Morphometric Analysis Based on Multi-Sources Data and Geographic Information System in the Cirasea Watershed, Indonesia

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Abstract. The Citarum River basin has witnessed civilization in Java, Indonesia since a hundred years ago. Upstream Citarum, currently, receives pollutants and requires a morphometric study to understand its characteristics. This research aims to analyze watershed morphometrics using multi-sources data and geographic information system (GIS). Our research was located in the Cirasea watershed, West Java, known as the starting area for the Citarum River basin. Data came from multiple sources such as DEMNas, SRTM, CopernicusDEM, AsterGDEM, Topographic Maps (RBI), BBWS-Citarum, high-resolution satellite imagery, as well as field surveys to obtain accurate information. Data integration and analysis referred to a geospatial approach using QGIS. This research showed that the Cirasea watershed has an area of 366.17 square kilometers (sq km), with permanent rivers and periodic rivers reaching 106.02 km and 298 km, respectively. The Cirasea watershed has a rounded shape with 10 reaches named 1) Baleendah, 2) Cikoneng, 3) Ciparay, 4) Ibun, 5) Jelekong, 6) Kertasari, 7) Majalaya, 8) Panca, 9) Rancakasumba, and 10) Sumbersari. The watershed's flow density is 170 m per square km with a trellis pattern and a meandering level of 11.40. The Cirasea has 8 river orders and 4 oxbow lakes downstream along 3.4 km. Multi-sources data and GIS have proven to reveal characteristics accurately both in detail and actual conditions.

Keywords: Citarum, GIS, River, Watershed Management.

1 Introduction

Environmental degradation is a major phenomenon in the 21st century because it causes various problems on the earth's surface, requiring serious and appropriate handling [1]. Addressing environmental degradation generally follows a formal regionalization approach with the division of administrative units from village to state level [2].

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However, the consequence of this approach is the emergence of new problems, specifically in managing environmental issues that aren't adequately coordinated and in the occurrence of conflicts of interest among administrative regions [3-5] Cooperation is necessary so that all stakeholders in each administrative area have the same perception of environmental development and management. This approach can refer to watershed units or river basins [6].

A watershed is an area identified by its topographical features that collect, store, and direct the flow of rainwater toward rivers, which ultimately flow into lakes or the sea [7]. This watershed is typically separated into three distinct sections: the upstream river area, the middle river area, and the downstream area [8]. Highlands are reservoirs for natural rainwater flows in watersheds, which flow through rivers to various areas [9]. Processes in the hydrological cycle, such as evaporation, transpiration, precipitation, infiltration, percolation, and run-off, occur in this ecoregion. Watersheds and river basins are often used in the context of similar ecoregions, the main difference being only in terms of size [10].

The problem of watershed management as an ecoregion seems to face new challenges, specifically regarding the precision and depth of data presented in morphometric analysis. Currently, spatial data available from global and national vendors can delineate watershed boundaries for medium-large scale studies [11, 12]. In Citarum, West Java, Indonesia, this data can only delineate sub-watershed boundaries and watershed parts – upstream, middle, and downstream. Research from Strayer et al. [13] showed that not detailed morphometric data causes various river flow analyses to be less accurate for small areas. A similar thing was also revealed by Lai et al. [14] and Niroula et al. [15], inaccurate morphometric analysis impacts hydrographic and hydraulic modelling, which is very useful for various development needs.

A similar problem exists in Indonesia, where watershed boundaries and river networks are available and analyzed by two institutions: 1) the Ministry of Environment and Forestry, and 2) the Ministry of Public Works and Public Housing [16]. Nevertheless, this data remains problematic for conducting in-depth environmental studies and management due to numerous errors and a lack of current information [17, 18]. These data cannot reveal river networks up to sub-ecoregion boundaries, even though the data is useful for environmental management. Therefore, this research aims to analyze morphometrics using multi-sources data and geographic information system (GIS) by taking a case study at Cirasea Watershed.

2 Methodology

This research focuses on the Cirasea Watershed, it is known as an ecological unit in Upper Citarum and is the southernmost point of the Citarum River Basin (Figure 1). The Cirasea watershed, administratively, is located in two regions: Bandung Regency and Garut Regency. In smaller formal units, this watershed is located in 16 sub-districts and 90 villages with social lifestyles ranging from rural to sub-urban for Bandung City with several industrial areas downstream, namely Baleendah, Ciparay and Majalaya [19]. The Cirasea watershed is home to around 700,000 to 900,000 residents, as reported by BPS Bandung Regency and BPS Garut Regency [20, 21]. Its location in the Greater Bandung region means that the Cirasea watershed requires extra attention to reveal its morphological and hydrological aspects due to its crucial role as the primary water source for the Citarum River Basin, which includes three artificial reservoirs (Cirata, Saguling, Jatiluhur) and is known to be densely populated with agricultural and non-agricultural areas [22, 23].

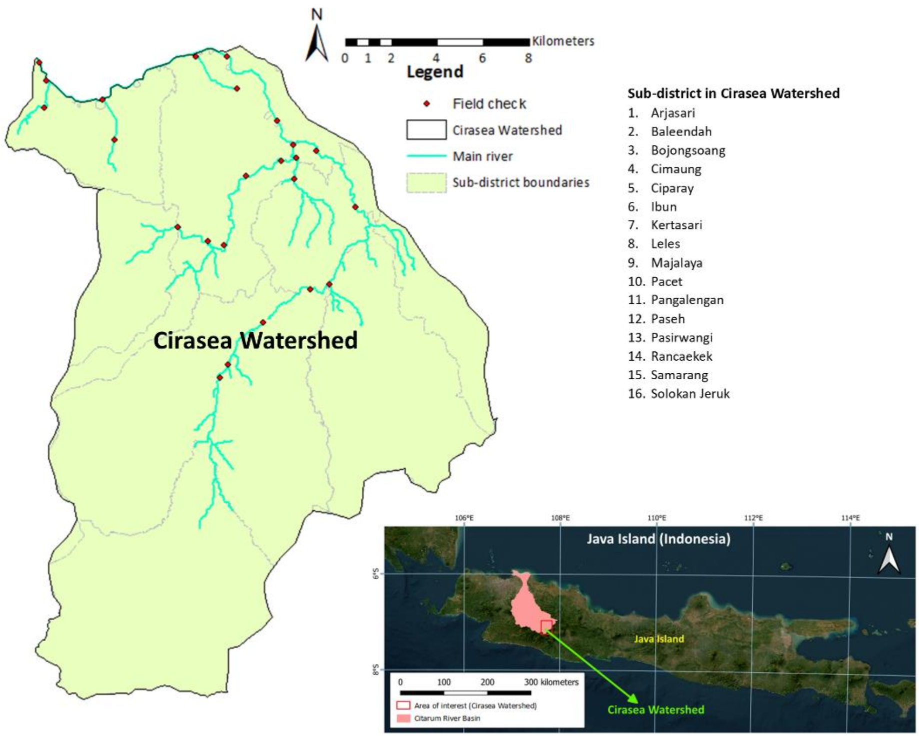

Fig. 1. The Cirasea watershed is based on official boundaries from the Indonesian Government with ground check points (field survey).

Revealing the surface attributes of the Cirasea watershed involves a morphometric assessment that relies on data from various sources originating from within and outside the country (Table 1). We combine it with primary data from field surveys (24 ground check points) and visual interpretation of high-resolution satellite imagery to maintain accuracy and information quality [24]. Field data collection is supported by an Android smartphone capable of capturing Global Navigation Satellite System (GNSS) signals – such as GPS, GLONASS, Beidou, Galileo, QZSS, and SBS – whose distortion is less than 2 meters. Data for morphometric analysis is generally in the form of geospatial data, which contains information on coordinates (x, y) and elevation (z) [25, 26].

This data requires a series of analyzes using geographic information systems (GIS) [27, 28]. This analysis is supported by free and open-source software (FOSS), namely QGIS version 3.28 (Firenze). The procedure is presented in Figure 2. Utilizing data from various sources, the Cirasea watershed is divided into smaller areal units in the form of reaches [29, 30]. There are six parameters for watershed morphometrics, named area, river length, circumference (Cf), shape, roundness, and width [32]. This analysis also reveals other parameters for an ecoregion such as flow density, stream gradient, stream pattern, meandering level, river order, and oxbow lakes [33].

Table 1. Data sources for the morphometric analysis

Dataset	Provider	Origin
Digital Elevation Model Nasional (DEMNas)	Indonesian Geospasial Agency (Badan Informasi Geospasial, BIG)	Indonesia
Shuttle Radar Topography Mission (SRTM)	National Aeronautics and Space Administration (NASA)	United States of America
Copernicus Digital Elevation Model (CopernicusDEM)	European Space Agency (ESA)	European Union
ASTER Global Digital Elevation Model (ASTER GDEM)	Japan Space Systems, Japan Aerospace Exploration Agency (JAXA)	Japan
Topographic Maps (Rupa Bumi Indonesia, Peta RBI)	Indonesian Geospasial Agency (Badan Informasi Geospasial, BIG)	Indonesia
Data BBWS-Citarum	Indonesian Ministry of Public Work and Housing (Kementerian PUPR)	Indonesia
High-resolution satellite imagery	Maxar Technologies Inc.	United States of America
Ground-check points	Field surveys by the researchers	Indonesia

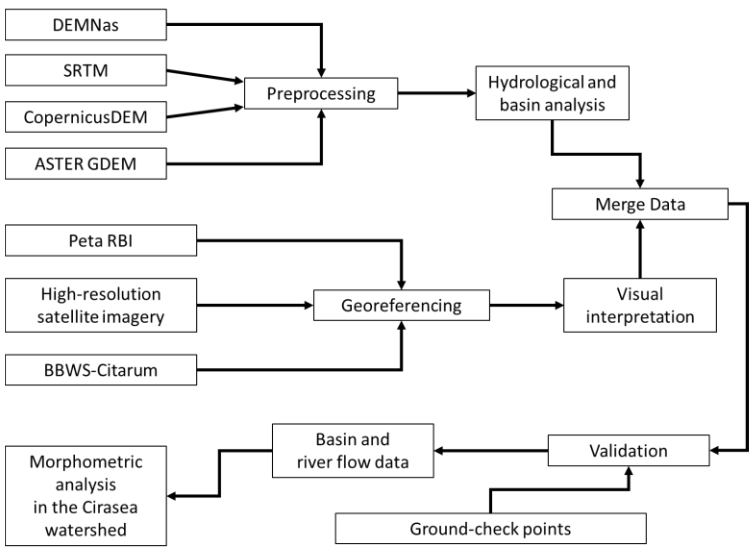

Fig. 2. The Cirasea watershed is based on official boundaries from the Indonesian Government with ground check points (field survey).

3 Results and Discussion

The Cirasea watershed is a landscape with 366.17 square kilometres (sq km) drained by permanent rivers and periodic rivers, reaching 106.02 km and 298 km, respectively. This research shows that the Cirasea watershed is divided into ten reaches named 1) Baleendah, 2) Cikoneng, 3) Ciparay, 4) Ibun, 5) Jelekong, 6) Kertasari, 7) Majalaya, 8) Panca, 9) Rancakasumba, and 10) Sumbersari with the direction of water flow stretching from south to north (Figure 3). The Cirasea watershed has a rounded shape because the basin circularity (RC) is below 0.5 (0.01), which means that peak discharge tends to decrease as well [33]. This watershed is dominated by a trellis flow pattern with a meandering level reaching 11.40 with eight river orders. This situation is caused by its geomorphological formation in the form of folds of the central mountains in West Java [34].

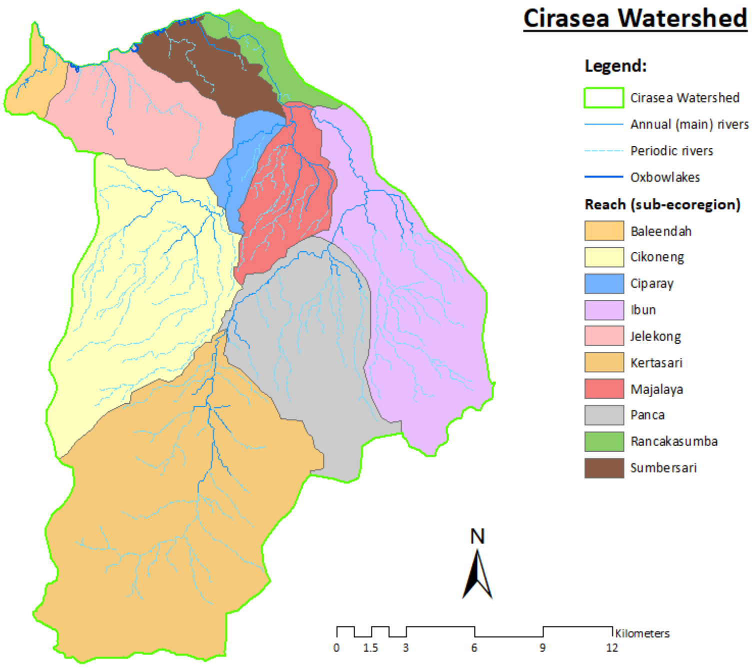

Fig. 3. The Cirasea watershed is based on official boundaries from the Indonesian Government with ground check points (field survey).

In terms of flow density, the Cirasea watershed has an average flow density of 170 meters (m) per square km, which is included in the high category [33], the amount is higher in the upstream part and ultimately decreases in the downstream part. The Cirasea watershed is at an altitude of 657-2357 meters above sea level. It has a stream gradient of 62.85, which means there is a significant change in the water flow elevation at intervals of 60-63 m. This figure is strengthened by survey results in the Cirasea watershed, which has a grain size type with variations in sand, gravel, and cobbles [35].

The general morphometry of the Cirasea watershed is unique, so that the upstream area, which is abundant in water, often becomes a flooded supply for the downstream during the rainy season, but this situation is inversely proportional during the dry season wherein two reaches (Jelekong and Baleendah) often facing drought [36-38]. From the results of analysis of multi-source data that has been verified through field survey activities, it was also found that there are four oxbowlakes in the downstream part of the main river in the Cirasea watershed along 3.4 km in the Jelekong and Sumbersari reaches. Oxbow lakes are evidence of the high dynamics of changes in the Citarum flow, which causes erosion and sedimentation in several meanderings, resulting in their natural isolation [39]. Human intervention through river engineering and pumping water flows means these oxbow lakes can still flow into the main river with very low discharge intensity.

Table 2. Morphometric characteristics in each reach of the Cirasea Watershed (part I).

Reach	Area (sq km)	Geometry (km)			Elevation			Slope (%)	Flow density (m per sq km)
		Cf	Length	Width	Min	Max	Mean		
Baleendah	5.87	11.58	3.15	1.96	656.50	1046.57	747.70	11.55	75.31
Cikoneng	65.22	38.13	9.73	5.72	727.96	2322.31	1146.79	14.55	22.60
Ciparay	7.75	15.57	4.57	1.66	666.13	997.27	708.73	4.79	78.64
Ibun	57.41	41.27	15.37	3.89	665.88	1896.49	1094.16	11.18	29.72
Jelekong	29.57	24.63	5.36	6.83	656.37	1147.62	741.27	9.77	19.41
Kertasari	111.16	47.58	14.27	9.29	875.36	2572.92	1575.30	16.24	13.54
Majalaya	20.18	21.74	6.74	3.56	662.72	864.24	720.39	3.24	65.72
Panca	46.41	33.76	9.56	5.44	702.23	1942.62	1102.00	15.58	27.74
Rancakasumba	8.41	17.98	4.93	2.15	659.26	678.52	664.03	0.87	72.10
Sumbersari	14.19	19.17	5.21	3.21	658.00	674.68	664.22	0.45	32.63

Table 3. Morphometric characteristics in each reach of the Cirasea Watershed (part II).

Reach	River (m)			RC	Stream pattern	Meandering level	Stream gradient	River order
	Annual	Periodic	Oxbowlake					
Baleendah	6.457	1.28	0	0.55	Dendritic	7.39	54.79	3
Cikoneng	14.17	76.92	0	0.56	Trellis	45.56	86.28	5
Ciparay	6.331	3.92	0	0.40	Trellis	11.68	107.74	1
Ibun	16.79	56.45	0	0.42	Trellis	36.21	221.04	4
Jelekong	7.371	15.01	1.20	0.61	Dendritic	5.22	105.86	2
Kertasari	14.56	65.83	0	0.62	Trellis	13.97	34.38	6
Majalaya	13.76	29.41	0	0.54	Trellis	12.46	185.75	5
Panca	14.41	39.63	0	0.51	Trellis	40.69	54.19	4
Rancakasumba	6.272	2.48	0	0.33	Dendritic	5.44	1737.40	1
Sumbersari	5.899	7.08	2.20	0.48	Dendritic	5.50	1585.75	2

The area of each sub-region of the Cirasea watershed is quite varied, ranging from 5.87-111.16 sq km (Table 2), where the reach in the upstream area is larger than the downstream area. The main river of the annual type is longer in reach with a trellis flow pattern, where the length can be more than 10 km (Table 3). A similar thing can also be seen in the periodic hang river which generally has a length of more than 25 km. On the other hand, the downstream reach is quite short, measuring less than 10 kilometers, and this is associated with the limited availability of surface water, particularly during the dry season. In areas where the river flow forms a dendritic pattern, the river's order typically falls within the range of 1 to 3, displaying a gentle flow and a lack of erosion on the river's cross-section [40, 41]. This is different from the trellis type, which generally has fast currents with high stream gradients, so meandering appears to be more intensive [42-44]. In the upstream area of the Cirasea watershed, differences in river levels can begin to appear at flow intervals of 30-40 meters. In terms of shape, it appears that six reaches in the Cirasea watershed have a round shape, although four reaches have an elongated shape, such as Ciparay, Ibu, Rancakasumba, and Sumbersari.

Kertasari is the largest reach in the Cirasea watershed based on analysis results that have been validated with field surveys. There is a natural boundary in the form of a ridge from the Bandung basin and Situ Cisanti [45]. The use of multi-source data and GS for morphometric analysis in the Cirasea watershed succeeded in revealing the uniqueness of this ecoregion, such as the presence of oxbowlakes, larger reach sizes in the upstream section, and differences in shape as well as flow patterns of each sub-landscape. The Cirasea watershed, as one of the upper regions of the Citarum River Basin, shows unique characteristics because it has strong anthropogenic determination, for example, the width of the river, its straightness, and irrigation canals which have significantly divided surface water flow before it reaches the outer outlet of this landscape. The Majalaya reach is known as an industrial center in Greater Bandung and a hub for suburban growth, the discharge from the Cirasea watershed appears to be smaller and ultimately unable to dilute waste from textile manufacturing and livestock, which is the cause of water pollution [46, 47].

4 Conclusion

The use of multi-source data and GIS has proven capable of conducting morphometric analysis studies in the Cirasea watershed. Field verification with support from high-resolution satellite imagery proves that the use of this data can reveal ecoregion details, which are very useful for environmental management and development. This research revealed ten reaches, river flows, and various morphometric parameters of the Cirasea watershed. The identification of ten distinct reaches provides valuable insights into the smallest natural units for promoting sustainable development in the Upper Citarum region. The results of the morphometric analysis reveal differences in the very distinctive natural features of the Cirasea watershed from upstream to downstream, such as differences in reach shapes, flow patterns, and slope aspects that influence the terrestrial and aquatic ecosystems there. The use of multi-source data with satisfactory results could be an inspiration for similar studies throughout the world if it still prioritizes field verification to produce accurate information. The biggest challenge in using multi-source data is geospatial integration because each provider has set different standards.

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References

1. Zipperer, W. C., Northrop, R., Andreu, M.: Urban development and environmental degradation. Oxford Research Encyclopedia of Environmental Science, (2020). https://doi.org/10.1093/acrefore/9780199389414.013.97
2. Dede, M., Asdak, C., Setiawan, I.: Spatial-ecological approach in Cirebon's peri-urban regionalization. IOP Conference Series: Earth and Environmental Science 1089(1), 012080 (2022a). https://doi.org/10.1088/1755-1315/1089/1/012080
3. Liu, J., Ouyang, Z., Miao, H.: Environmental attitudes of stakeholders and their perceptions regarding protected area-community conflicts: A case study in China. Journal of Environmental Management 91(11), 2254-2262 (2010). https://doi.org/10.1016/j.jenvman.2010.06.007
4. Robins, G., Bates, L., Pattison, P.: Network governance and environmental management: conflict and cooperation. Public Administration 89(4), 1293-1313 (2011). https://doi.org/10.1111/j.1467-9299.2010.01884.x
5. Mulyadi, A., Afriana, N. N., Widiawaty, M. A., Dede, M.: Water resources carrying capacity in the Bali Island: A history and local wisdom for environmental conservation. Historia: Jurnal Pendidik dan Peneliti Sejarah 6(1), 89-96 (2023). https://doi.org/10.17509/historia.v6i1.58168
6. Dede, M., Wibowo, S. B., Prasetyo, Y., Nurani, I. W., Setyowati, P. B., Sunardi, S.: Water resources carrying capacity before and after volcanic eruption. Global Journal of Environmental Science and Management 8(4), 473-484 (2022b). https://doi.org/10.22034/GJESM.2022.04.02
7. Tesema, T. A., Lam, K. C., GebreMariam, B., Tefera, W. M.: Multi-site calibration of SWAT for the spatial distribution of sediment yield, Middle Awash Dam watershed, Ethiopia. Geografia – Malaysian Journal of Society and Space 17(4), 256-273 (2021). https://doi.org/10.17576/geo-2021-1704-18
8. Sunardi, S., Nursamsi, I., Dede, M., Paramitha, A., Arief, M. C. W., Ariyani, M., Santoso, P.: Assessing the influence of land-use changes on water quality using remote sensing and GIS: A study in Cirata Reservoir, Indonesia. Science and Technology Indonesia 7(1), 106-114 (2022). https://doi.org/10.26554/sti.2022.7.1.106-114
9. Daramola, J., Ekhwan, T. M., Adepehin, E. J., Mokhtar, J., Lam, K. C., Er, A. C.: Seasonal quality variation and environmental risks associated with the consumption of surface water: implication from the Landzun Stream, Bida Nigeria. Heliyon 5(7), e02121 (2019). https://doi.org/10.1016/j.heliyon.2019.e02121
10. Dede, M., Sunardi, S., Lam, K. C., Withaningsih, S.: Relationship between landscape and river ecosystem services. Global Journal of Environmental Science and Management 9(3), 637-652 (2023). https://doi.org/10.22034/gjesm.2023.03.18
11. Racoviteanu, A. E., Paul, F., Raup, B., Khalsa, S. J. S., Armstrong, R.: Challenges and recommendations in mapping of glacier parameters from space: results of the 2008 Global Land Ice Measurements from Space (GLIMS) workshop, Boulder,

Colorado, USA. Annals of Glaciology 50(53), 53-69 (2009). https://doi.org/10.3189/172756410790595804
12. Dede, M., Mulyadi, A., Widiawaty, M. A.: Integrasi open data, urun daya, dan pemetaan partisipatif dalam pengelolaan sumber daya alam dan lingkungan hidup. Jurnal Sains Informasi Geografi 3(2), 78-86 (2020). https://doi.org/10.31314/jsig.v3i2.659
13. Strayer, D. L., Beighley, R. E., Thompson, L. C., Brooks, S., Nilsson, C., Pinay, G., Naiman, R. J.: Effects of land cover on stream ecosystems: roles of empirical models and scaling issues. Ecosystems 6, 407-423 (2003). https://doi.org/10.1007/PL00021506
14. Lai, Z., Li, S., Lv, G., Pan, Z., Fei, G.: Watershed delineation using hydrographic features and a DEM in plain river network region. Hydrological Processes 30(2), 276-288 (2016). https://doi.org/10.1002/hyp.10612
15. Niroula, S., Wallington, K., Cai, X.: Addressing data challenges in riverine nutrient load modeling of an intensively managed agro-industrial watershed. JAWRA Journal of the American Water Resources Association 59(2), 213-225 (2023). https://doi.org/10.1111/1752-1688.13097
16. Susiati, H., Dede, M., Widiawaty, M. A., Ismail, A., Udiyani, P. M.: Site suitability-based spatial-weighted multicriteria analysis for nuclear power plants in Indonesia. Heliyon 8(3), e09088 (2022). https://doi.org/10.1016/j.heliyon.2022.e09088
17. Riqqi, A., Taradini, J., Effendi, A. E.: Pemodelan Kualitas Informasi Geospasial Dasar Di Indonesia. Geomatika 24(1), 13-20 (2018). http://jurnal.big.go.id/index.php/GM/article/view/773
18. Hisanah, N. N., Subiyanto, S.: Kajian Teknis Penerapan Generalisasi Peta Rupabumi Indonesia (RBI) dari Skala 1: 50.000 Menjadi Skala 1: 250.000. Jurnal Geodesi Undip 4(4), 248-256 (2015). https://doi.org/10.14710/jgundip.2015.9951
19. Sugito, N. T., Gumilar, I., Hernandi, A., Handayani, A. P., Dede, M.: Utilizing semi-variograms and geostatistical approach for land value model in the urban region. International Journal of Engineering 36(12), 2222-2231 (2023). https://www.ije.ir/article_175428.html
20. BPS Kabupaten Garut.: Kabupaten Garut dalam angka 2023. Badan Pusat Statistik, Kabupaten Garut (2023). https://garutkab.bps.go.id/publication/2023/02/28/9c915d2e8b7374303606ddd5/kabupaten-garut-dalam-angka-2023.html
21. BPS Kabupaten Bandung.: Kabupaten Bandung dalam angka 2023. Badan Pusat Statistik, Kabupaten Bandung (2023) https://bandungkab.bps.go.id/publication/2023/02/28/35df6209127142673449ad5b/kabupaten-bandung-dalam-angka-2023.html
22. Jumiarni, D., Chaerun, S. K., Aryantha, I. N. P., Sato, T.: Sediments from three largest dam reservoirs (Saguling, Cirata, Jatiluhur) in West Java Province, Indonesia as natural biomineral fertilizers: An agricultural implication. In: Proceeding The 2nd USM Penang International Postgraduate Convention, pp. 1–13. Universiti Sains Malaysia, Penang (2008). https://tinyurl.com/5ddnhtjs
23. Chaerun, S., Pangesti, N. P. D., Jumiarni, D.: Biogeochemical characterization of sediments from three largest dam reservoirs (Saguling, Cirata, Jatiluhur) in West Java Province, Indonesia. In: Proceedings of the 8th International Symposium on

Southeast Asian Water Environment, pp. 169–182. Southeast Asian Water Environment, Thailand (2010). https://tinyurl.com/34hm5a2z
24. Svatonova, H.: Analysis of visual interpretation of satellite data. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 41, 675–681 (2016). https://isprs-archives.copernicus.org/articles/XLI-B2/675/2016/isprs-archives-XLI-B2-675-2016.pdf
25. Merwade, V., Olivera, F., Arabi, M., Edleman, S.: Uncertainty in flood inundation mapping: current issues and future directions. Journal of hydrologic engineering 13(7), 608–620 (2008). https://doi.org/10.1061/(ASCE)1084-0699(2008)13:7(608)
26. Widiawaty, M. A.: Mari mengenal sains informasi geografis. Aria Mandiri Group, Bandung (2019). https://doi.org/10.31227/osf.io/4s78c
27. Ali, A., Beg, A. A. F.: Morphometric toolbox: a new technique in basin morphometric analysis using ArcGIS. Global Journal of Earth Science and Engineering 2(2), 21–30 (2015).
28. Torrefranca, I., Otadoy, R. E.: GIS-based watershed characterization and morphometric analysis in Bohol Watersheds, Philippines. Geology, Ecology, and Landscapes, 1-12 (2022). https://doi.org/10.1080/24749508.2022.2158554
29. Robles, K.: WinTR55 – small watershed hydrology tutorial. https://www.slideserve.com/keely-robles/wintr55-small-watershed-hydrology-tutorial last accessed 2023/10/28.
30. Linke, S., Lehner, B., Ouellet Dallaire, C., Ariwi, J., Grill, G., Anand, M., Beames, P., Burchard-Levine, V., Maxwell, S., Moidu, H., Tan, F.: Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution. Scientific Data 6(1), p.283 (2019). https://doi.org/10.1038/s41597-019-0300-6
31. Raja, D. L., Sukiyah, E., Sulaksana, N., Endyana, C.: Morphometric and Land Use Analysis to Estimate Flood Hazard–A Case Study of Upper Cimanuk Watershed in Garut Regency, Indonesia. International Journal of Geomate 19(73), 126–133 (2020). https://doi.org/10.21660/2020.73.52312
32. Sahu, I., Prasad, A. D., Ahmad, I.: Integrated tool for morphometric analysis using QGIS. In: River and Coastal Engineering: Hydraulics, Water Resources and Coastal Engineering, pp. 103–113. Cham: Springer International Publishing, Berlin (2022). https://doi.org/10.1007/978-3-031-05057-2_9
33. Soewarno, S.: Hidrologi: Aplikasi metode statistik untuk analisis data. Penerbit Nova, Bandung (1995). https://pu.go.id/pustaka/biblio/hidrologi-aplikasi-metode-statistik-untuk-analisa-data-jilid-1/K18J3
34. Verstappen, H. T.: Garis besar geomorfologi Indonesia. Gadjah Mada University Press, Yogyakarta (2013). https://ugmpress.ugm.ac.id/id/product/geografi/garis-besar-geomorfologi-indonesia
35. Tanabe, S., Komatsubara, T., Hori, K.: Grain-size variability and formation process of lowstand river sediments in the Japanese Islands: A review and outlook. Earth-Science Reviews 243, 104504 (2023). https://doi.org/10.1016/j.earscirev.2023.104504
36. Kurniasih, N., Sukaesih, S.: Public health information behavior at flood-prone area in Bandung Regency: A case study in Baleendah Village, Andir Village, Bojongsoang Village and Dayeuh Kolot Village. Record and Library Journal 3(1), 1–9 (2017). https://doi.org/10.20473/rlj.V3-I1.2017.1-9

37. Mazlan, M., Tjahjono, B., Barus, B.: Bahaya banjir dan longsor di Kecamatan Baleendah Kabupaten Bandung Jawa Barat. Jurnal Ilmu Tanah dan Lingkungan 22(1), 1–9 (2020). https://doi.org/10.29244/jitl.22.1.1-9
38. Safarina, A. B., Lestari, N. D., Aprilianingsih, D., Syahrullah, F. M., & Sadidah, M.: Rainfall threshold of Citarum River flood for early warning on urban area. In: IOP Conference Series: Earth and Environmental Science, Vol. 728, No. 1, p. 012001. IOP Publishing, Bristol (2021). https://doi.org/10.1088/1755-1315/728/1/012001
39. Juliandar, M., Rohmat, D.: Development methods for the formulation of community empowerment-based oxbow stream utilization models in Citarum River. In: IOP Conference Series: Earth and Environmental Science, Vol. 286, No. 1, p. 012016. IOP Publishing, Bristol (2019). https://doi.org/10.1088/1755-1315/286/1/012016
40. Strahler, A. H., Strahler, A.: Introducing physical geography. 6th edn. New Jersey: Wiley, Boston (2013). https://archive.org/details/introducingphysi0000stra
41. Ritter, M.: The physical environment. LibreTexts, California (2017). https://geo.libretexts.org/Bookshelves/Geography_(Physical)/The_Physical_Environment_(Ritter)
42. Deline, B., Harris, R., Tefend, K.: Laboratory manual for introductory geology. LibreTexts, California (2015). https://geo.libretexts.org/Learning_Objects/Laboratory/Book%3A_Laboratory_Manual_For_Introductory_Geology_(Deline_Harris_and_Tefend)
43. Earle, S.: Physical geology. LibreTexts, California (2015). https://geo.libretexts.org/Bookshelves/Geology/Physical_Geology_(Earle)
44. Solada, K., Daniels, K. S.: Principles of Earth Science. Pressbooks, Canada (2021). https://openoregon.pressbooks.pub/earthscience/
45. Mulyadi, A., Dede, M., Widiawaty, M. A.: Spatial interaction of groundwater and surface topographic using geographically weighted regression in built-up area. In: IOP conference series: Earth and environmental science, Vol. 477, No. 1, p. 012023. IOP Publishing, Bristol (2020). https://doi.org/10.1088/1755-1315/477/1/012023
46. Dachlan, D.: Warna-warni citarum di Majalaya. Citarum Org (2013). http://citarum.org/citarum-knowledge/publikasi/laporan-foto-cita-citarum/137-warna-warni-citarum-di-majalaya/file.html last accessed 2023/10/28.
47. Nugroho, Z. B., Cahyandito, M. F., Astari, A. J., Dede, M., Abdoellah, O. S., Fadilah, K., Sunardi, S.: Preliminary development of indicators for assessing the sustainability of Indonesia's natural-dye-based Batik industry. International Journal of Sustainable Development & Planning 17(7), 2097–2107 (2022). https://doi.org/10.18280/ijsdp.170710