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CASE STUDY

Preventing water pollution using importance-performance análisis and terrain analysis

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ABSTRACT

BACKGROUND AND OBJECTIVES: The monitoring of the Brantas watershed showed a light-polluted status. This study began by identifying the priority of regional problems using importance-performance analysis. Furthermore, a hydrological analysis was conducted to determine the pollutant area of the Brantas watershed by applying terrain analysis. When terrain analysis in hydrology is combined with participatory community information, it can provide valuable insights into water pollution and help prioritize remediation efforts. Integrating local knowledge with scientific data can improve decision-making and increase the effectiveness of water management strategies.

METHODS: The methodological approach employed in this study included importance-performance analysis to determine priority problems in Batu City and terrain analysis as a hydrological analysis to determine the pollutant area in the Brantas watershed. The importance-performance analysis assessment data were obtained from 197 respondents representing the occupations of the people of Batu City. The terrain analysis data were derived from the surface elevation data in the form of a digital elevation model.

FINDINGS: According to the importance-performance analysis community assessment, urban trash management was one of the crucial yet low-rated features. The terrain analysis results demonstrated that business and industrial activities were distributed in locations with high flow accumulation values, indicating that the water pollution in Batu City was triggered by the presence of business and industrial activities in the watershed accumulation areas. Along the upstream Brantas watershed, 460 business and industrial activities were discovered. Therefore, the results of importance-performance analysis and terrain analysis had a correlation. They were also closely related to the assessment results of the contaminated Brantas watershed.

CONCLUSION: The following are some recommendations for the watershed's quality improvement: 1) cooperation among the Government, communities, and the private sector for addressing water pollution issues; 2) the development of environmentally friendly technologies in water treatment; and 3) education and outreach to communities about the importance of preserving water resources. As a city experiencing rapid urban development, environmental degradation constitutes a risk to be borne. Accordingly, Batu City must continue to develop good environmental management for the sake of nature conservation because the urban system is a unit formed by the social economy and ecological environment subsystem.

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INTRODUCTION

Compared to the previous year, Batu City's economic growth in 2021 showed positive movement at 4.04 percent (%). Batu City ranked eleventh out of 38 districts and cities in East Java as a region with positive economic growth (CBSBC, 2022a). However, sustainable urban development is not only based on the economic aspect but also requires coordinated development between the socio-economic and ecological environments to create prosperity for all current and future residents (Fan *et al.,* 2019; Lee *et al.,* 2021). The subject of sustainable urban development, which discusses coordinated development between socio-economic and ecological environments, has been increasingly studied in recent years (Jepson and Edwards, 2010; Rasoolimanesh *et al.,* 2011; Schluter *et al.,* 2012; Bai *et al.,* 2016; Liang and Yang, 2018; Fan *et al.,* 2019; Rasoolimanesh *et al.,* 2019; Xing *et al.,* 2019; Ahmed *et al.,* 2020; Li and Yi, 2020; Michalina *et al.,* 2021). There are many basic needs to live comfortably in a city with limited resources, one of which is clean water resources. Water resources are vital and inseparable from human life. Water also serves as a strategic economic resource and an indispensable necessity for human survival and social development (Xia *et al.,* 2011; Walter *et al.,* 2012). Meanwhile, population density and high economic activity in urban areas pose a risk to the resilience of water resources. Therefore, urban water security requires relatively high-risk management, so its governance arrangements need to be considered. In the case of urban areas, the main factors that can reduce water quality are environmental pressures, such as changes in land use and cover, and socio-economic pressures, such as population growth (Hoekstra *et al.,* 2018). Human activities can cause a decrease in water quality. In the long term, bad management can lead to a water crisis (Tan *et al.,* 2013; Wu *et al.,* 2014). The Brantas watershed is the second-largest watershed on the island of Java, located in East Java Province at 110°30' east longitude to 112°55' east longitude and 7°01' south latitude to 8°15' south latitude. The position of the Brantas watershed in Batu City, particularly upstream, functions as a buffer for water availability for people downstream. The watershed length is about 320 kilometers (km) with a watershed of ±12,000 square kilometers (km^2), which covers ±25% of the area of East Java Province or ±9% of the area of Java Island. The Brantas watershed, which springs from Batu City, crosses the areas of Kediri, Kertosono, and Mojokerto. Furthermore, this watershed branches into Kali Surabaya and Kali Porong (Sidoarjo) before emptying into the Madura Strait. Kali Surabaya forms two tributaries, i.e., Kali Mas and Kali Jagir (Wonokromo). East Java Governor Regulation Number 61 of 2010 stipulates that the water quality of the Brantas watershed is categorized as Class I drinking water. However, based on the Ecosystem Services-Based Environmental Carrying Capacity and Accommodation document of 2021, 31 sampling points in the monitoring of the Brantas watershed showed a light-polluted status (ESBC, 2021). It means the upper part of the Brantas watershed no longer complies with the standards of its designation class, Class I. Changes in land use in urban areas have decreased water quality in the Brantas watershed (Wirosoedarmo *et al.,* 2016). Deforestation in the Sumber Brantas watershed covered an area of 1.59 hectares (ha) between 1997 and 2001. The area was converted into an agricultural area for seasonal crops, especially vegetables, with poor soil and water conservation conditions (Widianto *et al.*, 2010). Based on the Regulation of the Minister of Public Works and Public Housing Number 04/PRT/M/2015, the Brantas watershed area is a National Strategic Watershed Area. The importance of handling the water resources problems in the Brantas watershed becomes the basis of this study. Marselina *et al.* (2022) and Utami *et al.* (2020) successfully implemented terrain analysis in the management of the Citarum River Watershed in West Java, Indonesia. Terrain analysis is applied to identify critical points contributing to water pollution and to identify areas vulnerable to pollution. With this information, the Government and local communities can design more effective strategies to reduce water pollution, such as constructing waste treatment facilities, enforcing regulations, and implementing greening initiatives in vulnerable areas. Lee and Xue (2021) adopted the importance-performance analysis approach to sustainable city assessment. By involving various stakeholders, including participatory mapping integrated with the importance-performance and terrain analysis, effective and sustainable strategies can be effected for managing water resources. The aims of the current study include identifying the priority of regional problems using importance-performance analysis (IPA) and determining the pollutant area of the Brantas watershed using terrain analysis. When terrain analysis in hydrology is combined with participatory community information, it can provide valuable insights into water pollution and help prioritize remediation efforts. Integrating local knowledge with scientific data can improve decision-making and increase the effectiveness of water management strategies. This study was conducted in Batu City, Indonesia, in 2022.

MATERIALS AND METHODS

The geographical location of Batu City is 7° 44' 55,11" until 8° 26' 35,45" NL and 122° 17' 10,90" until 122° 57' 00,00" EL, as presented in Fig. 1.

The methodological approach used in this study was IPA analysis to determine priority problems in Batu City and terrain analysis as a hydrological analysis to determine pollutant areas in the Brantas watershed. The IPA technique was first described by Martilla and James (1977). IPA is relatively easy to use, easy to interpret, and a good tool used by researchers to investigate the level of satisfaction and importance of an aspect by assessing several attributes (Simpson *et al.,* 2020). IPA is one of the common methods applied in sustainable development research (Riviezzo *et al.,* 2009; Lee *et al.,* 2021). Using IPA enables some attributes of a sustainable city to be measured on a scale of importance and performance. Therefore, this method is suitable for adoption in research involving the attributes of sustainable development. As a tool that assesses importance and performance aspects, IPA can identify key areas where management needs to be improved (Lee *et al.,* 2021). The IPA findings can also facilitate decision-making by providing further insight into urban development performance, including the occurrence of water pollution. Assessing urban sustainability contributes to sustainable development, including the availability of sustainable clean water (Lee and Xue, 2021). IPA is a two-dimensional matrix plot with important attributes ranked on the vertical axis and performance attributes plotted on the horizontal axis (Fig. 2). According to Taplin (2012), the IPA assessment incorporates a Likert scale with five possible points. The range of importance assessment is as follows: very important, important, moderately important, slightly important, and not important. The range of performance ratings is as follows: very good, good, acceptable, poor, and very poor. The attributes used in

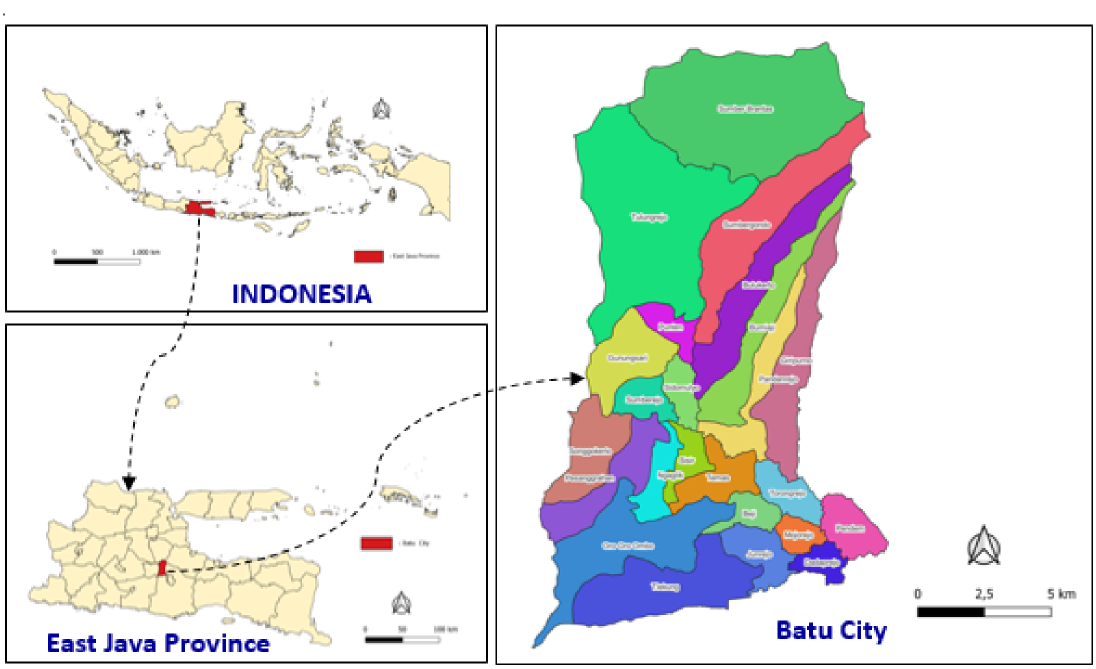

Fig. 1: Geographic location of the Batu City study area, Indonesia

this study refer to the Sustainable Development Goals (SDGs) related to sustainable urban development. The SDGs points include points 8, 9, 11, 13, and 15. Point 8 includes promoting inclusive and sustainable economic growth, productive and comprehensive employment opportunities, and decent work for all; point 9 includes building resilient infrastructure, promoting inclusive and sustainable industries, and encouraging innovation; point 11 includes making cities and settlements inclusive, safe, resilient and sustainable; point 13 includes taking urgent action to address climate change and its impacts; and point 15 includes protecting, restoring, and promoting the sustainable use of terrestrial ecosystems, managing forests sustainably, combating desertification, restoring land degradation, and stopping biodiversity loss. The IPA respondents comprised 197 people in Batu City, consisting of entrepreneurs, private employees, farmers, civil servants, teachers, students, and the unemployed. The community measured the importance and performance of the aspects related to Batu City's sustainable development through a questionnaire. Subsequently, the results of the questionnaire were interpreted into the IPA matrix.

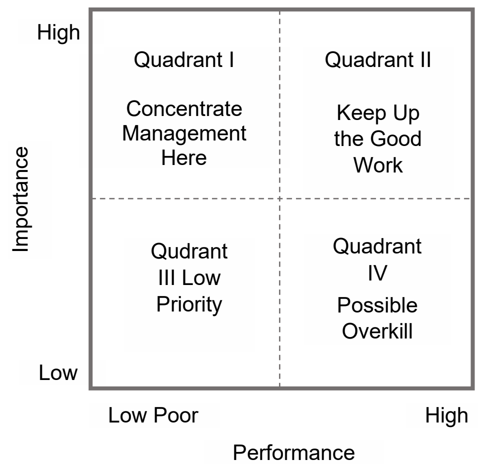

Fig. 2: Importance-Performance Analysis Matrix
(Martilla and James, 1977; Taplin, 2012; Jurdana and Frleta, 2012)

Next, the stages of finding areas to be handled and controlled regarding water pollution in the Brantas watershed were carried out by estimating the water accumulation area connected with industrial and business activities. These stages are demonstrated in Fig. 3.

Terrain analysis in hydrology is the processing of spatial data to examine the surface characteristics and water flow patterns in a given area. The steps in performing the terrain analysis in hydrology to produce flow accumulation involve data collection, data cleaning, slope and flow direction calculation, and the identification of watersheds and river networks. First, it is necessary to collect surface elevation data in the form of a digital elevation model (DEM) with appropriate resolution. DEM is a digital representation of the Earth's surface that presents elevation information at specific points. The second step is cleaning and processing the DEM to correct errors and remove noise. This step is essential for producing accurate and reliable data for further analysis. Third,

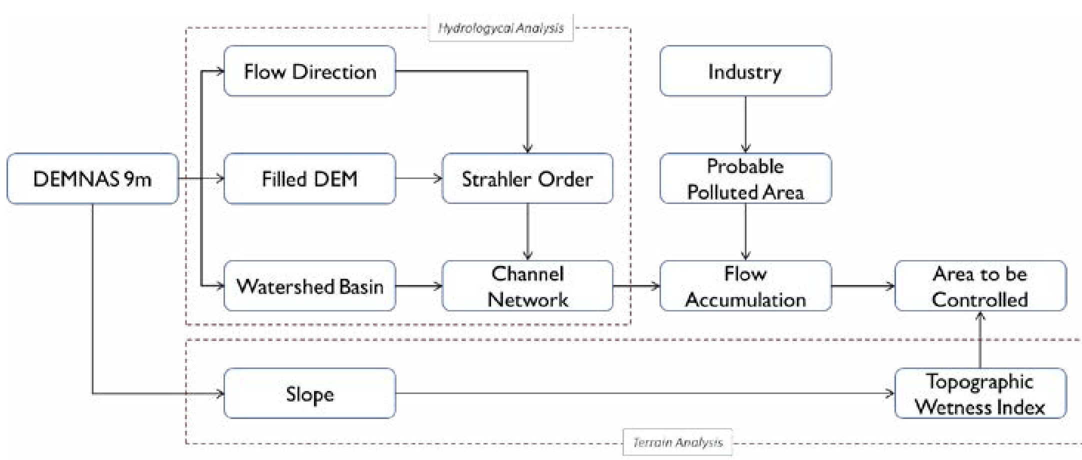

Fig. 3: Terrain analysis flow

using specialized algorithms to calculate slope and flow direction based on the DEM elevation data. The slope is the degree of surface incline, while the flow direction indicates the direction in which water will flow based on the lowest elevation in the vicinity. Fourth, flow accumulation is the number of cells along the water flow path that flows through each cell in the DEM. To calculate the flow accumulation, the flow direction must be performed earlier. Algorithms such as D8 or multiple flow direction (MFD) are used to calculate the flow accumulation. This process results in a map showing water flow patterns and areas with high flow accumulation. Fifth, from the flow accumulation results, watersheds and river networks can be identified. Areas with high flow accumulation indicate significant rivers or water channels, while watersheds cover areas that drain surface water to a specific collection point, such as a main river or lake. By understanding water flow patterns through terrain analysis, the potential for erosion, flooding, and water pollution can be measured in an area. This information is invaluable in managing water resources, land-use planning, and disaster mitigation. Terrain analysis is an analysis carried out to obtain a synthesis of the Earth's surface (Willson and Gallant, 2000). This analysis consists of tools adopting DEM to model the Earth's surface processes at various scales. DEM and its derivatives are part of a collection of digital terrain models (DTM) used in various fields to model material flow across the Earth's surface. Terrain analysis in hydrology characterizes how water and associated materials move across the landscape (Creed and Sass, 2011). This study required this analysis to determine the slope of the land and the level of wetness due to the formed topographic indentation. In addition, this analysis also found the possibility of accumulating pollutant collection from the area above it to determine how to handle it. The DEM map was obtained from the website of the Geospatial Information Agency with an accuracy of 8.5 meters (m). Furthermore, the Slope process in Qgis was carried out to find the slope level.

According to Fig. 4a, the DEM map shows that Batu City is at the lowest point in Pendem and Dadaprejo Villages, with an altitude of 580 meters above sea level (masl), and the highest point in Sumberbrantas Village, with an altitude of 3,317 masl. Fig. 4b displays that the slope ranges from 00 to 3070, where the sloping category is in the existing urban area. The highest slope is found in the Villages of Oro-Oro Ombo, Tlekung, Sumberbrantas, and Tulungrejo. The identification of the Topographical Wetness Level can be seen in Fig. 4c, where the most water accumulation is around the Brantas River and its tributaries. Administratively, this is in the villages of Pendem, Dadaprejo, Torongrejo, and Mojorejo.

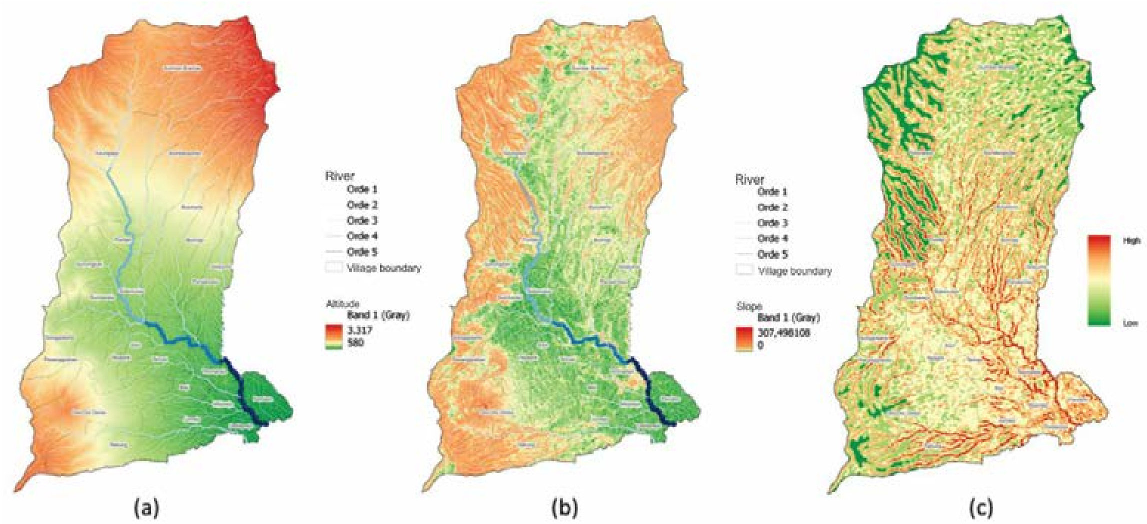

Fig. 4: Digital elevation model map: (a); Slope (b); Topographical Wetness Index (c)

RESULTS AND DISCUSSION

The characteristic of Batu City

On October 17, 2001, Batu City was officially separated as an Autonomous Region, which is no longer part of Malang Regency and includes three districts (Batu District, Bumiaji District, and Junrejo District) consisting of 19 villages and 4 urban villages. Batu City is the youngest autonomous city in East Java Province that has been experiencing rapid economic and population growth and playing a strategic role in maintaining the ecological sustainability of the Brantas watershed resources. The lands of Batu City are dominated by forests with a cold mountain climate, making this city a tourist attraction. In several tourism areas, most residents of Batu City work in the service support sector, including wholesale, retail, and business fields offering accommodation, food and beverages, arts, entertainment, and tourist attractions. The second business field that absorbs the most labor in Batu City is agriculture, forestry, hunting, and fishing (CBSBC, 2022b).

IPA analysis

Based on the analysis results, the formed IPA matrix can be seen in Fig. 5.

The analysis results indicate that economic growth (1), sustainable agricultural sector progress (4), social protection and employment programs (5), urban public transportation (11), orderly and easy licensing mechanisms (14), urban solid waste management (15), air quality yearly maintenance (17), and air temperature yearly maintenance (18) are included in quadrant I. Quadrant I shows attributes with high importance values and low performance, so the attributes in this quadrant must be the focus of management to increase the performance values. Quadrant II contains progress in education programs (6), supporting small industries (9), urban infrastructure to accommodate community needs (10), provision of green open spaces (16), disaster management (19), integration of capacity building for disaster prevention and management in schools (20), and strengthening disaster capacity in the neighborhood (21). Quadrant II covers attributes with high importance and performance values. Therefore, the quality of the management of the attributes in this quadrant is expected to be maintained so the performance remains good. Furthermore, quadrant III has both low importance and performance values. Attributes in quadrant III include informal employment in the non-agricultural sector (2), labor in the manufacturing industry sector (8), community participation in urban management planning (12), and Planning Dialogue Forum (13). Attributes in quadrant III have low management priority. Meanwhile, the contribution of the tourism sector (3) and the progress of the manufacturing industry (7) are included in quadrant IV, which has low importance but high performance. Attributes in quadrant IV are considered

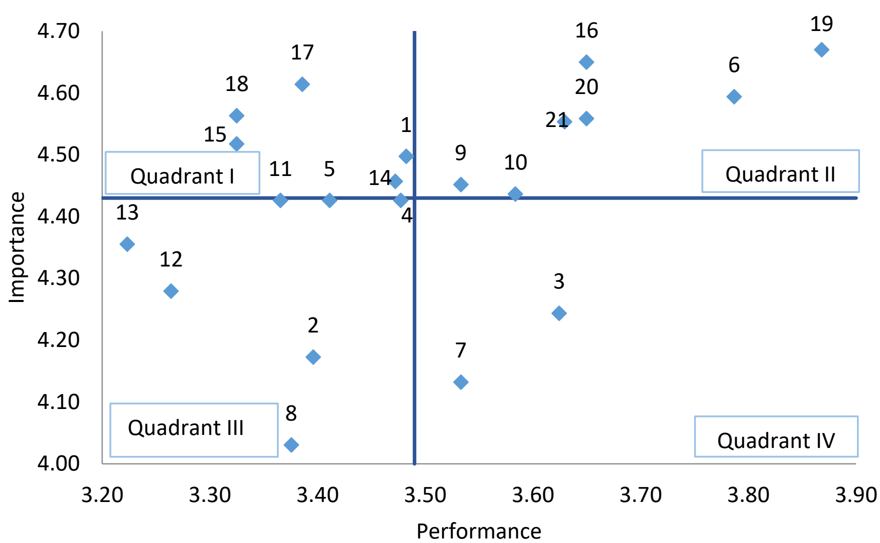

Fig. 5: IPA analysis result matrix on the sustainable development of Batu City

to have inappropriate and excessive management. Many studies have agreed that the carrying capacity of water resources is one aspect of sustainable development (Zhu *et al.,* 2002; Yang *et al.,* 2019). The community assessment analyzed in the IPA matrix (Fig. 4) shows the attributes that are considered important. However, their performance remains low and must be the management focus of the Batu City Regional Government to improve. These attributes include economic growth, sustainable agricultural sector progress, social and employment protection programs, urban public transportation, orderly and easy licensing mechanisms, urban solid waste management, air quality yearly maintenance, and air temperature yearly maintenance. Suppose it is associated with the lightly polluted condition of the Brantas watershed, among these attributes. In that case, 'management of urban solid waste' is related to this. As studied by Hoekstra *et al.* (2018), there is a strong correlation between waste management in cities and pollution in rivers and canals.

Terrain analysis

Batu City is located upstream of a large river in East Java Province, the Brantas watershed. The morphology of Batu City is influenced by the Brantas watershed. A hydrological analysis was essential to review how the accumulation of water flows from the morphological formation of the area. The hydrological analysis began with extracting DEM into watershed, flow direction, and filled DEM. The results of the filled DEM were processed by hydrological analysis in Qgis and produced river orders and channel networks. From this data, the flow accumulation area was calculated. The distribution of business and industrial activities in Batu City was concentrated along the main road from Malang City to Batu City and Pujon and from Batu City to Pacet. The overlapping concentration with Flow Accumulation (Fig. 6) and Flow Through (Fig. 7) demonstrated that business and industrial activities were found precisely in locations with high flow accumulation values. Thus, it was indicated that water pollution in Batu City was caused by business and industrial activities in the area of water flow accumulation.

The results of terrain analysis for Flow Accumulation (Fig. 6) and Flow Through (Fig. 7) showed that business and industrial activities were distributed in locations with high flow accumulation values, indicating that water pollution in Batu City was generated by the presence of business activities and industry in the watershed accumulation areas. Along the upstream Brantas watershed, 460 business and industrial activities were found. Companies and businesses operating around the Batu City watershed included real estate companies, tourism companies, flower plantations, horticultural plantations, canned mushroom industries, lodging (hotels, guesthouses, and villas), and eateries. Terrain analysis has become one of the essential approaches to preventing water pollution. In several cases, the application of this method successfully

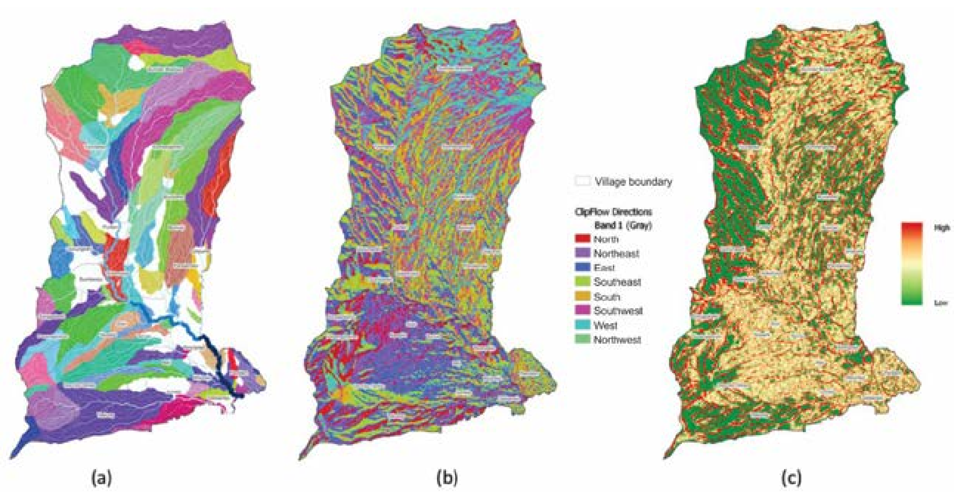

Fig. 6: Drainage watershed (a) Flow direction (b) Flow accumulation (c)

reduced the negative impacts of water pollution on the environment and human welfare. One example of the successful implementation of terrain analysis is the management of the Citarum River Watershed in West Java, Indonesia (Marselina *et al.,* 2022; Utami *et al.,* 2020). The Citarum River Watershed is one of the largest and most crucial river watersheds in Indonesia, providing clean water for over 25 million people. However, in previous years, the river experienced severe pollution due to the disposal of industrial and domestic waste. The application of terrain analysis in the management of the Citarum River Watershed includes detailed mapping and observation of the geographical, hydrological, and geological conditions in the area. This aims to identify critical points contributing to water pollution and areas vulnerable to pollution. With this information, the Government and local communities can design more effective strategies to reduce water pollution, such as constructing waste treatment facilities, enforcing regulations, and implementing greening initiatives in vulnerable areas. From the case of managing the Citarum River Watershed, it is important to note that the application of terrain analysis in water resource management is crucial for identifying critical points causing pollution and designing effective strategies to reduce the impact of pollution (Syeed *et al.,* 2023).

Water pollution of the upstream river

Compared with the data on the inventory status of the Brantas River conducted by Environmental Services in 2021, the Brantas watershed was in a mildly polluted condition with the terrain analysis results in this study (Figs. 6 and 7). Inventory data on the status of the Brantas watershed in the environmental carrying capacity and carrying capacity document in 2021 revealed that all chemical oxygen demand (COD) and biological oxygen demand (BOD) parameters, as well as several dissolved oxygen (DO), total suspended solid (TSS), phosphate (PO4), total coliform, and fecal coliform parameters have exceeded the Class I quality standard. Fig. 6 shows that industry and business activities in the Brantas watershed were mostly built in the Districts of Sumber Brantas, Tulungrejo, Punten, Sidomulyo, Sisir, Ngaglik, Pesanggrahan, Songgokerto, Beji, and Tlekung. This is in accordance with Darmawan *et al.* (2019). Total phosphate was assumed to be caused by residential waste, agricultural runoff, and plantations. Meanwhile, according to Yang *et al.* (2019), there were two sources of COD production, i.e., urban residents and industry. The study conducted by Wirosoedarmo *et al.* (2016) suggested that the change of forest land into dry land and plantations could affect the value of the Water Pollution Index occurred in the Brantas Coban Talun watershed. The

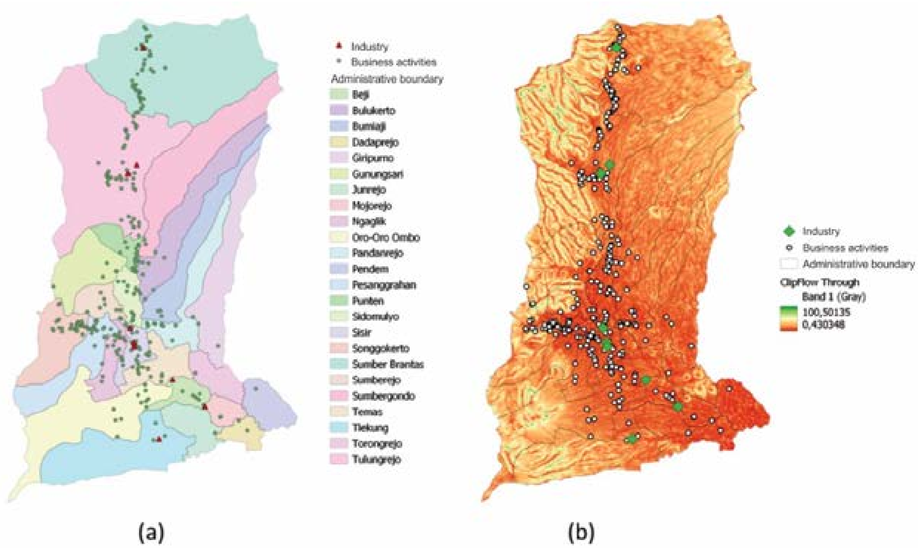

Fig. 7: Distribution of locations of business and industrial activities (a); Patching with flow through (b)

water pollution index status in 2008 met the quality standard, while in 2015, it was lightly polluted. The factors stimulating surface water pollution include agriculture, inadequate wastewater treatment, urbanization, and associated runoff and industrial activities. Pollution from nitrogen and phosphorus is a major problem caused by agriculture and wastewater stresses (Heneghan *et al.,* 2021). One activity that can potentially reduce water quality is agricultural intensification to increase agricultural production rapidly. The use of pesticides in agricultural intensification business activities is one example of a business that can reduce water quality (Lusiana *et al.,* 2017a). In turn, water pollution can contribute to water scarcity and impact the ecosystem and human health (Biswas and Tortajada, 2011). When groundwater or surface water sources are contaminated, it becomes unsuitable for use as untreated drinking water. At the same time, people experiencing poverty may not be able to afford treatment and face health risks. Communicable and non-communicable water-borne diseases have become a major source of human suffering and economic damage. In addition, poor sanitation may lead to urban water pollution. In many ways, water quality issues are much more complex than water quantity issues (Biswas and Tortajada, 2011; Falkenmark, 2011). The urban water environment is closely related to the residential environment, industrial development, and human health. As a result, the degradation and destruction of the urban water environment will result in widespread economic losses and security risks. Inventory data on industrial activities and business activities along the upstream area of the East Brantas River, as shown in Fig. 7, indicated that companies and businesses operating around the Batu City watershed consisted of real estate companies, tourism companies, flower plantations, horticultural plantations, canned mushroom industries, lodging (hotels, guesthouses, and villas), and eateries. In this regard, many studies examined that the problems of the Brantas watershed include the large proportion of land use changes to agricultural land and tourism without considering land conservation aspects (Lusiana *et al.,* 2017a), as well as the transfer of the riverbanks function designated as green areas whose function changes are not in accordance with their designation, for example, industrial or business activities (Sofyan *et al.,* 2015; Lusiana *et al.,* 2017b; Jariyah, 2018). As a city experiencing rapid urban development, environmental degradation is a risk that must be borne. Accordingly, Batu City must continue to develop good environmental management for the sake of nature conservation. The rapid development of cities has introduced many pollution-related challenges, such as the increasing need to collect and treat municipal waste (Chen, 2007). Environmental degradation is particularly challenging in rapidly developing urban areas where socio-economic development needs to consume large amounts of resources and emits many pollutants (wastewater, solid waste, and air pollutants) (Fan *et al.*, 2019). The significantly increased rate of economic growth and urban population growth creates challenges in terms of environmental pollution and overconsumption of resources (Yang *et al.,* 2013; Liu *et al.,* 2015). The population growth of Batu City was shown by the results of the 2010 population census projection. In 2021, the population of Batu City grew by 0.75%, while the population density reached 1,078 people/km^2 (CBSBC, 2022b). Meanwhile, the need for water resources will increase along with economic and population growth (Yang *et al.,* 2019). The quality of the aquatic environment reflects the sustainability of urban development and directly affects the quality of human life and the sustainable use of water resources (Kilkis, 2016). Increasing the level of urban socio-economic development is useful for increasing investment in technology for urban public pollution control infrastructure and other facilities. Meanwhile, implementing technology is effective in reducing energy consumption, reducing pollution emissions, and improving the urban environment. The attractive urban environment supports the improvement of the health situation of the urban population and attracts population inflows which help stimulate the economy and provide employment for social development. Fully socio-economically developed cities have further education, which is highly significant for encouraging people to practice a resource-saving and environmentally friendly lifestyle (Fan *et al.,* 2019). This illustrates that an urban system is a unit formed by the social economy and ecological environment subsystem (Wang *et al.,* 2011; Bai *et al.,* 2016; Fang *et al.,* 2016). As a result, several issues may be affected by the application of IPA and terrain analysis in this study to reduce water pollution. The first is identifying pollution sources. Participatory mapping with the community can help identify potential sources of pollution, such as industrial waste discharge, agricultural runoff, or untreated sewage. Integrating this information with terrain analysis can pinpoint pollution hotspots and enable targeted remediation efforts. The second is assessing vulnerability. Community participation can provide information on areas particularly vulnerable to water pollution, such as areas with high population density, poor sanitation infrastructure, or sensitive ecosystems. Overlaying this information with hydrological data from terrain analysis can help prioritize areas for intervention and protection. The third is developing effective management strategies. Collaborating with the community can help identify locally appropriate and culturally sensitive solutions for addressing water pollution. Integrating these ideas with terrain analysis data can help design effective and sustainable water management strategies that take into account local conditions and needs. The fourth is monitoring and evaluation. Engaging the community in monitoring and evaluation efforts can help track the effectiveness of implemented strategies, identify new pollution sources, and promote transparency and accountability in water management. One example of the successful integration of terrain analysis and participatory community information is the management of the Citarum River Watershed in West Java, Indonesia (Marselina et al., 2022; Utami et al., 2020). In this case, terrain analysis helped identify pollution hotspots, while community engagement facilitated the development and implementation of appropriate water management strategies. This collaborative approach resulted in improved water quality and more effective pollution control measures. In conclusion, combining terrain analysis in hydrology with participatory community information can provide valuable insights into water pollution and help prioritize remediation efforts. This integrated approach can lead to more effective and sustainable water management strategies that protect the environment and improve the well-being of communities. The following are some recomm-endations for the watershed's quality improvement. First, cooperation among the Government, comm-unities, and the private sector is essential in addressing water pollution issues. Second, the development of environmentally friendly technol-ogies in water treatment, such as biofiltration systems, can help reduce the negative impacts of water pollution on the environment and human welfare (Xu *et al.,* 2022). Third, education and outreach to communities about the importance of preserving water resources are also vital steps to prevent water pollution (Hemachandra and Sewwandi, 2023). Successfully managing the Citarum River Watershed can also serve as an example for other regions facing similar water pollution issues. The Brantas River Watershed in Batu City, which has been selected as a research area, also experiences similar problems; therefore, the successful management in Citarum can be replicated in this region. Water resource management based on terrain analysis, participatory approaches, and environ-mentally friendly technology-oriented solutions can be adapted and implemented in other areas according to their specific characteristics and local needs. For instance, developing countries facing water pollution challenges due to rapid industrial and urban growth can learn from and apply the successful approach implemented in the management of the Citarum River Watershed to address their water pollution problems (Marselina *et al.,* 2022; Utami *et al.,* 2020). In order to prevent water pollution, it is important to recognize that each region has unique characteristics and challenges. Therefore, an approach that is successful in one area may not always be suitable for implementation in another. However, by involving various stakeholders, including participatory mapping with importance-performance analysis, applying terrain analysis, and incorporating environmentally friendly technologies, effective and sustainable strategies can be effected for managing water resources. As a result, the environment will be protected, the negative impacts of water pollution will be reduced, and the welfare of communities worldwide will be improved.

CONCLUSION

In this study, IPA and terrain analysis are employed for identifying pollution sources, assessing vulnerability, developing effective management strategies, and monitoring and evaluation. The terrain analysis results reveal that business and industrial activities were distributed in locations with high accumulated flow values. Along the upstream Brantas watershed, 460 business and industrial activities have been found. Companies and businesses operating around the Batu City watershed comprise real estate companies, tourism companies, flower plantations, horticultural plantations, canned mushroom industries, lodging (hotels, guesthouses, and villas), and eateries. Therefore, it is identified that the water pollution in Batu City is caused by the presence of business and industrial activities in the accumulation area of water flows. When compared with the inventory data on the status of the Brantas River in the 2021 Environmental Carrying Capacity and Capacity document, all COD and BOD parameters and several parameters of DO, TSS, PO4, T. Coli and F. Coli have exceeded the Class I quality standard. Industry and many business activities in the Brantas watershed were built in the Districts of Sumber Brantas, Tulungrejo, Punten, Sidomulyo, Sisir, Ngaglik, Pesanggrahan, Songgokerto, Beji, and Tlekung. Regarding the lightly-polluted Brantas watershed, the results from the Community Assessment in IPA point out that 'urban solid waste handling' is one of the attributes considered important, yet the performance remains low. This study can be used as a reference for the Government, especially regarding the problems of the Brantas Watershed, which include the large proportion of changes in the function of land to agriculture and tourism without regard to the aspects of land conservation, as well as the transfer of the function of river banks designated as green areas, which are not in accordance with their designation. In turn, water pollution can impact the health of ecosystems and humans. Degradation and destruction of the urban water environment will result in widespread economic losses and security risks because the carrying capacity of water resources is an aspect of sustainable development. This should be the management focus of the Batu City Regional Government so that the performance increases. As a city experiencing rapid urban development, environmental degradation is a risk that must be borne, and accordingly, Batu City must continue to develop good environmental management for the sake of nature conservation. Therefore, enhancing the level of urban socio-economic development is beneficial for increasing investment in the technological level of urban public pollution control infrastructure and other facilities. Furthermore, increasing the level of technology is effective in reducing energy consumption, reducing pollution emissions, and improving the urban environment. In this case, the terrain analysis helps identify pollution hotspots, while community engagement facilitates the development and implementation of appropriate water management strategies. This collaborative approach results in improved water quality and more effective pollution control measures. In conclusion, combining terrain analysis in hydrology with participatory community information can provide valuable insights into water pollution and help prioritize remediation efforts. This integrated approach can lead to more effective and sustainable water management strategies that protect the environment and improve the well-being of communities. The following are some recommendations for the watershed's quality improvement: 1) cooperation among the Government, communities, and the private sector for addressing water pollution issues; 2) the development of environmentally friendly technologies in water treatment; 3) education and outreach to communities about the importance of preserving water resources.

AUTHOR CONTRIBUTIONS

The corresponding author, L. Sulistyowati, developed the idea and plan for this Project, collected the data for IPA, supervised the entire research, and reviewed and edited the manuscript. N. Andareswari collected the data for and performed IPA. F. Afrianto developed the idea and plan for this Project and performed the terrain analysis. A. Rais, M.F. Hafa, Darwiyati, and A.L. Ginting collected the data for IPA and conducted a literature review..

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
BOD	Biological oxygen demand
CBSBC	Central Bureau of Statistics of Batu City
COD	Chemical oxygen demand
DO	Dissolved oxygen
DEM	Digital elevation model
DEMNAS	DEM data provided as national data
DTM	Digital terrain model
ESBC	Environmental Services of Batu City
ha	Hectare
IPA	Importance-Performance Analysis
km	Kilometer
MFD	Multiple flow direction
mpsl	Meter above sea level
m	Meter
PO_4	Phosphate
SDGs	Sustainable development goals
TSS	Total suspended solid

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