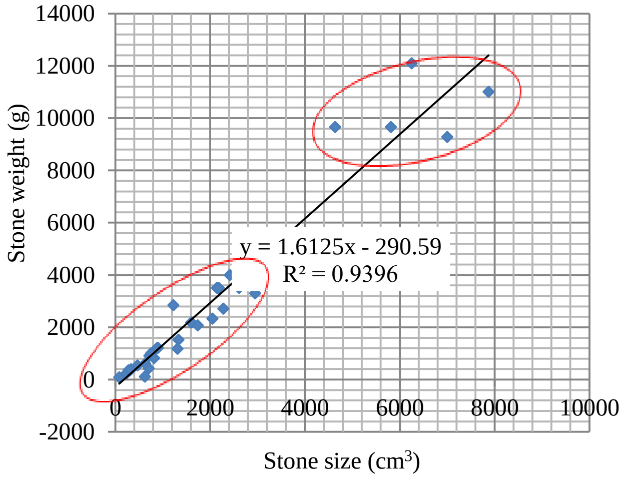

Fig.7 Relationship between stone size and weight: stone size and weight shows a strong correlation with a distinct variation between two clusters

Roughness varied from 0.78 to 0.17. Average roughness of stones was 0.50. Out of total, 25 % of observation have roughness less than 0.45. Half of the observations have roughness value less than 0.52 and 75% of the distribution have roughness value less than 0.55. Out of 34 grinding stones, 14 stones had roughness of <0.5 and rest 20 stones had roughness >0.5. Flatness and roughness of stones came from original shape of the clast and differential rate of abrasion. But long grinding reduced flatness of stones. Highest and lowest flatness were found 3.36 and 1.10 respectively with an average of 1.81. Sphericity (ψ) and flatness ($\mathbb{F}$) are opposit consideration about stones shape (Fig. 9) and finding of present study illuminate relation between them which is expressed as $\mathbb{F} = 0.989\psi^{-1.59}$ ($R^2 = 0.78$).

Sphericity and flatness of grinding stones are inversely related to each other. More flat the stone less force is applied on it when velocity is constant.

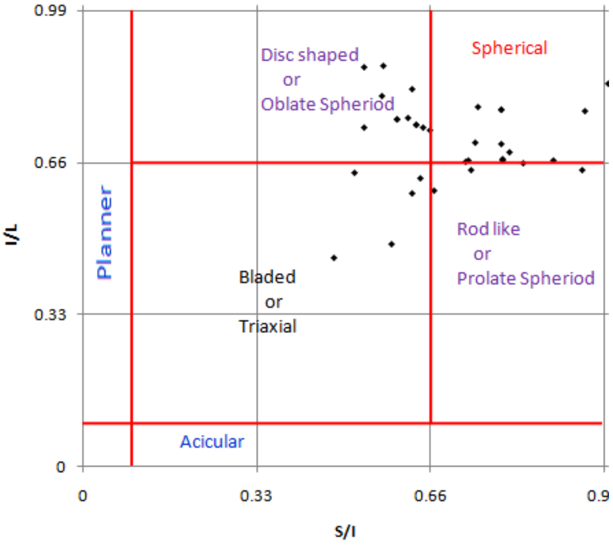

Fig. 8 Classification of the largest stones according to their sphericity (After Zingg, 1935)

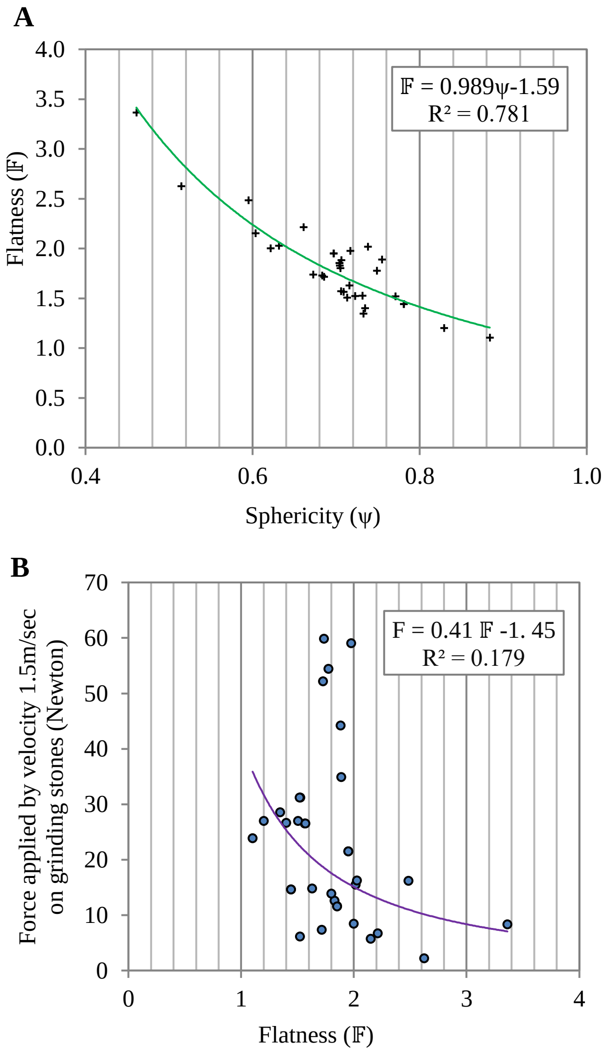

Fig. 9 Relationship between sphericity and flatness of grinding stones (A), relationship between flatness and the applied force by velocity (B)

Controls on stones shape

It was found that with increasing depth/radius ratio (γ) of pothole, sphericity of stones increased. It means that potholes with more depth were associated with more smoother or spherical stones. It happened because episodically entrained stones entrapped in potholes abrade atop floors years after years to increase γ . As a result gradually they became spherical. But bottom shear stress (τ_b) decreased rapidly beyond depth/radius ratio $\gamma \sim 2$. Stones size and shape control amount of force (F) to be applied on them by moving water. It was found that larger the grinding stone more was the force applied on it ($R^2 = 0.98$) and vice versa (Fig. 10A). Forces applied on stones are proportional to sphericity (ψ) and expressed in power relation as $F = 0.59\psi^{3.25}$. On the contrary, higher the flatness lower was the forces applied on stones (Fig. 10B).

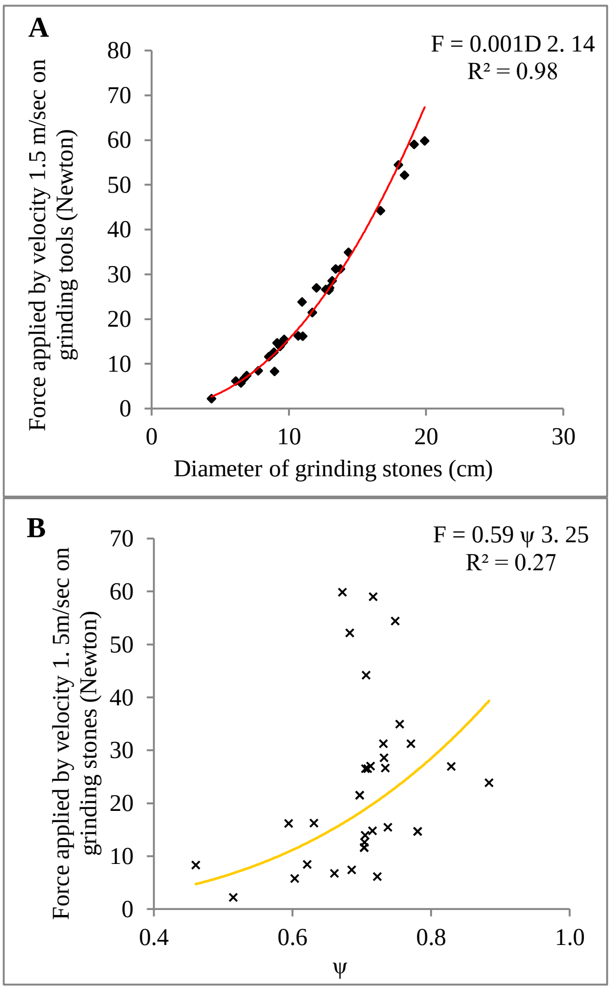

Fig. 10 Relationship between the force applied on a grinding stones and (A) size and (B) sphericity

Flow depth is also important for the process of abrasion work by stones and growth of a pothole and shapes of stones itself. With given channel slope (e.g.~ 10^{-1} m/m) flow depth required for the growth of a pothole is approximately equal to the diameter of the pothole (Pelletier et al., 2014). Data for this study were collected from 34 potholes not within bed of the river in true sense but atop a wide doleritic dyke (well above the river bed). That is why, frequency of necessary flow depth for pothole growth is annual when the dyke is over topped by the peak flow of rainy season. Moreover, Galudih barrage (completed in 1954) at 12.9 km upstream diverts a considerable share of the flow through irrigation canal. As a result discharge can not overflow onto normally dry doleritic dyke and stones in potholes remains idle for years to gather moss on them (Fig. 6D).

The largest grinding stone and potholes growth

The R^2between potholes size and stones size was much less (0.17) than R^2 between potholes size and stones weight (0.25). Yet, larger the pothole, larger and heavier was the largest grinding stone (Fig. 11). But present study does not confirm the finding of Pelletier et al. (2014) that 'pothole depths increase in proportion to the diameter of the largest clasts episodically stored in potholes'.

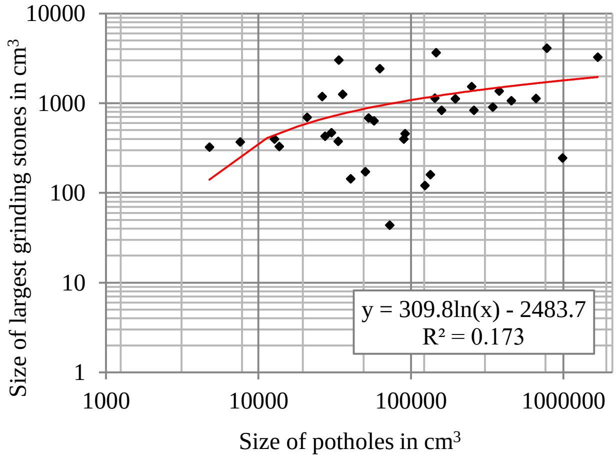

Fig. 11 Relationship between diameter of largest grinding stone and the size of potholes

Absence of convex floor in all potholes indicate the active role of largest grinding stone which abrade atop floor instead of protecting it. So sufficient eddy velocity was there to entrain the largest stones and abrade atop potholes floor. Considering stream velocity 1.5m^{-s} needed for entrainment of the grinding stone of diameter 19.89cm (largest among 34 stones), forces applied on grinding stones were calculated using equation (3). Average force applied on stone was 23.02 N (Newtons) with SD 15.65 avd CV 67.96%. Low variation in ψ and higher variation in applied force indicate that size of the largest stone is not proportional to pothole depths.

CONCLUSION

Grinding stones in potholes are important component of channel incision, as the largest grinding stone has significant control on pothole growth. Largest grinding stone made all the pothole floors concave by abrading atop it. The largest grinders found in potholes cluster of same locality were of same composition which was expressed in strong correlation between stone's size and weight. Diversion of flow by artificial efforts reduced discharge through channel and interfered adversely the natural fluvial environment. Grinding stones in potholes were left idle and mosses gathered on those unrolling stones. Very few grinding stones in potholes are spherical in shape. Drag force applied on the largest grinding stone and their entrainment velocity depends considerably upon their shapes. Therefore, to have an insight into the hydraulics and processes operating within potholes, size and shape of largest grinding stone may be considered as an instrument. This new insight into pothole dynamics will enable better understanding process-form feedbacks in bedrock channel.

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