



# JATIMPRO: A Native Species Reinforcement through the Penta Helix Approach in Brantas Watershed Management

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**Abstract.** The Brantas Watershed is a critical hydrological zone in East Java, underpinning essential services such as raw water supply, irrigation, industrial operations, and the livelihood of surrounding communities. However, shifts in land utilization, deforestation, and escalating pollutant inputs have significantly impaired water flow regulation, degraded the integrity of the watershed, and compromised water quality particularly in upstream regions that are crucial for water provisioning. These challenges present substantial threats to the long-term viability of regional water resource management. In response, a collaborative initiative led by a consortium of East Java's public universities aims to promote sustainable watershed governance. The program emphasizes the restoration of spring ecosystems, the reinforcement of native plant species, and the mobilization of local communities. Reforestation with indigenous vegetation has demonstrated positive impacts on both ecological resilience and watershed hydrology. Moreover, the adoption of inclusive governance models such as the penta helix approach has fostered cross sector collaboration, ensuring shared responsibility and adaptive management. Integrating ecological restoration with multi actor

institutional frameworks is vital to safeguarding water security and preserving the Brantas Watershed ecological function.

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## **1. Introduction**

The Brantas Watershed, the most extensive watershed in East Java, stretches over 320 kilometers and supports the livelihoods of more than 15 million residents<sup>1</sup>. It plays a crucial role in meeting regional demands for drinking water, agricultural irrigation, industrial processes, and hydroelectric power. Additionally, the river contributes significantly to sustaining ecological stability and regulating the hydrological cycle<sup>2</sup>. Given its multifaceted functions, the Brantas Watershed is often regarded as the backbone of water resilience in the region. Despite its strategic importance, the watershed is increasingly threatened by a combination of environmental degradation, shifting climatic patterns, and intensifying human activities, all of which undermine its capacity to provide essential ecosystem services<sup>3</sup>.

Recent hydrological assessments have revealed considerable changes in dry-season streamflow within several upstream areas of the Brantas Watershed during the past two decades<sup>4</sup>. These shifts are largely associated with extensive land-use transformation and reduced vegetative cover, both of which have adversely affected the overall hydrological functioning of the watershed<sup>5</sup>. Furthermore, previous assessments indicate that approximately 41.74% of the Brantas River Basin has experienced land degradation requiring rehabilitation, contributing to accelerated erosion, increased sedimentation, and reduced groundwater recharge capacity in upstream catchment areas<sup>6</sup>. These environmental stressors have substantially altered watershed hydrodynamics and weakened the system's capacity to respond to seasonal climatic fluctuations. These conditions highlight the necessity of implementing comprehensive rehabilitation measures and multi-stakeholder governance approaches to strengthen ecosystem integrity, improve adaptive hydrological capacity, and ensure the sustained availability of water resources within the Brantas Watershed.

One of the most critical challenges facing the Brantas Watershed is the growing threat of water scarcity. A marked decline in river discharge and spring flow, particularly in the upstream regions during the dry season, has been observed. Attribute this trend primarily to alterations in land cover, which diminish the soil's infiltration and water retention capabilities, thereby impairing both surface runoff and groundwater recharge<sup>7</sup>. These hydrological disruptions are compounded by the impacts of global climate change, which has led to altered precipitation regimes, rising ambient temperatures, and a higher incidence of extreme weather phenomena, including prolonged droughts and sudden floods<sup>8</sup>. Collectively, these factors highlight the Brantas Watershed's susceptibility to hydrological imbalance and climate induced stress.

In addition to hydrological concerns, shifts in land utilization have significantly compromised the ecological integrity of the Brantas River system. The replacement of forested areas with high intensity agriculture, urban development, and industrial zones has led to a substantial reduction in vegetative cover essential for regulating water cycles.

Such transformations have intensified surface runoff, accelerated erosion, and increased sediment accumulation along river channels<sup>9</sup>. Adding to the environmental burden, the detection of microplastics in the river underscores the complexity of pollution challenges, particularly given the limitations of traditional water treatment methods in addressing these contaminants<sup>10</sup>. Research conducted in the Jagir Sub-watershed further confirms that land cover changes are directly correlated with elevated concentrations of pollutants such as chemical oxygen demand (COD), total suspended solids (TSS), and excess nutrients, frequently surpassing established water quality thresholds<sup>1</sup>.

The degradation of water quality in the Brantas Watershed is further intensified by rising pollutant inputs originating from human activities. Effluents from residential areas, agricultural runoff, and industrial discharges continue to flow into the river, contributing to substantial deterioration in water conditions. Anthropogenic pressures remain a dominant factor in the declining water quality across numerous Indonesian watersheds, including the Brantas<sup>11</sup>. Moreover, recent investigations have detected microplastic contamination in the river system, raising serious ecological and public health concerns due to the potential bioaccumulation of these particles through aquatic food webs<sup>10</sup>. These findings underscore a shift in water pollution dynamics from traditional concerns such as elevated biochemical oxygen demand (BOD) and COD to emerging pollutants that are more complex and less manageable through conventional treatment approaches.

The diminishing functionality of the Brantas River catchment has significant repercussions for water security across East Java. The erosion of the region's ecological carrying capacity has resulted in increasingly erratic raw water availability, deteriorating water quality, and escalating treatment costs<sup>12</sup>. These impacts are felt across multiple sectors: communities experience reduced access to potable water, agricultural yields decline due to insufficient irrigation, and both industrial and energy sectors face growing uncertainty in resource supply. Consequently, the degradation of the Brantas watershed represents not only an environmental concern but also a broader socio-economic challenge requiring urgent intervention. In response, comprehensive restoration efforts are essential, particularly in the form of targeted reforestation initiatives. The strategic planting of endemic tree species in upstream zones and riparian buffers has proven effective in enhancing infiltration rates, sustaining spring flow, stabilizing soils, and mitigating erosion<sup>11</sup>. Beyond hydrological benefits, native vegetation contributes to biodiversity conservation, reinforces ecosystem processes, and bolsters the watershed's adaptive capacity in the face of climate variability<sup>13</sup>. Thus, reforestation serves as both a practical and sustainable strategy for restoring the Brantas watershed's ecological integrity.

State Universities with Legal Entity (PTN-BH) status in East Java have shown proactive engagement in the stewardship of the Brantas River Basin, particularly in its upstream regions. A recent example of their collaborative and sustainable initiatives is the "Akar Brantas, Nafas Jawa Timur" program. This effort brings together institutions such as Universitas Brawijaya (UB), Universitas Airlangga (UNAIR), Institut Teknologi Sepuluh Nopember (ITS), Universitas Negeri Surabaya (Unesa), and Universitas Negeri Malang (UM), working alongside government bodies like the East Java Environmental Agency and Perum Jasa Tirta I. The program includes a reforestation project at the Sumber Brantas Arboretum in Batu City, aimed at ecological restoration and watershed preservation. Furthermore, student involvement in practical field activities—such as site visits to Perum Jasa Tirta I (PJT I) and the Brantas Sampean Watershed Management Agency (BPDAS)—serves to enhance local competencies in soil and water conservation,

as well as in river ecosystem monitoring. These initiatives reflect the broader commitment of PTN-BH institutions beyond academic pursuits, encompassing community engagement, ecological rehabilitation, public education, and the reinforcement of resilience to climate change and land degradation. Such upstream interventions play a vital role in ensuring the sustainability and quality of water resources for downstream regions.

JATIMPRO (East Java Innovative Province) represents a flagship initiative launched by the East Java Provincial Government to foster transformative development driven by innovation, research, and multi-sector collaboration. This program serves as a strategic platform that integrates key stakeholders—such as universities, research centers, industry players, community organizations, and government agencies—to develop practical, sustainable solutions aimed at enhancing community well-being. The primary goal of JATIMPRO is to reinforce the regional innovation ecosystem by establishing a cooperative environment that promotes the application of research findings and technological advancements to address pressing local challenges. Additionally, the program seeks to build human capital in East Java by advancing both scientific expertise and entrepreneurial skills through activities including innovation incubation, capacity-building workshops, mentorship, and dissemination of research outcomes. JATIMPRO also actively engages youth, including students and emerging entrepreneurs, encouraging their participation in context-specific social and technological innovation processes. Furthermore, the initiative provides universities and research institutions with opportunities to assume pivotal roles in regional development planning and execution, thereby enhancing the contribution of higher education’s tridharma in advancing sustainable development goals (SDGs) at the provincial level.

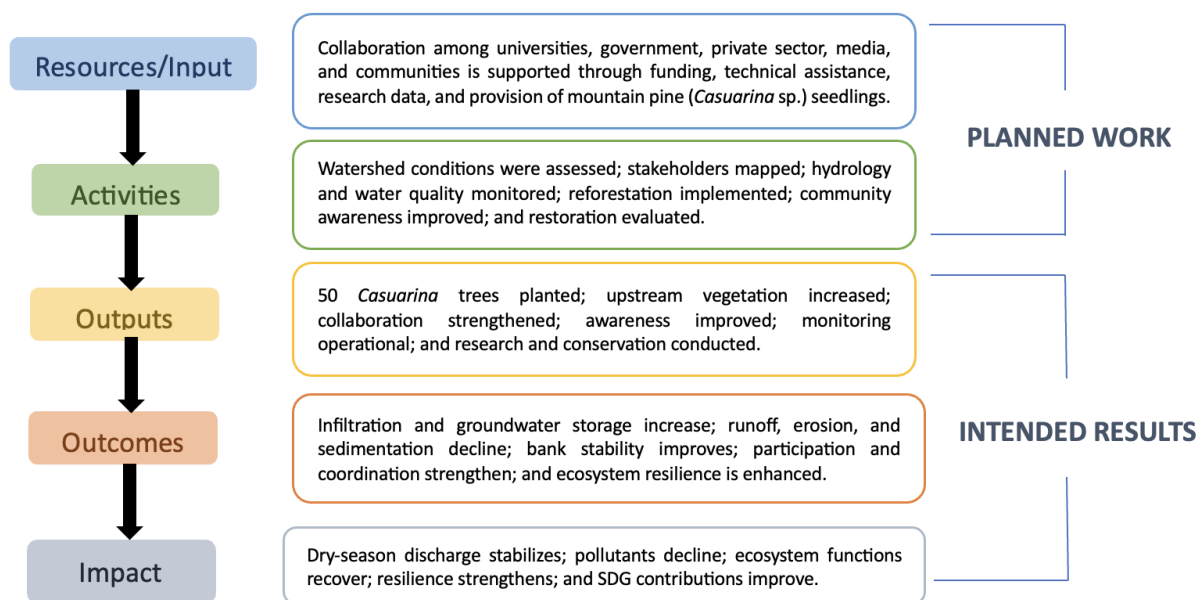


Figure 1. Diagram Theory of Change

This study is conducted to assess the application of the penta helix model in promoting sustainable management of the Brantas Watershed, with emphasis on the establishment of native tree species as a restoration strategy. The research is situated in the Sumber Brantas area, a critical upstream zone that plays a pivotal role in maintaining

the ecological balance of the watershed. By analyzing the collaborative roles of multiple stakeholders, this study seeks to generate empirical evidence on the effectiveness of the penta helix approach in watershed governance. The outcomes are expected to contribute to the broader discourse on sustainability and policy formulation for the Brantas Watershed management.

## 2. Methodology

### 2.1. Study Area

The JATIMPRO initiative concentrates its efforts in the upstream segment of the Brantas Watershed, specifically within the Sumber Brantas area, located in Bumiaji District, Batu City, East Java. This study area includes two strategic restoration points, which are the Sumber Brantas spring ( $7^{\circ}45'14.9''\text{S}$ ,  $112^{\circ}31'35.4''\text{E}$ ) and the Arboretum conservation zone ( $7^{\circ}45'32.7''\text{S}$ ,  $112^{\circ}31'39.8''\text{E}$ ). This site was strategically selected due to its role as a critical recharge zone and the primary source of the Brantas River. Its ecological and socio-economic importance is substantial, as the health and sustainability of this headwater area directly influence water availability and quality downstream<sup>14</sup>. Given that the Brantas River supports millions of residents throughout East Java, preserving the integrity of Sumber Brantas is essential for maintaining long-term water security and ensuring the continued provision of ecosystem services throughout the watershed.



Figure 2. Sumber Brantas Water Spring

### 2.2 Preparations

The preparation phases the program involves identifying and analyzing key challenges in the upstream Brantas Watershed, which include declining spring discharge, deteriorating water quality, shifts in land use patterns, and the overall reduction in

catchment functionality<sup>7,8</sup>. Following this diagnostic phase, relevant stakeholders both primary and peripheral are mapped. These include the Batu City Environmental Office (DLH), the East Java Provincial Environmental Agency, spring custodians, end-users of water resources, and local communities. The applied framework encompasses issue identification, data acquisition, and collaborative formulation of remedial strategies.

### 2.3 Native Tree Species Reinforcement

The approach employed in the native tree reinforcement program emphasizes reforestation using endemic species that are well-adapted to the specific ecological characteristics of the Brantas Watershed. In this program, a total of 50 *Casuarina* trees (*Casuarina* sp.) were planted as part of the native vegetation reinforcement strategy. The process begins with a comprehensive site assessment aimed at pinpointing critical zones in need of replanting, particularly within the upstream segments of the watershed. Subsequently, tree species are carefully selected based on criteria such as ecological compatibility, effectiveness in enhancing water retention, and overall contribution to watershed conservation<sup>14</sup>. Utilizing native species is preferred due to their superior adaptability to local soil and climatic conditions, alongside increased resilience against pests and diseases, thereby ensuring greater success and sustainability of reforestation efforts<sup>15</sup>.

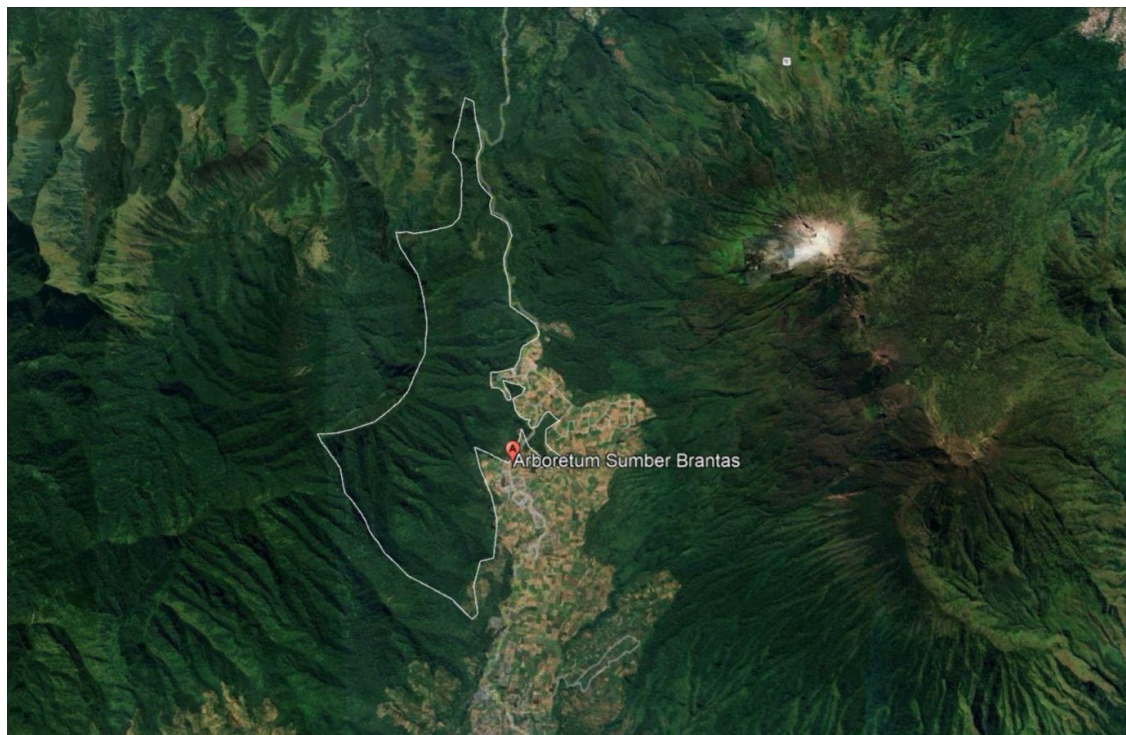


Figure 3. Arboretum Conservation Zone

The planting activities were conducted through a participatory approach that engaged students, researchers, local residents, and institutional stakeholders, including Perumda Air Minum Surya Sembada. These efforts aimed not only to expand vegetation cover but also to protect water springs and enhance the watershed's ecological capacity. According to<sup>22</sup>, successful watershed management relies on conserving native vegetation to promote long-term environmental sustainability. Alongside the planting efforts,

systematic monitoring of tree development and water quality was implemented. This monitoring employed techniques such as vegetation surveys, water quality assessments, and evaluations of community involvement. This integrated strategy reflects the principles of the penta helix model, which fosters collaboration among government bodies, academic institutions, industry, local communities, and media to ensure the sustainable management of natural resources<sup>16</sup>.

### 3. Results and Discussion

#### 3.1 The Role of Native Tree Species in Sustaining the Water Cycle

During the intervention, 50 *Casuarina* trees (*Casuarina* sp.) were planted in the Sumber Brantas area. Native tree species are essential for sustaining the hydrological cycle, especially within critical water catchment zones like the Brantas Watershed. The deep-rooting and extensive root networks characteristic of endemic trees enhance soil permeability, facilitating groundwater recharge and helping to maintain consistent spring flow year-round<sup>17</sup>. This ecological role is particularly vital in upstream locations, where the preservation of springs is fundamental to securing reliable water supplies for downstream populations. Previous studies have demonstrated that reforestation using native vegetation can significantly improve infiltration capacity, reduce runoff, and strengthen watershed hydrological functions, thereby supporting the claim that native tree reinforcement contributes positively to the water cycle<sup>18</sup>.

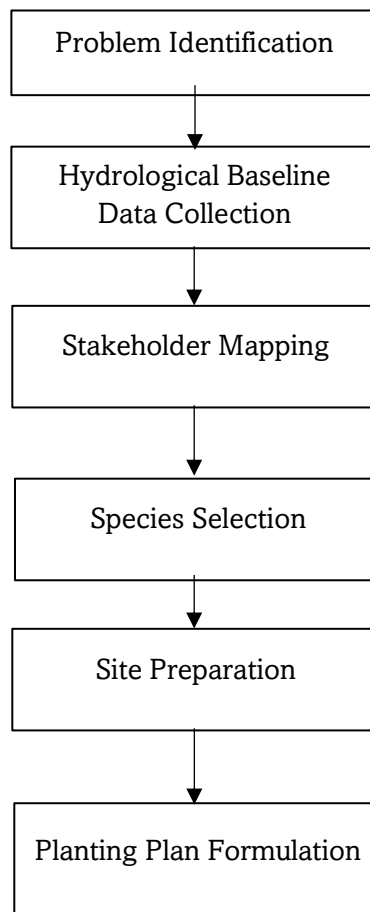


Figure 4. The workflow diagrams

From an ecological perspective, indigenous tree species play a vital role in enhancing biodiversity due to their adaptation to local soil and climatic conditions. Native trees also contribute significantly to enhancing water quality by functioning as natural filters. Fallen leaves, litter, and native plant roots filter sediment and pollutants before they reach water bodies. Tropical forests with native vegetation act as natural "biofilters," effectively reducing dissolved sediment levels and improving downstream water quality<sup>19</sup>. The contribution of native tree species to the hydrological cycle is strongly intertwined with climate regulation. Through evapotranspiration, indigenous vegetation releases moisture into the atmosphere, enhancing humidity levels that facilitate cloud development and increase the probability of localized rainfall. This dynamic illustrates a reciprocal relationship: while forests rely on precipitation for their growth and survival, they simultaneously influence regional climate patterns by generating conditions that promote rainfall<sup>20</sup>. Native plants provide stable habitats for a wide range of flora and fauna, thereby bolstering the ecosystem's capacity to withstand environmental fluctuations<sup>21</sup>. Studies conducted in the Watujali and Silengkong catchments in Kebumen indicate that areas surrounding springs with native vegetation exhibit significantly higher baseflow levels compared to regions dominated by exotic species<sup>22</sup>.

From a hydrological standpoint, endemic tree species play a crucial role in regulating essential components of the water cycle, including interception, stemflow, and throughfall. The canopy layer intercepts rainfall, limiting the volume of water reaching the soil surface, which in turn reduces surface runoff and mitigates peak flow events<sup>23</sup>. Research conducted in Hawaii demonstrated that native forests possess a superior canopy water retention capacity compared to areas overrun by invasive species, thereby enhancing runoff stabilization and preserving hydrological equilibrium<sup>24</sup>. In addition, the extensive and deep root systems characteristic of endemic trees promote increased soil infiltration, which supports groundwater replenishment and helps prevent soil erosion. Investigations into stemflow infiltration zones within mixed oak-beech forests revealed that water channelled along tree trunks creates concentrated infiltration hotspots, facilitating faster percolation into deeper soil strata<sup>25</sup>. Consequently, endemic vegetation contributes not only to sustaining surface water flows but also to maintaining groundwater reserves during periods of low rainfall.

The existence of indigenous tree species is vital for regulating and sustaining the microclimatic conditions within water catchment zones. Expanding forest canopy cover substantially diminishes surface heat accumulation during high temperature, enabling forested areas to sustain more stable and moderate thermal conditions compared to exposed or non-vegetated landscapes<sup>22</sup>. The structural complexity of a forest—encompassing canopy height, branch density, and the vertical arrangement of foliage—plays a crucial role in shaping the microclimatic characteristics within the canopy layer, particularly by regulating fluctuations in air temperature and humidity<sup>23</sup>. This microclimate effect is not only beneficial for the soil, but also influences the stability of local air temperatures. Areas dominated by native vegetation have lower daytime air temperatures compared to open areas or areas dominated by exotic vegetation<sup>24</sup>.

### **3.2 Penta Helix Model for Integrated Water Resource Management in Brantas Watershed**

Water resource management within the Brantas Watershed is confronted with multifaceted challenges, including reduced water flow, deteriorating water quality, and

increasing pressures from agricultural, industrial, and residential sectors. The complexity of these interrelated issues underscores the necessity for a comprehensive management approach grounded in collaborative engagement among diverse stakeholders<sup>26</sup>. The penta helix framework offers an effective model by integrating the efforts of government bodies, academic institutions, industry representatives, local communities, and the media<sup>16</sup>.

The penta helix model as seen in Figure 5 has demonstrated its effectiveness in multiple water resource governance initiatives across Indonesia. In this particular program, partnerships were established with key stakeholders, including Perum Jasa Tirta I, regional water utilities (Perumda Air Minum), and academic institutions such as Universitas Brawijaya (UB), Universitas Airlangga (UNAIR), Institut Teknologi Sepuluh Nopember (ITS), Universitas Negeri Malang (UM), and Universitas Negeri Surabaya (UNESA). The media, local communities, the Batu City Environmental Office, and the East Java Provincial Environmental Agency also played integral roles in supporting watershed management activities. Within this collaborative framework, the government is primarily responsible for policy formulation, regulatory enforcement, and the coordination of watershed, flood, and pollution management. Meanwhile, academic institutions contribute scientific research, hydrological analysis, and environmental technology innovations to support evidence-based decision-making and sustainable watershed governance.

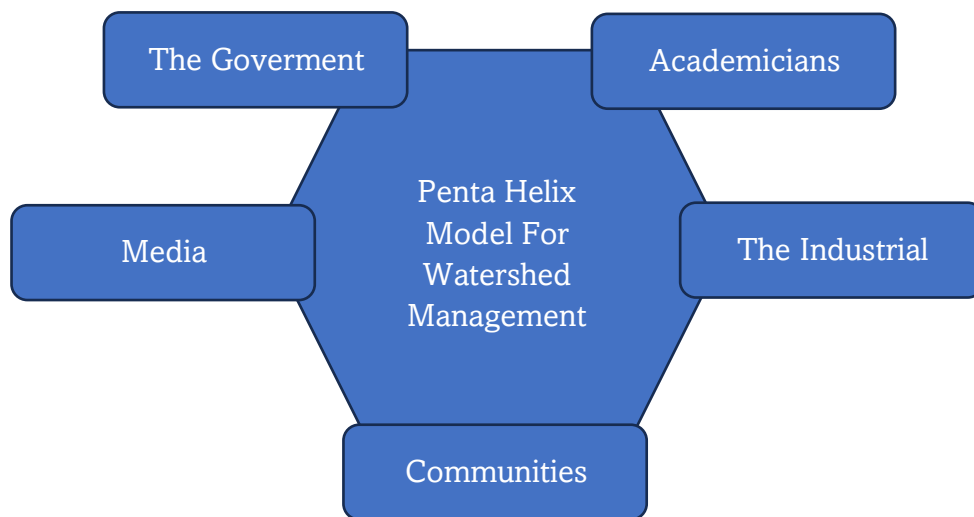


Figure 5. Penta helix model for watershed management

Universities serve as key actors in advancing the Penta Helix model by contributing scientific expertise and fostering innovation in environmental technology. Institutions such as UB, UNAIR, ITS, UM, and UNESA actively engage in research addressing water resource management, flood risk reduction, and watershed conservation across the Brantas Watershed. Academic researchers supply critical datasets, spatial analyses, and hydrological modelling frameworks that inform evidence-based policy formulation. In addition, universities drive the development of eco-innovations, including sensor-integrated water quality monitoring systems and microclimate mapping tools, which enhance ecosystem resilience to climate variability. Through community outreach initiatives and multi-sectoral collaboration, higher education institutions also strengthen the capacity of local communities and governments to implement sustainable

environmental management practices.

In the JATIMPRO program, the industrial sector contributes by adopting sustainable production methods and investing in advanced waste treatment technologies to minimize environmental impact. Local communities are essential actors in field-based conservation efforts, including the planting of native tree species, managing household waste, and protecting riparian zones. Their participation is particularly vital, as they serve both as primary beneficiaries and stewards of the water ecosystem<sup>27</sup>. Additionally, the media serves a strategic function by facilitating public communication, enhancing environmental awareness, and promoting accountability and transparency in watershed governance.

The implementation of the penta helix framework within the Brantas Watershed represents a strategic approach toward achieving more inclusive, sustainable, and integrated water governance. The active engagement of multiple stakeholders not only enhances the technical proficiency and adaptive capacity in watershed management but also reinforces a shared sense of accountability and long-term commitment to safeguarding the ecological stability of the Brantas River. By fostering collaboration among government institutions, academic entities, industries, local communities, and media organizations, the processes of planning, execution, and evaluation of water resource initiatives become more transparent, participatory, and grounded in scientific evidence<sup>28</sup>. This integrative approach facilitates the convergence of scientific knowledge, policy formulation, and on-the-ground implementation, producing adaptive decisions that respond effectively to evolving social, economic, and environmental conditions. The collaborative framework not only focuses on improving water use efficiency and mitigating hydrometeorological risks but also emphasizes the restoration of watershed ecological functions. As a transformative mechanism, the penta helix model serves as a catalyst for achieving equilibrium between environmental preservation and the equitable utilization of water resources. Moreover, it provides a scalable framework that can be replicated across other watershed systems in Indonesia to promote sustainable and inclusive water governance

### **3.3 Impact on Water Availability and Quality in the Brantas Watershed**

The Brantas Watershed is currently experiencing critical environmental stress marked by reduced spring discharge, inconsistent flow regimes, and declining water quality<sup>29</sup>. These issues are largely driven by land conversion, expanding industrial activities, and increasing domestic waste inputs. Such degradation poses a direct threat to water security in East Java, where over 15 million residents rely on the Brantas as a primary source of freshwater. Elevated concentrations of organic pollutants, excess nutrients, and the recent detection of microplastics in several stretches of the river highlight a shift from conventional water quality concerns to more complex and hazardous forms of contamination posing risks not only to aquatic ecosystems but also to human health<sup>30</sup>.

One effective ecological strategy for enhancing both water availability and quality is the restoration of landscapes through the planting of native tree species. Indigenous vegetation plays a vital role in promoting soil infiltration, supporting aquifer recharge, and mitigating surface runoff thereby reducing the risk of erosion and sediment accumulation<sup>31</sup>. From an ecological standpoint, reforestation efforts contribute to

improved soil integrity, enhanced species diversity, and the stabilization of local microclimates<sup>22</sup>. Consequently, implementing endemic-based reforestation in the upper reaches of the Brantas River holds significant potential for sustaining baseflow conditions while simultaneously improving overall water quality.

Beyond ecological measures, the effectiveness of Brantas Watershed restoration is strongly influenced by institutional dynamics, particularly through the adoption of the penta helix framework within the Integrated Water Resource Management (IWRM) paradigm. This collaborative model brings together five critical stakeholder groups: government agencies, academic institutions, the private sector, local communities, and media, each contributing distinct roles and expertise [32]. Public authorities are responsible for formulating regulatory frameworks and guiding conservation policy; scholars contribute empirical research and technological solutions; the business community engages through sustainable investment practices and corporate social responsibility (CSR) initiatives; community members act as stewards of upstream ecosystems; and the media facilitates public awareness and ensures transparency in policy implementation<sup>16,27</sup>.

The integration of endemic tree reforestation within the penta helix framework of Integrated Water Resources Management (IWRM) yields substantial hydrological advantages by enhancing water resilience across the catchment landscape. The establishment of native vegetation in upstream zones improves the soil's capacity for water absorption and retention, as the extensive and deep root systems of endemic species enhance soil permeability while reducing surface runoff velocity. This increased infiltration allows a greater portion of rainfall to percolate into subsurface layers, and studies indicate that such interventions can improve soil infiltration capacity by approximately 20-40% depending on initial land conditions<sup>33</sup>. Consequently, groundwater recharge is enhanced, potentially increasing baseflow contributions to rivers by around 10-25%<sup>34</sup> thereby facilitating aquifer replenishment and ensuring more stable discharge from springs and rivers throughout seasonal fluctuations. This aspect is particularly crucial in regions like the Brantas Watershed, where pronounced variations in water discharge frequently might lead to hydrometeorological hazards, including flooding during the wet season and droughts in the dry period<sup>35</sup>. Reforestation using native species also contributes to restoring balance within the hydrological cycle by enhancing the interplay between evapotranspiration and atmospheric moisture. The recovery of local tree cover promotes greater infiltration and water-holding capacity in the soil, thereby reinforcing the overall stability of watershed hydrodynamics<sup>36</sup>. Therefore, this approach enhances not only the soil's capacity to retain water but also reinforces long-term hydrological stability, which is fundamental for maintaining the sustainability and reliability of water supply systems<sup>15</sup>.

From a water quality perspective, the existence of endemic forest cover and native vegetation markedly decreases erosion and sediment deposition, which are primary drivers of aquatic quality deterioration<sup>37</sup>. The robust root systems of endemic tree species enhance slope and riverbank stability, thereby minimizing the risk of landslides and mitigating pollutant influx resulting from bank erosion<sup>38</sup>. A decrease in sedimentation rates directly enhances water transparency and lowers the concentration of suspended particulates and nutrient elements such as nitrogen and phosphorus that can contribute to eutrophication processes<sup>39</sup>. This condition fosters a more balanced and efficiently functioning aquatic ecosystem, where environmental stability supports natural biogeochemical processes such as organic matter decomposition, nutrient cycling, and

the maintenance of trophic network equilibrium<sup>40</sup>. Such ecological stability ultimately enhances the water system's resilience to external stressors, including pollution and thermal fluctuations, thereby sustaining long-term ecological equilibrium within the aquatic environment.

From an institutional perspective, cross-sectoral collaboration promotes shared accountability and reinforces the long-term governance framework for managing the Brantas River. The integration of ecological restoration with participatory and inclusive management holds substantial promise for enhancing water security across East Java—not only by improving resource quantity and quality, but also by ensuring the resilience and long-term sustainability of water supply systems amid emerging environmental and socio-economic challenges<sup>41</sup>. This collaborative framework facilitates the exchange of knowledge, expertise, and innovation among diverse stakeholders, thereby enhancing the overall effectiveness of water resource management strategies and policies. Partnerships that unite government institutions, academic researchers, private sector actors, community organizations, and the media promote greater transparency and ensure that planning and implementation processes are grounded in scientific evidence. Moreover, the active participation of local communities in conservation initiatives and environmental monitoring nurtures a stronger sense of stewardship toward regional water resources. The sustained synergy among these sectors forms a vital foundation for developing water governance systems that are resilient, inclusive, and adaptive to the evolving environmental and socioeconomic challenges of the future.

#### **4. Conclusions**

The Brantas Watershed, as the principal freshwater source for East Java, is under significant environmental stress due to diminishing discharge, deteriorating water quality, and ongoing land use transformations all of which pose a serious threat to regional water security. Reforestation using native tree species has demonstrated effectiveness in restoring hydrological processes by enhancing infiltration, stabilizing spring flow, and contributing to improved water quality. Concurrently, the implementation of the penta helix model within the Integrated Water Resource Management (IWRM) framework facilitates robust multi stakeholder collaboration, engaging government bodies, academic institutions, private sector actors, civil society, and the media. This integrated approach offers a strategic pathway to rehabilitate ecological functions, enhance institutional coordination, and support the long-term sustainability of watershed management.

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#### **Conflict of Interest**

The authors declare that there is no conflict of interest regarding the publication of this paper.

## Authors Contribution

All authors contributed substantially to the work. **N.F.** conceived the research idea and designed the methodology. **M.F.**, **A.W.**, **O.F.**, and **E.J.** carried out the experiments and data collection. **Z.Z.K.** and **M.B.P.P.** conducted the data analysis and interpretation. **N.F.**, **Z.Z.K.**, and **M.B.P.P.** contributed to the main manuscript writing. All authors reviewed and approved the final version of the manuscript.

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