1版

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科学研究費助成事業　　研究成果報告書

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研究課題名（和文）Analysis of morphodynamic evolution in a meandering estuarine channel in the context of climate change

研究課題名（英文）Analysis of morphodynamic evolution in a meandering estuarine channel in the context of climate change

研究代表者

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交付決定額（研究期間全体）：（直接経費）　　3,200,000円

研究成果の概要（和文）：河口域は乾季に潮汐による土砂輸送によって堆積した。洪水期の強い洪水によってこれらの泥の堆積物が浸食され、河道の容積は急速に増加した。河床高は洪水後の季節に再び上昇し、次の洪水まで続く。河口部の形態は、季節的なスケールで見ると、乾季には堆積傾向、洪水期には浸食傾向を示した。長期的なスケール（1953-2022年）では、調査期間を3つに分けた：1)人間活動の期間、2)人間活動も災害もない期間、3)気候災害の期間。P1では、大規模な人間活動により河床が低下した。P2では、河床高が0.5～1m上昇した（強い洪水が発生しなかった）。P3では、大洪水が河口の泥堆積物を浸食したため、河床高が低下した。

研究成果の学術的意義や社会的意義
The study describes the long-term and seasonal changes in estuarine morphology, considering the effects of human activities, tidal forcing, and climate disasters; which can help to plan and manage the water environment suitably and minimize the impact of climate change on biodiversity and wildlife.

研究成果の概要（英文）：The estuarine channel experienced deposition by the tidal sediment transport during the dry season. The channel volume rapidly increased due to the erosion of these mud deposits by the strong flood in the flood season. The bed elevation rises again during the post-flood season by the tides and continues until the next flood. Hence, the estuarine morphology showed a deposition trend during the dry season and an erosion trend during the flood season on a seasonal scale. On a long-term scale, the study period (P) was divided into 3: the period of 1) human activities (1953-1998), 2) no human activities and no disasters (1998-2003) and 3) climate disasters (2003-2022). During P1, the riverbed was lowered due to extensive human activities (dredging, sand mining, etc). During P2, the bed elevation increased by 0.5-1m by the tidal influence (absence of strong flood events). During P3, the bed elevation decreased as extreme flood disasters eroded the sediment deposited upstream of the estuary.

研究分野：Hydraulics and water resources

キーワード：Chikugo River estuary　Sediment transport　Erosion　Human activities　Climate disasters　Morphological change　Long-term scale　Seasonal scale

１．研究開始当初の背景

Estuaries are important regions locally as well as internationally due to their high commercial, recreational, and ecological values. The estuarine turbidity maximum (ETM) zones located at the salt front in the upper reaches of estuaries are an important nursery ground for many fish and shellfish communities. Generally, the sediment imports to this ETM by tides during the dry season and sediment exports by the river discharge during the flood season maintain a dynamic equilibrium condition on an annual scale. This controls the morphology of the riverbed and will have a significant impact on the coastal and estuarine environments. For example, the sediment deposition will reduce the water depth, which will further lead to a reduction in flood carrying capacity, difficulties in navigation and fishing, etc. In addition, the organic-rich cohesive sediments deposited at the ETM zone supply huge amounts of nutrients to the organisms and habitats in estuaries.

In recent years, increasing attention has been paid to the changes in estuarine environments driven by climate change disasters and human actions. Climate change disasters and human actions will have the potential to cause changes in coastal and estuarine morphology in a number of ways and thereby influence the ecology of estuarine-dependent organisms. The sediment dynamics of the estuaries have been threatened by human interventions such as dam impoundment, sand and gravel mining, and river training dikes or embankments. Further, one extreme flood can also change the estuarine morphology dramatically in a short period of time. Therefore, an insight into the estuarine morphodynamic processes in the context of climate change and human interventions is essential for better planning and management options for adaptation measures. However, the existing methods to assess the impact of climate change across an estuary are highly simplified or lack site-specific detail. The exact extent of that change is still largely unknown and requires detailed scientific analysis. Further research on estuarine morphodynamic processes using detailed field surveys and long-term historical data is needed to explain the exact impact of climate change on estuaries.

２．研究の目的

- To determine the (i) short-term morphological changes on a seasonal scale in an estuarine channel influenced by both tidal and river forcing.
- To determine the long-term morphological changes in an estuarine channel influenced by (ii) past human activities and (iii) recent climate change disasters.

３．研究の方法

Target Area

The target area, the Chikugo River estuary in Japan, is a macro tidal estuary with a tidal range of 1.5 m during neap tide and 5 m during spring tide. The muddy brackish water area (the ETM zone) in the upper reaches of the estuary is an important nursery ground for many continental-relict fishes. Due to its rich in water resources and high productivity, the Chikugo River estuary has been playing an important role not only for the people in surrounding prefectures but also for the major food web of Japan, especially “Etsu” (Coilia Nasus) that is found around the Ariake Sea in Japan. Further, the 23 km long estuary is strongly affected by the freshwater from the Chikugo River (mean dry discharge of 54 $m^3\ s^{-1}$ and mean annual storm discharge of 2,800 $m^3\ s^{-1}$) and high tidal range of the bay (5 m during spring tide and 1.5 m during neap tide). In addition, sand supply from the Chikugo River into the Ariake Sea is playing an important role in maintaining the sandy tidal flat of the Ariake Sea, the largest tidal flat in Japan in current days.

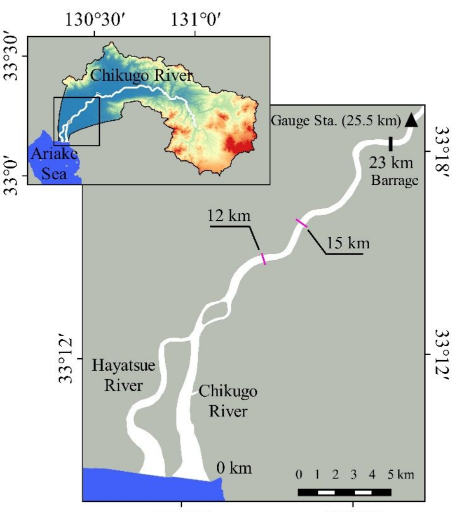

Fig. 1 Location map of study area.

Data Collection: Climatic factors and estuarine topography

The long-term (1953 to 2020) topographic data of cross-sections at 200 m intervals of the Chikugo River estuary (0-23 km) in almost every five-year interval were collected from the government. Further, detailed topographic surveys of 17 cross-sectional lines (at an interval of 100 to 200 m) and 5-6 longitudinal lines from 12 km to 14.6 km station were conducted during the project period. The long-term (1953-2021) river discharge data (in one-hour intervals) monitored at the Senoshita gauge station located in the freshwater region (25.5 km upstream from the river mouth) were collected from the Japanese Ministry of Land, Infrastructure, Transport, and Tourism. Further, the one-hour interval water level data (1984-2021) at 7 km and 14.6 km upstream from the river mouth were collected from the Japan Water Agency. The high-resolution water level data at the 13.1 km station was collected using a HOBO U20 water level logger during every detailed topographic survey for the bed elevation calculation.

Data Analysis:

The bed elevation was estimated from the collected acoustic image data and water level data (using HOBO U20 water level logger) and data. The mean bed elevation (MBE), the mean elevation of each transect between left and right banks, of each surveyed year was calculated and elevation changes of those years were determined (Fig. 2). Initially, the width of every cross-section to calculate the mean bed elevation was decided. Secondly, the area (Aj) of the cross-section was calculated using the trapezoidal formula.

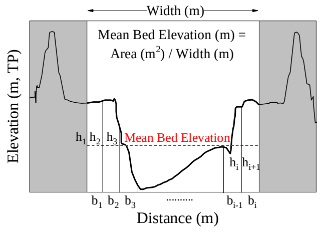

Fig.2 Calculation of mean bed elevation of the channel cross-section.

$$A_j = \frac{(h_i+h_{i+1})b_i}{2} \quad \text{(i=1,2,3…, j=1,2,3…)}$$

where, h_i and h_{i+1} mean the elevation of two consecutive points of a cross-section in meters, and bi represents the distance between two consecutive points of a section in meters. Then, the mean bed elevation was calculated by dividing the calculated area by the predefined width.

4．研究成果

Seasonal changes in estuarine morphology

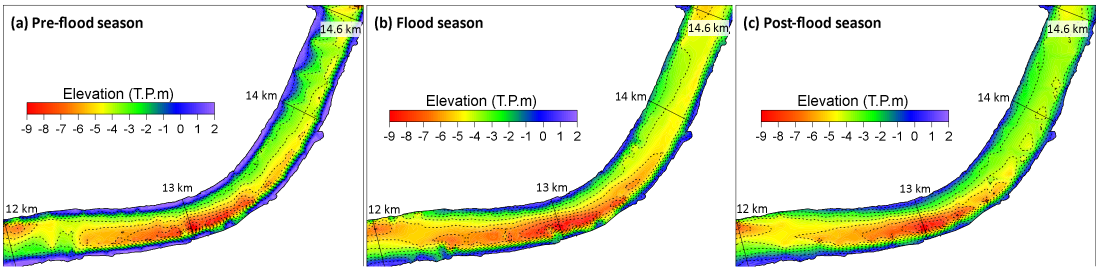

Fig. 3 The detailed riverbed topographic map of the meandering channel in the upstream section (12 to 14.6 km from the river mouth) before the flood, just after the flood, and a few months after the flood season.

Fig. 3 shows the detailed riverbed topographic map of the upstream meandering channel (12 km to 14.6 km upstream from the river mouth) of the Chikugo River estuary before the flood (29 July 2021), just after the flood (04 December 2021), and a few months after the flood season (03 March 2022). The estuarine channel experienced gradual deposition by the tide-induced upward sediment transport during the dry season of 2021, which resulted in a decrease in channel depth, especially in the inner part of the channel (Fig. 3a). The estuarine channel capacity rapidly increased due to the erosion of these mud deposits by the strong flood in 2021 that exported the sediment downstream (Fig. 3b). As a result of this, the estuarine channel becomes wider and deeper. The bed elevation rises again after the flood season by the tidal forcing and results in a decrease in channel capacity (Fig. 3c). This trend continues until the next flood season in 2022. This shows the topography of the estuarine channel maintains a dynamic equilibrium on a seasonal scale. This dynamic equilibrium on the seasonal changes in mean bed elevation at the 14 km station during 2005-2022 was evident in Fig. 4.

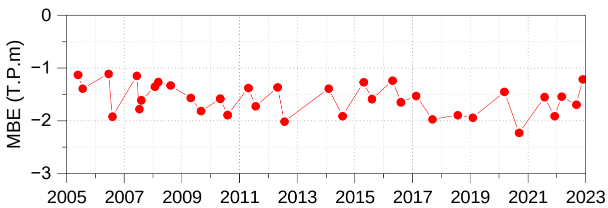

Fig. 4 Seasonal changes in mean bed elevation (MBE) at the 14 km station from 2005 to 2022.

Long-term changes in estuarine morphology

On a long-term basis, the study period (1953-2022) was divided into three periods based on the historical river improvement works, recent climate change disasters, and long-term river discharge trend (Fig. 5a): (1) the period of human activities (1953-1998), (2) the period of no human activities and no disasters (1998-2003), and (3) the period of recent climate disasters (2003-2022).

During period-1, the riverbed in the estuary was lowered due to extensive human activities such as dredging (flood control), land reclamation, sand mining, etc. (Fig. 5b). However, the bed elevation increased by 0.5-1 m during period-2, which was due to the tide-induced landward sediment transport and deposition process. During period-3, the bed elevation decreased as extreme flood disasters eroded the sediment deposited upstream of the estuary. Although the extreme floods and landslide disasters supplied massive sediments into the Chikugo River, it seemed that sediments supplied by disasters were trapped upstream of the river and were not enough to reach the estuary. The erosion of existing deposits and lack of sediment supply from the upstream caused the decrease in estuarine bed elevation during period-3.

Fig. 6 shows the longitudinal riverbed elevation profiles and elevation changes between two survey years during the three periods. From 1953 to 1979, the estuary experienced a significant decrease in elevation (~1.29 m) due to extensive human activities (Fig.6a1, b1). However, the decrease was less than 0.7 m from 1979 to 1990. For period-2, the average decrease in elevation from 1990 to 1998 was less than 0.14 m as the sediment extraction was weakened (Fig. 6a2, b2). The riverbed elevation of the estuary increased from 1998 to 2003, especially between 10-21 km, with an average value of 0.6 m. This means that the increase in elevation was related to sediment transported by tide from downstream. From 2003-2009, erosion was observed between 10-23 km with a value of 0.2-0.3 m. Those eroded sediments were supposed to be deposited between 0-10 km since the bed elevation between 0-10 km increased from 2003-2009. During period-3, the riverbed of the estuary was eroded with a maximum erosion depth of about 0.5 m from 2009 to 2014 and 0.8 m from 2014 to 2019 (Fig. 6a3, b3).

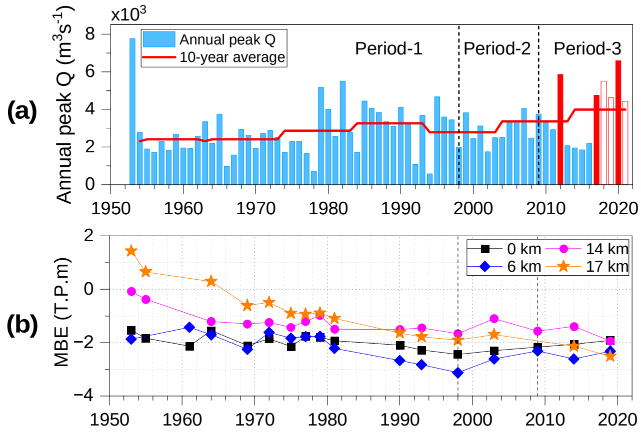

Fig. 5 (a) Annual maximum daily discharge measured at 25.5 km (red solid columns represent the years when recent disasters occurred and red outline columns represent the years of high river flow without disasters in recent years) and (b) temporal mean bed elevation (MBE) changes in the estuary.

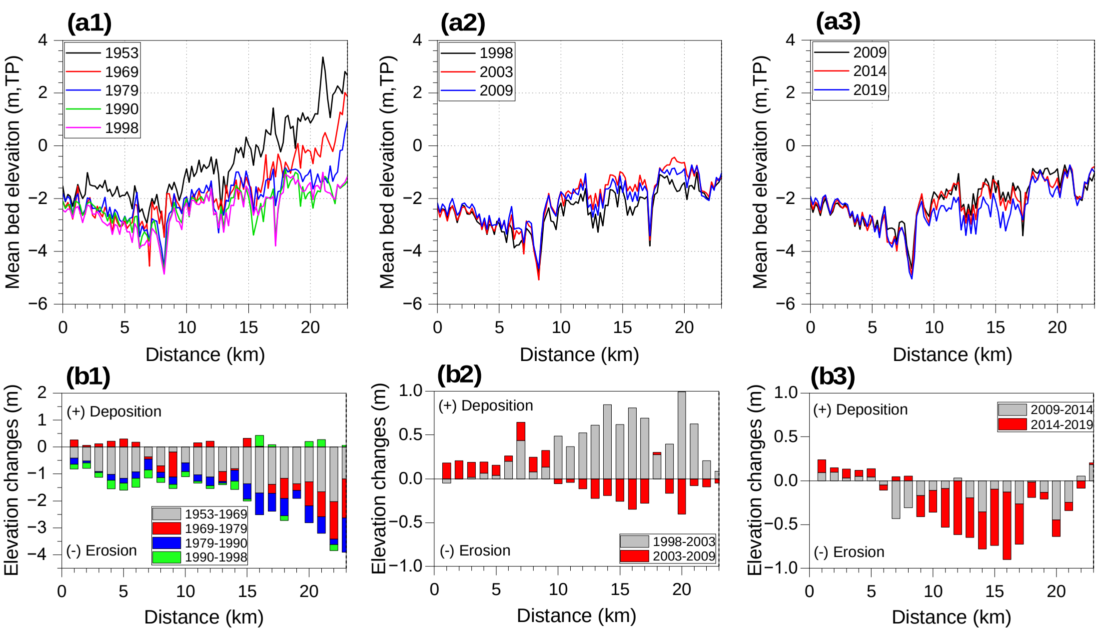

Fig. 6 (a) Longitudinal riverbed profile and (b) elevation changes between two surveys during the three periods of (1) Period-1, (2) Period-2, and (3) Period-3.

Therefore, the riverbed elevation of the estuarine channel showed a decreasing trend on a long-term scale, although the topography of the estuarine channel maintains a dynamic equilibrium on a seasonal scale. The study concludes that the riverbed morphology of the Chikugo River estuary is affected by both tidally induced sediment transport from downstream and an increase in river flow by recent disasters and human disturbances that were implemented in the past. The prediction of morphological changes in the estuarine channel using numerical simulation modeling can significantly aid in proposing a control technique to manage their water environment appropriately and to minimize the impact of climate change on biodiversity and wildlife. Currently, we are trying to find a suitable model for predicting the morphological changes of the estuarine channel using the measured data of water level (downstream), discharge (upstream), bed geometry, sediment characteristics, sediment volume, etc.

5．主な発表論文等

〔雑誌論文〕　計8件（うち査読付論文　8件／うち国際共著　7件／うちオープンアクセス　7件）

1．著者名	4．巻
Nwe Lett Wai、Yokoyama Katsuhide、Azhikodan Gubash	850
2．論文標題	5．発行年
Phytoplankton habitats and size distribution during a neap-spring transition in the highly turbid macrotidal Chikugo River estuary	2022年
3．雑誌名	6．最初と最後の頁
Science of The Total Environment	157810～157810
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.1016/j.scitotenv.2022.157810	有
オープンアクセス	国際共著
オープンアクセスとしている（また、その予定である）	該当する

1．著者名	4．巻
NWE Lett Wai、AZHIKODAN Gubash、YOKOYAMA Katsuhide	78
2．論文標題	5．発行年
CHANGES IN SIZE DISTRIBUTION OF PHYTOPLANKTON IN RESPONSE TO TIDAL VARIABILITY IN THE CHIKUGO RIVER ESTUARY	2022年
3．雑誌名	6．最初と最後の頁
Journal of Japan Society of Civil Engineers, Ser. B1 (Hydraulic Engineering)	I_1069～I_1074
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.2208/jscejhe.78.2_I_1069	有
オープンアクセス	国際共著
オープンアクセスではない、又はオープンアクセスが困難	－

1．著者名	4．巻
Phyu P.E.、Yokoyama K.、Azhikodan G.	-
2．論文標題	5．発行年
LONG-TERM (1953-2020) MORPHOLOGICAL CHANGES OF CHIKUGO RIVER, JAPAN	2023年
3．雑誌名	6．最初と最後の頁
Proceedings of the 19th Annual Meeting of the Asia Oceania Geosciences Society	127-129
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.1142/9789811275449_0043	有
オープンアクセス	国際共著
オープンアクセスとしている（また、その予定である）	該当する

1．著者名	4．巻
Azhikodan Gubash、Phyu Pan Ei、Yokoyama Katsuhide	-
2．論文標題	5．発行年
Long-term (1953-2020) changes in morphology of Chikugo River, Japan in response to natural and anthropogenic forces	2023年
3．雑誌名	6．最初と最後の頁
Proceedings of EGU General Assembly 2023	1
掲載論文のDOI（デジタルオブジェクト識別子）	査読の有無
10.5194/egusphere-egu23-15323	有
オープンアクセス	国際共著
オープンアクセスとしている（また、その予定である）	該当する

1．著者名 Nwe Lett Wai、Yokoyama Katsuhide、Azhikodan Gubash	4．巻 -
2．論文標題 PHYTOPLANKTON HABITATS RESPONSE TO THE VARIABILITY OF ESTUARINE HYDRODYNAMIC CONDITION IN THE MACROTIDAL CHIKUGO RIVER ESTUARY	5．発行年 2023年
3．雑誌名 Proceedings of the 19th Annual Meeting of the Asia Oceania Geosciences Society	6．最初と最後の頁 121-123
掲載論文のDOI（デジタルオブジェクト識別子） 10.1142/9789811275449_0041	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

1．著者名 PHYU Pan Ei、AZHIKODAN Gubash、YOKOYAMA Katsuhide	4．巻 12
2．論文標題 EFFECTS OF PAST HUMAN ACTIVITIES AND RECENT DISASTERS ON RIVERBED MORPHOLOGY OF THE CHIKUGO RIVER ESTUARY	5．発行年 2024年
3．雑誌名 Journal of JSCE	6．最初と最後の頁 1-6
掲載論文のDOI（デジタルオブジェクト識別子） 10.2208/journalofjsce.23-16019	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

1．著者名 PHYU Pan Ei、AZHIKODAN Gubash、YOKOYAMA Katsuhide	4．巻 4
2．論文標題 Morphological response of the Chikugo River to climate change events.	5．発行年 2023年
3．雑誌名 Proceedings of the 4th IAHR Young Professionals Congress	6．最初と最後の頁 26-27
掲載論文のDOI（デジタルオブジェクト識別子） なし	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

1．著者名 Rawat Vishal Singh、Fujikawa Ryunosuke、Azhikodan Gubash、Yokoyama Katsuhide	4．巻 302
2．論文標題 Relationship between hydro-environmental variables and Coilia nasus catch in a highly turbid macrotidal estuary in Japan	5．発行年 2024年
3．雑誌名 Estuarine, Coastal and Shelf Science	6．最初と最後の頁 108773～108773
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.ecss.2024.108773	査読の有無 有
オープンアクセス オープンアクセスとしている（また、その予定である）	国際共著 該当する

〔学会発表〕　計8件（うち招待講演　1件／うち国際学会　5件）

１．発表者名 Azhikodan Gubash、Phyu Pan Ei、Yokoyama Katsuhide
２．発表標題 Long-term (1953-2020) changes in morphology of Chikugo River, Japan in response to natural and anthropogenic forces
３．学会等名 EGU General Assembly 2023（国際学会）
４．発表年 2023年

１．発表者名 NWE Lett Wai、AZHIKODAN Gubash、YOKOYAMA Katsuhide
２．発表標題 CHANGES IN SIZE DISTRIBUTION OF PHYTOPLANKTON IN RESPONSE TO TIDAL VARIABILITY IN THE CHIKUGO RIVER ESTUARY
３．学会等名 67th Annual Conference in Hydraulic Engineering, Japan Society of Civil Engineers
４．発表年 2022年

１．発表者名 Phyu, P.E., Yokoyama, K., Azhikodan, G.
２．発表標題 Long-term (1953-2020) Morphological Changes of Chikugo River, Japan
３．学会等名 19th Annual Meeting of Asia Oceania Geosciences Society 2022（国際学会）
４．発表年 2022年

１．発表者名 Azhikodan, G., Yokoyama, K., Shintani, S., Priyal, K.L.
２．発表標題 Session: Recent Trends in Estuarine Hydro- and Morphodynamics in the Context of Climate Change
３．学会等名 19th Annual Meeting of Asia Oceania Geosciences Society 2022（国際学会）
４．発表年 2022年

１．発表者名
Nwe, L.W., Yokoyama, K., Azhikodan, G.

２．発表標題
Phytoplankton habitats response to the variability of estuarine hydrodynamic condition in the macrotidal Chikugo River estuary

３．学会等名
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４．発表年
2022年

１．発表者名
Nwe, L.W., Azhikodan, G., Yokoyama, K.

２．発表標題
Influence of salinity intrusion and suspended sediment concentration (SSC) on temporal distribution of diatoms (phytoplankton) in the Chikugo River estuary

３．学会等名
River, Coastal and Estuarine Morphodynamics (RCEM) conference 2021, Session: “Ecomorphodynamics”.（国際学会）

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１．発表者名
Gubash Azhikodan

２．発表標題
Saltwater Intrusion, Sediment Transport and Morphological Changes in Estuaries

３．学会等名
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４．発表年
2020年～2021年

１．発表者名
Phyu, P.E., Azhikodan, G., Yokoyama, K.

２．発表標題
Effects of recent disasters on changes in riverbed morphology of the Chikugo River estuary, Japan

３．学会等名
4th University of St. La Salle Graduate Research Conference, Bacolod City, Philippines

４．発表年
2023年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

Researchgate https://www.researchgate.net/profile/Gubash-Azhikodan Google Scholar https://scholar.google.co.jp/citations?user=Q3mSn34AAAAJ&hl=en University Webpage https://www.tmu.ac.jp/stafflist/data/alphabet/30820.html https://www.researchgate.net/profile/Gubash-Azhikodan https://scholar.google.co.jp/citations?user=Q3mSn34AAAAJ&hl=en Tokyo Metropolitan University - Researcher page https://www.tmu.ac.jp/stafflist/data/alphabet/30820.html Google Scholar https://scholar.google.co.jp/citations?user=Q3mSn34AAAAJ&hl=en Researchgate https://www.researchgate.net/profile/Gubash-Azhikodan Researchmap https://researchmap.jp/gubash

６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関