

Malatgao Integrated Watershed Management based on Water Availability Assessment

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ABSTRACT:

Limited access to sufficient water resources hinders sustainable development, particularly in vulnerable regions. Integrated Watershed Management (IWM) is essential for ensuring water security by coordinating land, water, and other natural resources. However, its implementation is often constrained by inadequate hydrological data. This study analyzes water availability in the Malatgao River in Palawan, Philippines, to inform IWM strategies. Specifically, it aims to estimate missing streamflow data, characterize the river's flow regime, propose suitable management strategies, and validate them through stakeholder engagement. Random Forest regression was used to impute missing streamflow values, followed by creating a Flow Duration Curve (FDC), and stakeholder consultations through expert interviews and surveys. The Random Forest model demonstrated good prediction performance (RMSE=0.97; MAE=0.76). Results revealed probable flash floods during high-flow periods, though perennial storage supports sustained baseflow. Experts recommended a combination of nature-based solutions, structural measures, sustainable farming practices, strict land-use regulation, and community participation as Best Management Practices (BMPs) that are well-aligned with the basin's hydrologic conditions. Broad stakeholder support for these strategies implies a strong potential for successful IWM implementation in the Malatgao Watershed.

Keywords: Watershed, Random Forest, Flow duration curve, best management practices, Nature-based solutions, Stakeholder engagement

Introduction:

Global sustainability is not attainable without ensuring the availability of water for everyone. The current water shortage escalates quickly and impacts an increasing number of residential, commercial, industrial, and agricultural water consumers worldwide [1], [2], [3]. In recent years, constructive efforts have been made to enhance water security concerns. Water security encompasses the sustainable utilization and management of water resources, protection from

water-related risks, sustainable development of water resources, and protection of water functions and services for human communities and the environment [4], [5]. The Integrated Watershed Management (IWM) approach is one of the reliable planning strategies that the international community has accepted [6], [7]. Many studies discuss IWM broadly, but few explore detailed assessments of water availability specific to various ecological and socio-economic contexts. This study aims to evaluate sustainable

watershed management strategies based on a comprehensive understanding of water availability in the Malatgao River in Palawan, Philippines.

The lack of knowledge about the physical condition of water resources due to limited measurements, and a lack of institutional and technical capacity exacerbate the challenges faced by water managers across the globe [8], [9]. Therefore, current presumptions about water resources management, particularly the relationship between data, evidence, and decision-making in this process should be reassessed [10]. According to [11], a full dataset of streamflow records is necessary for water management in river basins and the design of water resources projects. Most often streamflow data at sites selected for management of water resources is unavailable or incomplete. The problem is particularly pronounced in developing countries, where not only is data scarcity an issue, but pressure on water resources is often already substantial and increasing [10]. In the Malatgao River, a gauge station exists provided by the Department of Public Works and Highways (DPWH) to monitor streamflow, however, it is not continuously operational resulting in long periods of missing streamflow data. Therefore, there is a pressing need to create methodologies that can effectively reconstruct missing streamflow data and enhance the completeness of hydrological datasets. In short, the primary motivation behind this study arises from the critical importance of ensuring accurate streamflow data in integrated watershed management.

Generally, this study aims to assess water availability in the Malatgao River, aiding the development of integrated watershed management strategies. Specifically, it seeks to estimate missing daily streamflow data; characterize the river's flow regime; evaluate water availability; investigate the differences in water availability among various periods; propose IWM strategies; and determine whether the identified management strategies align with community needs and preferences. This study will provide information about the variability and

reliability of water supply in the Malatgao River, enabling better planning and management of resources. It will also help in policy development and support the implementation of sustainable watershed management practices that provide water security for future generations. Ensuring water availability is one of the major goals (SDG6) of the UN2030 agenda for sustainable global development (UN, 2015). Commonly referred to as the 'water goal', SDG 6 provides a framework to achieve water security and is essential for meeting the targets of all the SDGs. Target 6.5 focuses on implementing integrated water resources management [12]. Additionally, the output of this study can significantly contribute to meeting the objectives of SDG 15, particularly in terms of conserving terrestrial ecosystems and promoting sustainable land use practices.

Methods and Methodology:

This study has four stages: (1) data collection and preprocessing employing a random forest model to predict the missing daily streamflow data in the Malatgao River; (2) water availability assessment; (3) statistical analyses; (4) evaluation and validation of IMW strategies using stakeholder engagement.

Data Collection and Preprocessing

The compilation of data for the study "Malatgao integrated watershed management based on water availability assessment" relied on secondary data to calculate water availability. The data in question included streamflow measurements from the Malatgao River gauge station, obtained from the Department of Public Works and Highways- Streamflow Management System database available at https://apps.dpwh.gov.ph/streams_public/home.aspx. Daily streamflow data for the destination site were compiled, noting the periods with missing data.

In data preprocessing, a Random Forest (RF) regression was employed to predict the missing daily streamflow values in the Malatgao River station. The RF model was implemented in Python 3.10.4 language. The

Scikit-learn 1.1.2 library [13] was used as the base library. The RandomForestRegressor from this library was used to address the issue of missing values in the dataset. The modules of the Scikit-learn library were integrated for data preprocessing including transformation using the MinMaxScaler normalization function and the TimeSeriesSplit function for data split specific to time series[14]. The training set comprised 70% of the dataset while the remaining 30% was assigned as the test set.

The Random Forest (RF) algorithm performed bootstrap sampling with replacement based on 70% of the training samples and 30% of the test samples. For each sample set, a decision tree was established. At the decision node in each decision tree, a random subset of N features was selected from the n ($n < N$) features of the sample set as the basis for the classification features of the node. After entering the decision tree of each sample data set, the feature at each decision node was selected from among the n features that best match the data for branch splitting, and the decision process was repeated at the next node until the decision tree can no longer branch[15]. The prediction performance of the RF model will be calculated using metrics like Root Mean Squared Error (RMSE) and Mean Absolute Error (MAE):

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The complete dataset was sorted in descending order. Each discharge value was assigned a rank (m), starting with 1 for the largest daily discharge value. Finally, exceedance probability (P) was calculated using the following formula:

$$P = 100 * [m / (N + 1)] \quad (1)$$

Where;

P = the probability of a given flow magnitude being equaled or exceeded (% of time) m = the ranked position on the listing (dimensionless)

N = the total number of stream flows (dimensionless)

Finally, the discharge values (Q) vs P were plotted, the resulting graph was the Flow Duration Curve (FDC).

The FDC was developed considering streamflow records extending over 10 years (2010-2020). Historical flow quantile estimates corresponding to 15 exceedance probabilities 0.1% ($Q_{0.1}$), 0.5% ($Q_{0.5}$), 1% (Q_1), 5% (Q_5), 10% (Q_{10}), 20% (Q_{20}), 30% (Q_{30}), 40% (Q_{40}), 50% (Q_{50}), 60% (Q_{60}), 70% (Q_{70}), 80% (Q_{80}), 90% (Q_{90}), 95% (Q_{95}), and 99% (Q_{99}) were calculated using Equation (2)[11]. [16] provide a detailed classification of flow, categorizing it into five classes: very high flow (with exceedance probability $< 5\%$), high flow (with exceedance probability 5–20%), average flow (with exceedance probability 20–70%), low flow (with exceedance probability 70–95%), and very low flow (with exceedance probability $> 95\%$).

Statistical analyses

The Kruskal-Wallis test was used to examine differences in water availability across time periods, followed by a post hoc test to identify which groups differed significantly. Water availability values were ranked for each period and compared to assess statistical significance. This analysis provided insights into patterns and trends in water availability in the Malatgao River over time.

Evaluation and Validation of BMPs

The best management practices (BMPs) to control or increase the amount of water in the Malatgao River were developed based on water availability assessment. A co-management approach and structured surveys were conducted with stakeholders. First, the results of the water availability assessment were presented to stakeholders (only technical experts). Next, participants were asked to propose management strategies they considered suitable for the Malatgao Watershed. Second, the perceptions of the three main stakeholders in the Malatgao Watershed were used to validate the identified IWM strategies. These three groups comprised local stakeholders, technical experts, and policymakers [17], [18].

This study employed a non-probability sampling technique. Six (6) barangays- Estrella Village, Malatgao, Tinagong Dagat, Sandoval, Bagong Sikat, and Dumagueña- located in the immediate vicinity of the Malatgao River were purposively sampled across three groups- technical experts, local stakeholders, and policymakers. This study targeted all available technical experts (managers and senior engineers) in the National Irrigation Administration (NIA)-Palawan Irrigation Management Office (PIMO) who have specialized knowledge of watershed management. A total of 5 technical experts, 53 local stakeholders, and 42 policymakers residing within the Malatgao Watershed were surveyed. Next, they were asked to answer the survey questionnaire according to their experiences, and indigenous, technical, and political knowledge. A 5-point Likert scale survey was used to measure the level of agreement among the three stakeholder groups regarding the expertrecommended watershed management strategies. A Kruskal-Wallis H test was performed to assess whether significant differences existed in the ratings among the groups.

Results:

Imputation of missing data

Figure 1 shows the completed daily streamflow records for 10 years from 2010 to 2020 at Malatgao river station. As shown in the plot, blue circles represent the known data showing the recorded daily streamflow measurements in the Malatgao River basin. The imputed data represented by yellow crosses was used to fill the missing values. Imputation was performed using a random forest regression to ensure that the missing values were closely aligned with the observed streamflow trends and underlying patterns. The root square mean error (RMSE) was computed to be 0.97, while the mean absolute error was calculated as 0.76. This implies a good prediction performance of the random forest model.

Natural flow regimes create temporal and spatial fluctuations in river water level and flow, which are crucial to maintaining productive environmental and ecological systems [19].

However, significant changes in river flow mainly caused by climate change and human intervention threaten ecosystem productivity and sustainable development. These changes can disrupt the integrity of rivers, contribute to bank erosion, lead to successive saturation and draining, and alter natural hydrological rhythms [20], [21].

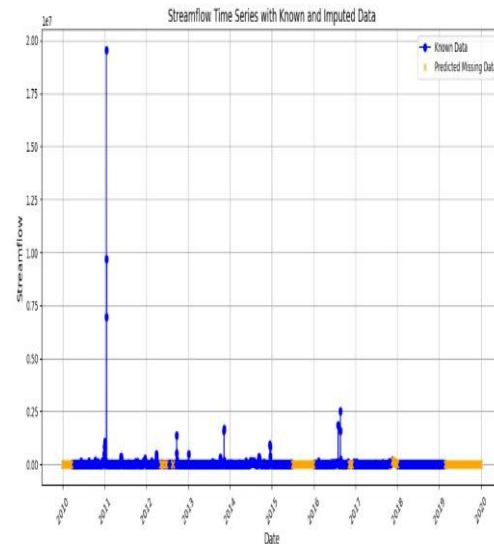


Figure 1. Time series plot of streamflow in L/s from 2010-2020 in the Malatgao River.

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The Malatgao River's flow duration curve, which exhibits a steeper slope at the upper end compared to the lower end is shown in Figure 2. It also presents a classification of flow based on exceedance probabilities and corresponding flow rates in liters per second (L/s). Flows were categorized into five distinct classes: Very High Flow, High Flow, Average Flow, Low Flow, and Very Low Flow. While the shape of the low-flow region characterizes the capacity of the basin to sustain low flows during dry seasons, the shape of the curve in the highflow region suggests the type of flood regime the basin is likely to experience, [22]. The steep slope near the upper limit of Figure 4 indicates a rapid decrease of flow as the exceedance probability increases. [22], [23] suggest that the river may experience intense flood events that doesn't long. The characteristics of the perennial storage in the drainage basin are illustrated by the slope of the lower end of the duration curve. A gentler slope

at the lower end of the FDC indicates that the basin has strong perennial storage, allowing it to sustain low flows for longer periods. Water managers need to consider these low-flow and high-flow events in planning and management to effectively mitigate the risk of water scarcity and flooding.

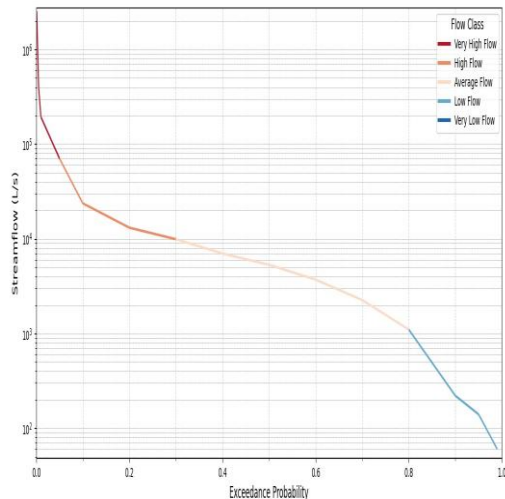


Figure 2. Water availability in the Malatgao River.

Statistical Analyses

Based on the Kruskal-Wallis Test, there is a significant difference among the flow rates. Therefore, the null hypothesis, which assume no significant difference in streamflow across various exceedance, is rejected.

Table 1. Kruskal-Wallis Test results for water availability assessment.

Source of Variation	Between Flow Classes
Degrees of Freedom	4
Kruskal-Wallis H	13.2
Asymptotic Significance	0.010*

Note: A significant difference was found between flow classes ($p = 0.010$).

A post hoc test was then used to determine which groups differ statistically. Figure 3 shows the results of Dunn's test with Bonferroni correction. The p-values are displayed in each cell within the matrix. They are color-coded; lower p-values are represented by darker shades of blue, while increasingly darker shades

of red represent values closer to one. The diagonal elements of the matrix comparing each flow level against itself, resulting in a p-value of 1, indicating no significant difference. The off-diagonal elements display p-values comparing pairs of different flow levels. The p-value comparing Low Flow and Very High Flow is 0.026-less than 0.05- indicated by a darker blue color. This suggests a statistically significant difference between these two flow levels. Such a significant difference in flow rate between very high flow and low flow periods highlights the need for seasonally adaptive watershed management-planning for flood protection during wet periods and drought resilience during dry periods.

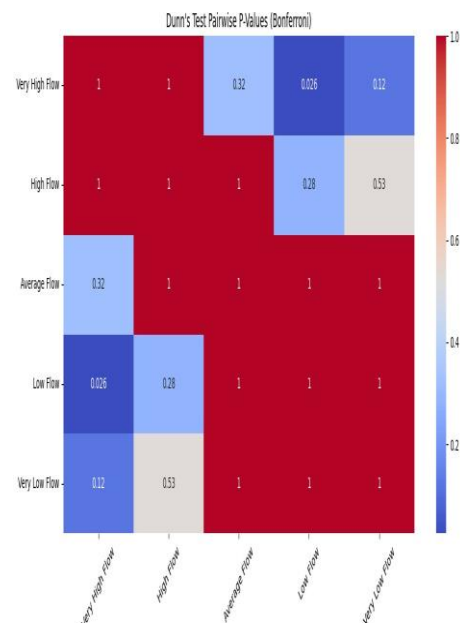


Figure 3. Results of Dunn's test with Bonferroni correction.

Recommended Best Management Practices for Watershed Management

The following are experts' recommended Best Management Practices (BMPs) suitable for the Malatgao Watershed, primarily to manage and mitigate the impacts of probable intense, short-lived floods during very high flows, and enhance water availability during low flows in the Malatgao River.

Nature-based solutions such as reforestation, assisted natural regeneration (ANR), streambank stabilization(bioengineering), riparian buffers, and the use of coconut coir mats for slope protection were found effective in restoring degraded lands, reducing erosion and enhancing water retention. By stabilizing soil and improving infiltration, they help reinforce watershed resilience. Structural and hydrologic interventions-including Sabo dams, dikes, and rainwater harvesting systems-serve as critical infrastructure to manage flood risks and conserve water. These practices reduce downstream damage during extreme weather events and promote sustainable water use. Soil and agricultural water management practices like contour plowing, terracing, and alternate wetting and drying (AWD) for efficient irrigation support water retention while minimizing erosion and water consumption. These strategies enhance both agricultural productivity environmental sustainability. With regard to policy and enforcement, strict regulation of quarrying and strengthened legal frameworks against slash-and-burn (kaingin) agriculture are essential to maintain watershed integrity. Poorly regulated land use activities significantly increase runoff, erosion, and sedimentation in nearby water bodies. Lastly, institutional and participatory approaches-including hydro-meteorological monitoring, collaborative coordination, public awareness campaigns, and the promotion of sustainable livelihood alternatives (e.g. agroforestry)- are crucial for long-term watershed management. These measures ensure inclusive decision-making, foster shared responsibility among stakeholders, and enable individuals and communities to thrive economically without compromising ecological health.

Table 2. Best management practices by thematic area for integrated watershed management.

Thematic Areas	Best Management Practice (BMP)
Vegetation & Land Cover Management	Reforestation and Assisted Natural Regeneration (ANR)

	Riparian Buffer Zones
	Streambank Stabilization (Bioengineering)
	Slope Protection Using Coconut Coir Mats
Structural & Hydrologic Interventions	Sabo Dams
	Protection Dikes
	Rainwater Harvesting Systems
Soil Management	Contour Plowing
	Terracing
Agricultural Water Management	Alternate Wetting and Drying (AWD)
Land Use Regulation & Enforcement	Strict Regulation of Quarrying Activities
	Strengthening Legal Framework to Prohibit Slash-and Burn Agriculture
Institutional & Technological Support	Monitoring and Forecasting Hydro-Meteorological Conditions
	Strengthening Joint Coordination Between Authorities & Communities
Community Engagement	Watershed Education and Awareness Campaigns
	Promoting Sustainable Livelihood Alternatives

Note: BMPs are grouped according to their corresponding thematic areas for integrated watershed management.

Validation of experts' recommended BMPs

Statistical analysis using Kruskal Wallis revealed no significant differences in the ratings of local stakeholders, technical experts, and policymakers for any of the identified BMPs. The ratings given by these three groups on the effectiveness and suitability of the BMPs for the Malatgao watershed were comparable with each other. This implies that the three groups share a common understanding on the effectiveness and

suitability of these BMPs in the Malatgao watershed.

Table 3. Kruskal-Wallis test results comparing the opinions of the three stakeholder groups.

BMP	Kruskal-Wallis H	Degrees of Freedom	Asymptotic Significance
Reforestation and ANR	0.000	2	1.000 ^{ns}
Riparian buffer zones	1.929	2	0.381 ^{ns}
Streambank stabilization (bioengineering)	1.925	2	0.382 ^{ns}
Slope protection using coconut coir mats	3.793	2	0.150 ^{ns}
Sabo dams	0.000	2	1.000 ^{ns}
Protection dikes	0.000	2	1.000 ^{ns}
Rainwater harvesting systems	0.395	2	0.821 ^{ns}
Contour plowing	1.010	2	0.604 ^{ns}
Terracing	0.662	2	0.718 ^{ns}
Alternate Wetting and Drying (AWD)	0.000	2	1.000 ^{ns}
Strict regulation of quarrying activities	1.792	2	0.408 ^{ns}
Strengthening Legal Framework against Slash-and-Burn	2.715	2	0.257 ^{ns}
Monitoring and forecasting hydrologic conditions	0.314	2	0.855 ^{ns}
Joint coordination between authorities & communities	3.656	2	0.161 ^{ns}
Watershed Education and Awareness Campaigns	0.887	2	0.642 ^{ns}
Promoting Sustainable Livelihood Alternatives	1.791	2	0.408 ^{ns}

Note: All differences are not statistically significant ($p > 0.05$), as indicated by ns as shown in Table 3.

Conclusions:

This study revealed that Random Forest regression is an effective method for predicting missing streamflow data with high predictive accuracy. The root square mean error (RMSE) of the random forest model was computed to be 0.97, while the mean absolute error (MAE) was calculated as 0.76. This implies a good prediction performance of the random forest model for the imputation of missing daily streamflow data essential for an accurate generation of a FDC. Additionally, a flow duration curve is a valuable tool to assess water availability by providing a good representation of flow variability, supporting watershed management decisions. Based on the results, the FDC has a steep slope near the upper limit, suggesting that the river might experience intense flood events that doesn't long. A gentler slope at the lower end of the FDC indicates that the basin has strong perennial storage, allowing it to sustain low flows

for longer periods. Statistical analysis using the Kruskal Wallis test revealed a significant difference in streamflow, particularly between the very high flow and low flow classes, indicating that these groups have distinct hydrological conditions-crucial for effective flood and drought management.

To mitigate the impact of probable flash floods and sustain baseflows in the Malatgao River, experts recommended nature-based solutions for vegetation and land cover management such as reforestation and Assisted Natural Regeneration (ANR), riparian buffer zones, streambank stabilization (bioengineering), and slope protection using coconut coir mats as BMPs. For structural and hydrologic interventions, experts suggested the construction of Sabo dams, and protection dikes for flood control, rainwater harvesting systems for water conservation, and the use of AWD for efficient irrigation. Contour plowing and terracing were

also seen as ideal and effective soil management suitable for the Malatgao watershed as they improve groundwater recharge. For land use regulation & enforcement, strict regulation of quarrying and other land-disturbing activities, and strengthening legal frameworks to prohibit illegal slash-and-burn agriculture were also identified as crucial practices. Monitoring and forecasting hydro-meteorological conditions and strengthening joint coordination between authorities & communities were recommended as best institutional & technological support. Lastly, watershed education and awareness campaigns and promoting sustainable livelihood alternatives were identified as significant BMPs by experts. According to surveys, there is general acceptance of these BMPs among three stakeholder groups- local residents, technical experts, and policymakers-within the immediate vicinity of the Malatgao River Basin, indicating strong potential for successful IWM implementation in the watershed.

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Data Availability:

The data supporting the finding of this study are available from the relevant repository/datasets link.

Conflict of Interest:

The authors declare no conflict of interest.

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