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SEDIMENTOLOGICAL CHARACTERISTICS OF GRAVELS ON REFRESHED GRAVEL BAR BY TYPHOON 1721 IN THE MIDDLE OF THE TAMA RIVER, CENTRAL JAPAN

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Abstract A gravelly point bar enlarged by Typhoon 1721 on October 23, 2017 in the middle Tama River, central Japan was investigated. The authors reported the topographical characteristics (reliefs of chute flow cutting across a point bar) and the tendency of grain size distribution along a survey line that was set perpendicular to the usual river flow direction from the river channel. The gravel bar was divided into the usual (low) riverbed, which was composed mainly of boulder–cobble-sized clasts and the high-water level (high) riverbed composed mainly of pebbles, and regularly arranged 2-dimensional (2D) dunes composed mainly of pebbles were observed on the edge of the high-water level riverbed. Additionally, the authors focused on roundness as one of the common shape parameters of gravel to discuss the representative value of gravel shape in the gravel bar. At each of the five sites selected along the survey line, cobble-sized (64–128 mm in diameter) and pebble-sized (16–32 mm in diameter) sandstones, which are the major rock type in the Tama River basin, were obtained, and the roundness of the gravel was measured. On the usual riverbed, cobbles were more rounded than pebbles, while the average roundness of cobbles on the high-water level riverbed were almost similar to that of the pebbles. Based on the tendency of coarser grains to be more rounded than finer grains, it might be concluded that the breaking and abrasion mechanisms acting on the gravel and transport process of pebble-sized clasts have differed between the two riverbeds. Therefore, the representative roundness of gravels measured at usual riverbed can be obtained in a gravel bar.

Keywords: gravel, roundness, 2-dimensional (2D) dune, Typhoon 1721, the Tama River

1. Introduction

Fluvial clastic sediment has been studied to evaluate the geomorphological and sedimentological characteristics of rivers. For example, studies have discussed river gradients based on the decrease in grain size, like downstream fining (e.g., Yatsu 1955; Ikeda 1970), grain transportation based on the relationship between grain size and shape (e.g., Sneed and Folk 1958; Nakayama and Miura 1964), and the relationship between grain size and rock type (e.g., Kodama 1994). It is important to note that field survey of many studies occurred on gravel bars, which are created and/or refreshed by flooding. In other words, the researchers observed the clastic sediments transported by flooding and reliefs on the gravel bar (e.g., current dunes and ripples) set by the

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sediments. As time advances, the deposits move and the reliefs become deformed due to rain, wind, bioturbation, human activity, and so on. To gain accurate information, i.e. geomorphological and/or sedimentological characteristics of a river, it is important to research the refreshed bar immediately after flooding.

In this study, the authors report the reliefs observed on a gravel bar in the middle Tama River that was refreshed by Typhoon 1721 on October 23, 2017, and discussed the relationship between the reliefs in the gravel bar and roundness of clastic sediment. It is well-known that particle size varies broadly depending on the survey point in a gravel bar, such as the top or side of the dune, or bottom or side of a chute channel that cuts across the point bar (e.g., Suzuki 2015). However, it is insufficient to investigate the variation of particle shape such as roundness, one of the common shape parameters, depending on its topographic position in a gravel bar. Estimating "representative value" of roundness on a gravel bar, it becomes possible to more accurately discuss relationship between grain shape and grain transportation.

2. Study Area

Geographical and geological settings of the Tama River

The Tama River is 138 km long with a drainage basin area of 1,240 km^2. It originates in Mt. Kasatoriyama (1,953 m a.s.l.) in the Kanto mountainous region, central Japan, and flows into the Kanto Plain at Ome City, Tokyo Metropolis and runs along the southwestern side of Musashino Upland to Tokyo Bay (Fig. 1). The Musashino upland formed by the paleo-Tama River are fluvial terraces (e.g., Juen 1965). Lake Okutama (Ogochi Dam) is located on the border between Tokyo Metropolis and Yamanashi Prefecture, and it collects approximately 1,200–1,600 mm of precipitation annually (A.D. 2012–2017; Ministry of Land, Infrastructure, Transport and Tourism 2019). Generally, the upstream of the Ogochi Dam is referred to as the Taba River and the downstream is called the Tama River.

The geological map of the region is shown in Fig. 1c. There are 15–7 Ma plutonic rocks (granitoids) distributed near the source of the Tama (Taba) River. Clastic rocks (sandstone, shale, and alternating sandstone and mudstone) and cherts with partially basalt and limestone blocks as the Cretaceous to Paleogene Shimanto Belt has been distributed from the source to the Ogochi Dam. Shales and cherts with partial sandstones, basalts, and limestones as the Jurassic to Cretaceous southern Chichibu belt has been distributed on the eastern side of the Ogochi Groups in Shimanto Belt. As a result, sandstone is the major component of the gravel bars in the Tama River.

Typhoon 1721 around the Tama River Watershed

Typhoon 1721 (international name: Typhoon Lan) made landfall near Kakegawa City, Shizuoka Prefecture, central Japan at 3 am on October 23, 2017, and then hit the Kanto region with storms (Japan Meteorological Agency 2019). It caused a large amount of rainfall in the Okutama area in the western part of Tokyo Metropolis, the source of the Tama River. Between 0 am and 5 am on October 23, rainfall of 12.0–22.0 mm/hour was observed at Ogochi Dam (Ministry of Land, Infrastructure, Transport and Tourism 2019). At the Chofu Bridge in Nagabuchi, eastern Ome City (Fig. 1c), the water level rose by approximately 2 m between 6 am and 7 am (Ministry of Land, Infrastructure, Transport and Tourism 2019). A submerged gravel bar at the Miyanoshita Sports Park in Hamura City, approximately 5.5 km downstream from the Chofu Bridge, which is the study site, had been obversed at 4 pm on October 23 (Fig. 2a). The water level change in the Tama River basin

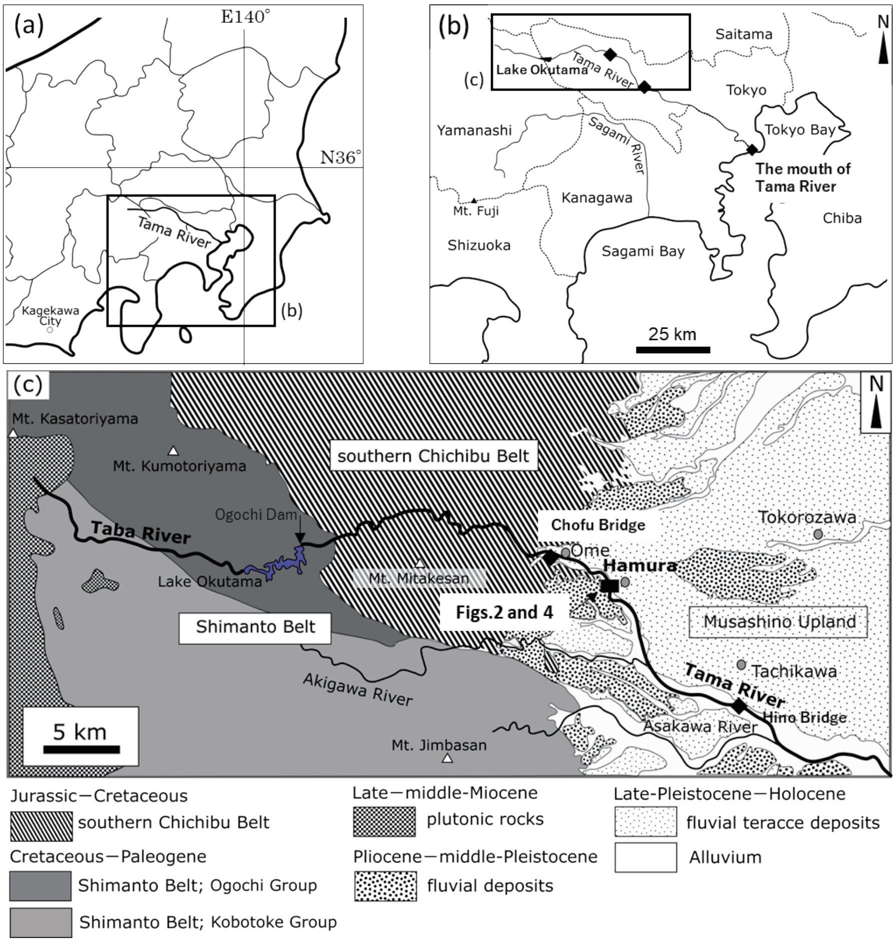

Fig. 1 (a) Index map. (b) Location map of the Tama and Sagami rivers.
(c) Geological map. Modified from Utsugawa (2019).
Black diamonds indicate the locality of water level observation stations.

mainly tends to rise due to the typhoon from summer to autumn (Fig. 3).

Sampling site

The authors focused on a gravelly point bar located at the Miyanoshita Sports Park in Hamura City (Figs. 2 and 4), which is located 55 km upstream from the mouth of the Tama River. This site is upstream of the Hamura intake weir, which is the entrance of Tamagawa Josui water supply (Fig. 4). On the opposite side, there is the Kusabana Hills (Fig. 4) composed of gravels derived from the paleo-Tama River deposited 2.5 Ma (Ueki 2006). However, it could be mentioned that the amount of gravel supplied from the hills is a minor component compared to the one transported from upstream because of the bank protection. Along the gravelly point bar, the half that is farthest away from the river channel is used as the Miyanoshita Sports Park, while the half closest to the river channel is a gravel bar that is partially covered by vegetation (Fig. 2b). The half closest to the river channel was submerged as a result of Typhoon 1721 (Fig. 2a).

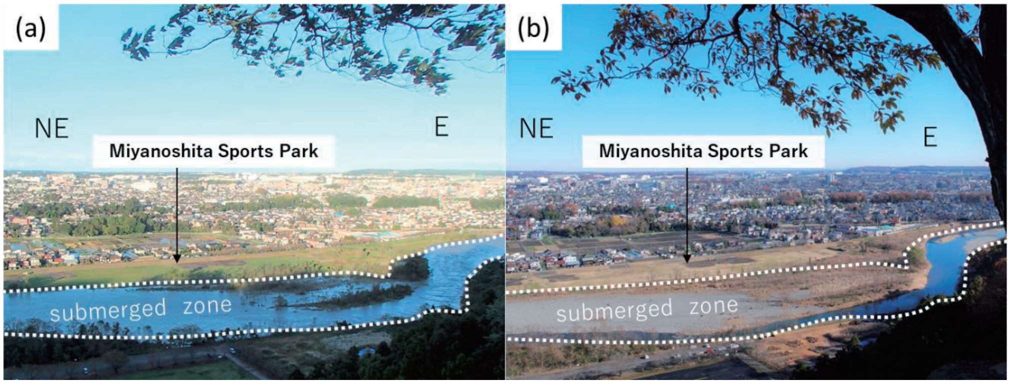

Fig. 2 Photographs of the area surrounding the Miyanoshita Sports Park in Hamura City. (a) October 23, 2017 (taken by Ms. Kato, S.). (b) December 6, 2017.

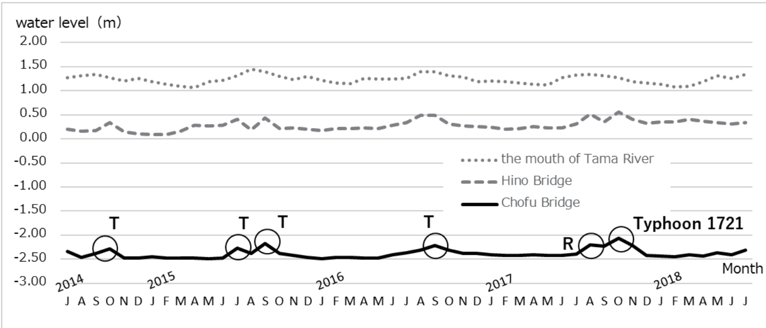

Fig. 3 Monthly average of water level of the Tama River from July 1, 2014 to July 31, 2018. T: typhoon, R: torrential rain. Water level is the water surface level from watermark (0 m) at each observation station (Fig. 1). Data from Ministry of Land, Infrastructure, Transport and Tourism (2019). Modified from Utsugawa (2019).

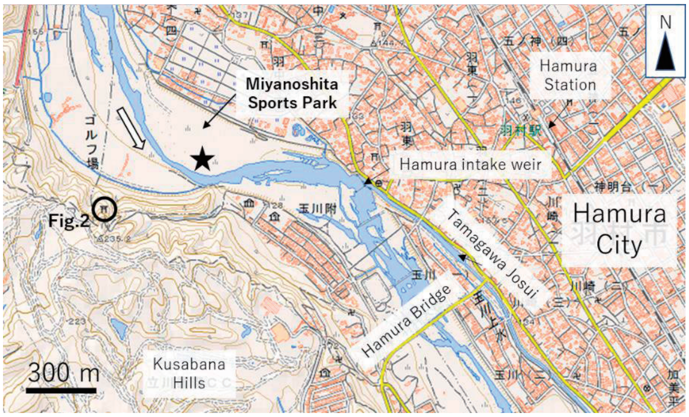

Fig. 4 Sampling site (star). Data from the Geospatial Information Authority of Japan. Circle and white arrow indicate the photo site of Fig. 2 and the flow direction of the Tama River, respectively.

3. Methods

Parameter selection: Roundness

Fluvial clastic sediment grains experience alternating angulation and rounding; ultimately, they are rounded during the transport process. Roundness, one of common shape parameters that evaluates the smoothness of a particle's outline, has been utilized to estimate the depositional environment (e.g., Beal and Shepard 1956; Suzuki *et al.* 2015) and transport–depositional processes (e.g., Wentworth 1919; McBride and Picard 1987) of gravel–sand-sized grains. Roundness depends on rock type, its durability, and grain size (Utsugawa and Shirai 2019); therefore, the authors focused on two representative size fractions of cobble (64–128 mm in long axis) and pebble (16–32 mm in long axis) of sandstone, one of the dominant rock types. In this paper, the authors adopted the most usual roundness (range: 0 to 1) as defined by Wadell (1932).

Field Survey

On October 26, 2017 (three days after the typhoon), the authors surveyed the topography of riverbed utilizing hand level and measuring tape, and obtained cobbles and pebbles of sandstone in the Miyanoshita Sports Park described above. At the gravel bar, a line was set perpendicular to the usual river flow direction from near the river, and five sampling sites (A, B, C, D, E) were selected along the line, taking into consideration the distance from the river flow, the difference of height from the water surface, and the sediment components of the riverbed surface (Fig. 5a). At each site, approximately 50–55 gravels of each size fraction (64–128 mm and 16–32 mm in long axis) were randomly extracted from a 1 m × 1 m square along the line; each sample was then measured along three axes and evaluated for roundness using the Krumbein roundness chart (Krumbein 1941). The flow diagram supporting the roundness measurement based on the Krumbein roundness chart (Utsugawa and Shirai 2016) was used subsidiary.

4. Results and Discussion

Gravel Deposition on the Gravel Bar

The transverse profile of the gravel bar in this study is illustrated in Fig. 5a. The gravel bar was divided into the usual (low) riverbed and high-water level riverbed connected by a 17 m wide slope. Sites A and B were set on the usual riverbed, site C was set on the slope between the usual and high-water level riverbed (Fig. 5b), and sites D and E were set on the high-water level riverbed.

Site A was closest to the usual river flow (Figs. 6a and 6f). Boulders (maximum: 40 cm in long axis) and cobbles were mainly deposited with sand and granule grains in this site. Site B was second closest to the river flow after Site A (Figs. 6b and 6g). Cobbles and pebbles were deposited with sand and granule grains in this site. At Site C (Figs. 6c and 6h), many pebbles and some cobbles were deposited on sand and granule-sized grains. Site D was on the edge of the high-water level riverbed (Figs. 6d and 6i). Many coarse pebbles and some cobbles were deposited with granules to fine pebbles in this site. Regularly (approximately 1 m interval) arranged wave reliefs composed mainly of pebbles were observed. Site E was farthest from usual river flow (Figs. 6e and 6j). Pebbles were deposited with silt in this site.

The NE-SW elongated (perpendicular to the usual river flow direction) gravel wave reliefs with width of 4–5 m observed at the Site D, the size of the relief was almost 4 to 5 m in width, 1 m in

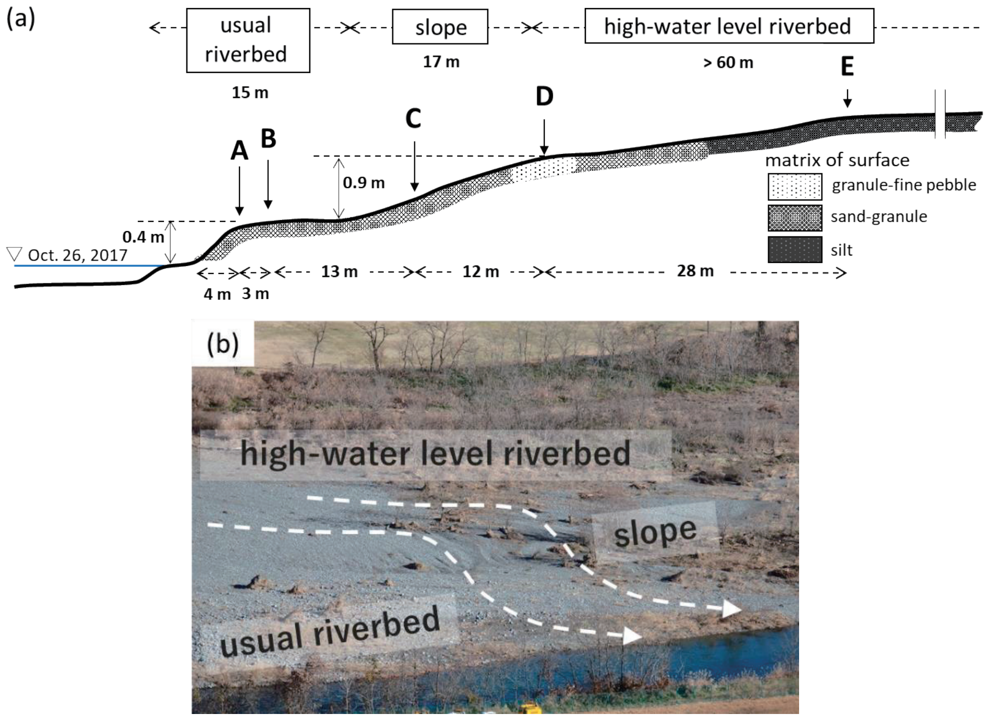

Fig. 5 (a) Scheme of traverse profile, perpendicular to the usual river flow direction.
(b) Photograph of investigated gravel bar. White broken arrows indicate the chute flow.

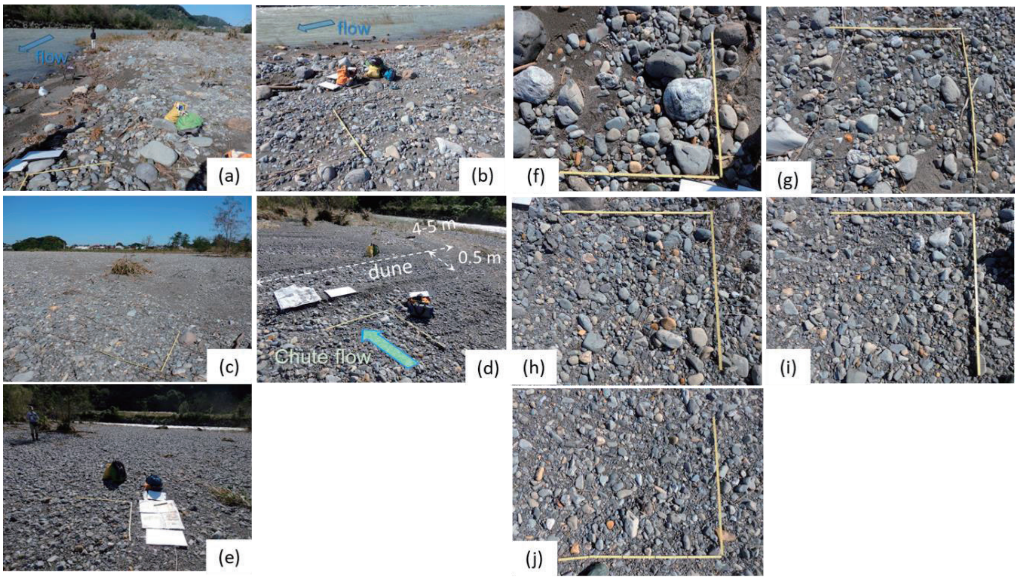

Fig. 6 Photographs of sampling sites. Arrows indicate the direction of flow.
(a) Site A. (b) Site B. (c) Site C. (d) Site D. (e) Site E.
Measured 1 m × 1 m quadrat of (f) Site A, (g) Site B, (h) Site C, (i) Site D, (j) Site E.

Table 1 Roundness of cobble and pebble

(a) cobble (64-128 mm)

	A	B	C	D	E
n	50	50	51	50	50
average	0.58	0.58	0.54	0.55	0.57
stdev	0.12	0.12	0.12	0.09	0.12
median	0.60	0.60	0.50	0.50	0.60

(b) pebble (16-32 mm)

	A	B	C	D	E
n	55	53	54	55	53
average	0.53	0.52	0.57	0.55	0.57
stdev	0.14	0.11	0.14	0.12	0.11
median	0.50	0.50	0.60	0.60	0.60

A, B, C, D, E: sampling sites. n: number of measured gravels.

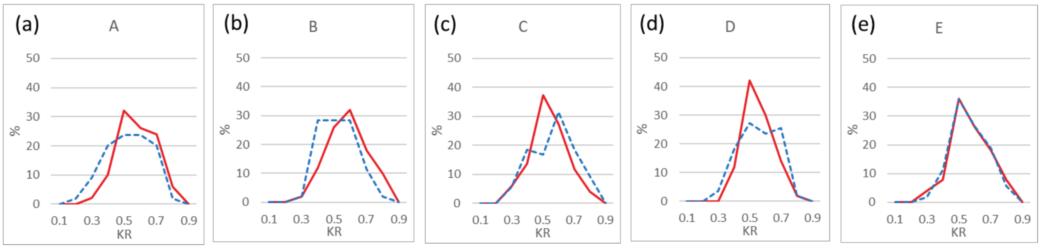

Fig. 7 Histogram charts of Krumbein Roundness (KR).
(a) Site A. (b) Site B. (c) Site C. (d) Site D. (e) Site E.
Red line and blue dotted line indicate cobble and pebble of roundness, respectively.

wavelength, and almost 10 to 20 cm in amplitude. Asymmetric combinations of the gentle stoss (upstream) side and the lee (downstream) side formed by current flow were observed in these reliefs, hence these were recognized 2-dimensional (2D) dune characterized by transverse arrangement of straight crests and troughs. The direction of long axis of pebbles deposited in troughs tends to perpendicular to the 2D-dune crest (Fig. 6i). Ultimately, the chute may be flowed along the troughs of the 2D-dune from the high-water level (high) riverbed to usual (low) riverbed during the late-waning phase.

Representative value of roundness in a gravel bar

The roundness measured at each site is shown in Table 1 and Fig. 7. The average roundness of cobbles was 0.54–0.60 and the average roundness of pebbles was 0.52–0.57; in other words, sub-rounded gravels mainly deposited on the investigated gravel bar. At sites A and B near the river (i.e. on the usual riverbed), cobbles were more rounded than pebbles focusing on the average roundness (cobble: 0.58, pebble: 0.52–0.53), median (cobble: 0.60, pebble: 0.50), and the mode and distribution of roundness histograms (Figs. 7a and 7b). This tendency is obvious as compare to sites C to E (Figs. 7c, 7d and 7e).

Studies have indicated that coarse gravels are more likely to become rounded (abraded) in fluvial transportation than fine gravels (e.g., Utsugawa and Shirai 2019). Our findings on the usual riverbed were consistent with this tendency, while our findings on the high-water level riverbed differed. The similar roundness values of cobbles and pebbles on the high-water level riverbed may imply that transportation of gravels ceased abruptly at the waning phase of the flood, whereas, on the usual riverbed, pebbles may have been transported and collided actively during the waning phase. Similar findings were illustrated in Shirai *et al.* (2018), which examined tuff pebbles (32–64 mm in long axis) in the middle of the Sagami River, Kanagawa Prefecture. The roundness of gravels obtained on the high-water level riverbed and on the reliefs (dunes) differed from those obtained on and near the usual riverbed.

Therefore, the representative roundness value of gravels in a fluvial gravel bed can be obtained by measuring gravel on a usual riverbed taking account of constancy of roundness from immediately after flood to usual water condition. It is important to investigate the changes in roundness value in a gravel bar over time, especially when the usual riverbed is frequently swollen.

5. Conclusion

The reliefs observed on the gravel bar of the Tama River affected by a typhoon in October 23, 2017 were reported. The gravel bar was divided into low (usual) and high (high-water level) riverbeds. 2D dune-shaped gravel deposits were observed on the edge of the high-water level riverbed.

It was indicated that the shape of gravel tends to depend on reliefs on the gravel bar. On the high-water level riverbed, it is considered that transportation of gravels have ceased abruptly at the waning phase of the flood, whereas, on the usual riverbed, the transportation and collision of pebbles may have occurred during the waning phase. As a result, breaking and abrasion mechanisms acting on gravels may have differed between the usual riverbed and the high-water level riverbed. Therefore, the representative roundness value of gravels measured at the usual riverbed can be reliably obtained in a gravel bar, hence it is concluded that when comparing roundness of gravels from upstream to downstream at sites along a river, it is desirable to conduct surveys on a usual riverbed including the egde of water.

The gravel bar surveyed in this study was swept away by Typhoon 1919 on October 12, 2019, when the water level rose higher than during Typhoon 1721. As a result, more substantial sediment relocation occurred, the grain size distribution in the gravel bar changed substantially, and various sizes of 2D dunes were formed. These observations will be reported in another paper.

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