Water ecosystem services of Merawu Watershed, Banjarnegara, Central Java, Indonesia

H P Astuti\(^1\*) and H Suryatmojo\(^2\)

\(^1\)Master of Environmental Science, Universitas Gadjah Mada, Indonesia
\(^2\)Faculty of Forestry, Universitas Gadjah Mada, Indonesia

\(^*\)E-mail: heni.puji.a@mail.ugm.ac.id

Abstract. Merawu watershed is one of the upstream areas of Serayu Watershed that serves as catchment area and protect the downstream area. In addition, the condition of natural landscape development which is accompanied by population growth potentially affects spring water ecosystem services. This study aims to determine the potential condition of spring as one of water providers in Merawu, then also to analyze the status of spring. Water balance analysis and Pollution Index (IP) analysis ecosystem services management were used. In this study, 12 springs were discovered with Kasimpar spring having the highest discharge (5.01 liters/second). The overall condition of the spring ecosystem services is one of surplus water / carrying capacity has not been exceeded (Dda ratio > 1), and the condition appropriate with water quality standards (IP < 1). In conclusion, this study plays an important thing to figure it out about the existence of water ecosystem services in this area, as well as being a pioneer study on Payment for Ecosystem Services (PES) model in Banjarnegara Regency with an integrated upstream-downstream concept and based on the principle of sustainability.

1. Introduction

The Merawu watershed is one of the upstream areas in the Serayu river basin, located in Banjarnegara Regency, Central Java Province Indonesia. Merawu watershed as an upstream area has function to protect downstream area and becoming catchment area. Watershed ecosystem has a function, one of which is to provide materials and ecosystem services that are required to meet human needs, either directly or indirectly [1].

One of the ecosystem services that humans can use is the provision services, particularly water ecosystem services [2] The use of various types of ecosystem services will have an impact on human well-being and quality of life [3]. In the context of a watershed, the greater the area's ability to support human life and other living, the higher carrying capacity of area [4]. Within a watershed, the quality, quantity and timing of water draining into and flowing along rivers is modified by topography, geology, soil type, vegetation cover, land use and other human activities. Along the way, water is lost – primarily via evaporation from lakes, wetlands, the soil surface and wet vegetation, and through transpiration by plants and trees. Water moving down slopes and stream channels, as well as underground, may carry sediment, nutrients and other chemicals or contaminants. The quality and quantity of water available to downstream users in a watershed thus depends on the particular types and distribution of vegetation, the underlying geology, the soil types present and the way that land is used and managed [5]. In watershed, sustainable upstream land management practices are expected to help protect or improve the quantity and quality of water in the entire of watershed [6]. The relationship between the condition of ecosystems in a watershed and its capacity to provide watershed services is fundamental to the concept of payments.
for watershed services. It is the basis for linking the needs and welfare of downstream users of water or aquatic resources to the actions of managers responsible for upstream waterways, vegetation cover, soil use and land management.

Merawu watershed is currently in a critical condition caused by population growth and regional developments. Increasing human population and advancing levels of social and economic development have led to a rapid increase in the demand for freshwater provisioning services. In its natural state, fresh water varies considerably in terms of its availability in time and space [7]. In addition, it is undeniable that humans need land and water resources. Land conversion from forest into intensive agriculture is one of human effort to meet these needs. The conversion of the land affected on land cover change, reducing catchment areas, and then also changing hydrological process on area such as increasing surface runoff (Figure 1). Any land conversion will affect the water balance and connected to ecosystems. hydrological cycle plays a very important role in maintain the seasonal water availability, which is necessary to take decisions in water resources management. Land use change is one of the dominant driving factors of hydrological change at the watershed scale. Thus, understanding the hydrological responses to land use changes can facilitate development of sustainable water resource management [8-10]. All activities involving human behaviour in the upstream area potentially affect the entire Merawu watershed and accelerated the degradation of the area. The type of land use in Merawu watershed makes a large contribution to sedimentation in Mrica Reservoir.

Figure 1. The upstream area of Merawu Watershed

Clean water ecosystem services are available from a variety of water sources, including rainwater, groundwater, surface water, and springs [11]. Ground water is one of the most essential resources for the maintenance of human life. On a global scale, 20% of the irrigation water and 40% of the water used in industry are derived from ground water. Groundwater recharge via precipitation is complemented by naturally infiltrating surface water or by artificial recharge. In the opposite direction, ground water leaves the subsurface via springs and wetlands (sustaining groundwater-dependent ecosystems = supporting service, drought attenuation = regulating service), enters surface waters (provision of water and nutrient cycling = supporting services), or is being exploited for different types of usage, the latter directly contributing to the category of provisioning ecosystem services and goods [12]. Springs ecosystems are places on the Earth’s surfacethat are influenced by the exposure, and often the flow,of groundwater. Springs ecosystems are globally abundant, geomorphologically diverse, and bio-culturally productive, but are highly imperiled by anthropogenic activities. Springs considered to be perennial if their discharge was constant, and “intermittent” if discharge was interrupted, periodic, or sporadic (episodic) on a seasonal, annual, intermittent, or entirely erratic basis. [13,14].

Water ecosystem services are important for achieving sustainable development goals, but when the ecosystem is degraded, it becomes a barrier to achieving sustainable development [15]. One source of water which is used by most of the population in the Merawu watershed area is a source of water springs. Basically, the potential of water resources is divided into two, namely related to water supply and related to water demand [16]. To maintain the condition of water sources in the form of springs in the Merawu watershed area, it is necessary there is a balance between supply (water supply) and utilization (water demand). One of the initial efforts to achieve a balance between the supply and use of spring ecosystem
services in the Merawu watershed is to look at the condition and status of the spring ecosystem services so that they remain sustainable. Until now, there has been no research study that focuses on the condition and the potential of ecosystem services for providing clean water in the Merawu watershed, especially water sources from springs. Based on the critical condition of the Merawu watershed, it has the potential to affect the condition of the watershed and the potential of spring ecosystem services as a source of regional clean water. This study aims to determine the potential condition of spring as one of water providers in Merawu, then also to analyze the status of spring, it will be useful as pioneer research for developing of water ecosystem services management.

2. Methodology

The research focused on the entire Merawu watershed area with an area of 23,717.4 ha and covers 8 sub-districts, namely Banjarmangu, Batur, Kalibening, Karangkobar, Madukara, Pagentan, Pejawaran, and Wanayasa. Administratively, the Merawu watershed is located on Banjarnegara Regency, Central Java Province. Based on its geographical location, it is located at 109° 41' 24" - 109° 50' 24" East Longitude and 7° 10' 12" - 7° 22' 12" South Latitude.

![Research sites](image)

Figure 2. Research sites

Water balance analysis is used to identify the water balance of the watershed area. There are two components used in the calculation of the water balance, namely as water supply and water demand. Different calculation from this formula showing the water ecosystem services (Deficit (DA) / Surplus (SA). If SA>DA, the springs’ carrying capacity is surplus, whereas if SA<DA, the springs’ carrying capacity in the Merawu watershed is deficit/exceeded [16]. In this study, water demand (DA) is calculated using the respondent's water use approach from springs for domestic needs. The calculation of domestic or household water use is based on the need for drinking, cooking, bathing, and washing latrines. Whereas water supply (SA) is calculating using volumetric discharge.

\[
\text{water balance} = Q \text{ water supply} - Q \text{ water demand} \tag{1}
\]

Where, Q water supply is spring total availability (liters/years atau \(\text{m}^3/\text{year}\)), Q real use of spring /demand = Total use of springs (liters/years atau \(\text{m}^3/\text{year}\))

The value of the carrying capacity of water based on ecosystem services that provide water can also be expressed in the value of the comparison ratio (DDL A), where comparasion of the value of water supply and demand.

\[
DDL_a = \frac{SA}{DA} \tag{2}
\]

DDL a < 1 = a lack of water carrying capacity (beyond the limit), DDL a 1-3 = Medium water carrying capacity (conditional/moderate), DDL a >3 = a large capacity for water
Furthermore, for quality measurement data at springs based on physical and chemical parameters taken in the field and then compared with water quality standards. Referring to the results of the spring water quality analysis, it is status can be determined using the Pollution Index (IP) method approach as outlined in the Minister of the Environment Decree Number 115/2003 [17]. Based on the Pollution Index (IP) value approach, there are several water quality statuses, which are as follows.

1. In good condition (meets quality standards) with an IP value of (0 < IP < 1.0);
2. Lightly polluted by IP value (1 < IP < 5);
3. Moderately polluted by IP value (5 < IP < 10);
4. Heavily polluted by IP value (10 < IP).

3. Result and Discussion
The presence of clean water in the form of springs in the Merawu watershed area is one of the potential sources of clean water ecosystem services that residents can access. According to the quantity and quality conditions, 12 springs in the Merawu watershed have generally good physical quality with fresh conditions and still flowing during the dry season. Information on the distribution of springs in the Merawu watershed area is critical for water management and distribution to underserved communities.

Tabel 1. Quality and quantity of spring in Merawu Watershed

| Parameter | Value |
|-----------|-------|
| Discharge (liters/second) | 1.15 |
| DHL < 500 μmhos/cm | 1.05 |
| Turbidity 25 NTU | 0.45 |
| Temperature °C | 5.01 |
| pH | 1.02 |
| Dry conditions | 0.71 |
| Flow | 1.06 |
| Flow | 1.39 |
| Flow | 0.57 |
| Flow | 0.36 |
| Flow | 1.25 |

According to the results, springs in the Merawu watershed area have a discharge range of class V (1-10 liters/second) and VI (0.1-1 liters/second), DHL of spring sources ranges from 26 -168 mhos/cm, pH value ranges from 6.26 to 7.7, temperature ranges from 24.6°C to 37.7°C, and turbidity ranges from 0.11-17.60 NTU, as can be seen in Table 1. The presence of abundant water will result in a variety of vegetation in the area. Lithology, geomorphology, topography, aquifers, and surface hydrological characteristics all have a strong influence on the potential and presence of springs (Santosa et al, 2014). On the other hand, type of ecoregion and land use also influence to the spring’s presence.

The Merawu watershed area is dominated by landforms originating from structural processes, which are strongly influenced by geological structures. Geologically, the constituent rocks in the Merawu watershed are very diverse with the largest majority consisting of andesite lava, volcanic clastic rocks, and volcanic breccias with the geological structure formed is the type of fault. Lava rock has characteristics as an aquifer or a good water-carrying layer. The presence of these constituent rocks illustrates the biodiversity and potential of the area such as the number of springs appearing.

The researchers grouped several springs in the same village location among the 12 springs to calculate the availability of spring discharge / water supply. Kasimpar spring has the potential for the availability of the largest spring, which has a total discharge value of 157,890.530 liters/ year, or equivalent to 157,890 m³/year. This presence is influenced by the landuse around spring, which is near to the forest. Madukara has the lowest water availability, with 29,536,332 liters/year, or 29,536.3 m³/year. Leksana spring, Kalilunjur spring, and Grogol spring have the highest total use of water from springs in the Merawu watershed area, with 42,380,992 liters/year/population, 34,073,906 liters/year/resident, and 30,943,037 liters/year/resident. Water balance analysis results show that the
availability of water from springs in each village in the Merawu watershed area has a surplus of water, as indicated by a DDLa ratio value greater than one.

### Table 2. Water balance from springs in Merawu Watershed

| No | Springs   | Sub-district     | population | Demand (liter/year) | Supply (liter/year) | Water balance (liter/year) | Ratio DDLa | Status DDLa |
|----|-----------|------------------|------------|--------------------|--------------------|----------------------------|------------|-------------|
| 1  | Kalilunjar| Banjarmangu      | 1491       | 34,073,906         | 55,947,998         | 21,874,092                 | 2          | Moderate    |
| 2  | Rakitan   | Madukara         | 1205       | 27,537,932         | 29,536,332         | 1,998,400                  | 1          | Moderate    |
| 3  | Leksana   | Karangkobar      | 1855       | 42,380,992         | 33,137,205         | -9,243,786                 | 0.8        | exceeded    |
| 4  | Paweden   | Karangkobar      | 686        | 15,665,770         | 32,044,657         | 16,378,887                 | 2          | Moderate    |
| 5  | Slatri    | Karangkobar      | 1241       | 28,360,642         | 36,205,788         | 7,845,146                  | 1          | Moderate    |
| 6  | Grogol    | Pejawaran        | 1354       | 30,943,037         | 47,347,745         | 16,404,708                 | 2          | Moderate    |
| 7  | Kasimpar  | Wanayasa         | 845        | 19,299,405         | 157,890,530        | 138,591,125                | 8          | Good        |
| 8  | Pagergunung| Wanayasa        | 1012      | 23,127,292         | 43,700,348         | 20,573,056                 | 2          | Moderate    |
| 9  | Penanggunung| Wanayasa        | 1210      | 27,640,771         | 39,420,000         | 11,779,229                 | 1          | Moderate    |

The results of calculating the status of water quality from springs using the Pollution Index (IP) method show that all springs in the Merawu watershed area are in good condition status that meets quality standards with an IP value score of < 1 with the parameters used are electrical conductivity, pH, and turbidity. The status of the best spring quality is at the Kasimpar spring with an IP value of 0.07, followed by Slatri springs, Leksana springs and Kalilunjar 2 springs with IP values respectively 0.21, 0.23, and 0.24. If the IP score is <1, it means that the spring is in good condition and according to quality standards. The Merawu watershed is influenced by geological factors, vegetation and land use conditions around the springs which affect the parameters used in calculating IP values. Leksana springs are in a deficit condition, but the results of the water quality are in good condition that meets the quality standards. The deficit condition in the Leksana spring is influenced by the findings of researchers who can only found one spring in the area, but if further studies are carried out, the area has the potential to have a water surplus. The appearance of spring ecosystem services in Merawu watershed area is an advantage for people who live in this area to support the fulfillment of water needs. On the other hand, landscape conditions contain with landform ecocoregion unit fault structural mountains and land uses such as agroforestry make the area potential of spring. Cooperation is required between the government and community for managing spring ecosystem services. Based on the condition of the area that has been degraded, the Merawu watershed requires a conservation effort to save the area to protect the area's water ecosystem services so that it remains sustainable for the future. One of the efforts is to rehabilitate the area through an agroforestry pattern and formulate a design payment for ecosystem services.

### Table 3. Spring ecosystem services status

| Spring Code | Springs | Pollution Index (IP) | Condition | Carrying capacity (Dda = S/D) |
|-------------|---------|----------------------|-----------|-----------------------------|
| 1           | Slatri  | 0.21                 | Good condition and on the standard quality | Surplus          |
| 2           | Leksana | 0.23                 | Good condition and on the standard quality | Deficit          |
| 3           | Grogol 1| 0.61                 | Good condition and on the standard quality | Surplus          |
| 4           | Grogol 2| 0.59                 | Good condition and on the standard quality | Surplus          |
| 5           | Kasimpar| 0.07                 | Good condition and on the standard quality | Surplus          |
| 6           | Paweden | 0.42                 | Good condition and on the standard quality | Surplus          |
| 7           | Kalilunjar 1| 0.27             | Good condition and on the standard quality | Surplus          |
| 8           | Kalilunjar 2| 0.24            | Good condition and on the standard quality | Surplus          |
| 9           | Pagergunung| 0.25            | Good condition and on the standard quality | Surplus          |
| 10          | Rakitan | 0.55                 | Good condition and on the standard quality | Surplus          |
| 11          | Bogoan  | 0.33                 | Good condition and on the standard quality | Surplus          |

### 4. Conclusion
In general, the spring ecosystem services' status as a provider of clean water in the Merawu watershed is good and in accordance with water quality standards, as evidenced by the Dda value > 1 and the IP value < 1. Researchers recommend developing a compensation scheme for environmental services and
implementing an agroforestry pattern with Multiple Purpose Tree Species (MPTS) plants as a strategy for managing spring ecosystem services in the Merawu watershed area

References

[1] De Groot R S, Wilson and Boumans R M J 2002 *J. Ecological Economics* *41* 393-408
[2] Millennium Ecosystem Assessment 2005 *Ecosystem and Human Well-being Multiscale Assessments 4* (London: IslandPRESS)
[3] Amaruazaman S, Leimona B, Tanika L 2018 *Guidelines for the Implementation of Payments for Environmental Services* (Indonesia: World Agroforestry Centre)
[4] Muta’ali L 2019 *Environmental Services-Based Carrying and Accommodating Capacity for Environmental Planning* (Yogyakarta: UGM Faculty of Geography Publishing Agency)
[5] Ina P, Bruce A and Jeff D 2013 *Monitoring Payments for Watershed Services Schemes In Developing Countries* (London: International Institute for Environment and Development)
[6] International Union for Conservation of Nature 2006 *Established Payments for Watershed Services* ed Mark Smith *et al* (Switzerland: IUCN) p 15
[7] Bruce A, Jayanta B, and Juan C B 2005 *Ecosystems and Human Well-being: Policy Responses.* Ed Robert C *et al*
[8] Castro A J, Julian J P, Vaughn C C, Mikle C J M, and Soriano C Q 2018 *Ecosystem Services and Global Ecology*
[9] Hu J, Wu Y, Wang L, Sun P, Zhao F, Jin Z, Wang Y, Qiu L, and Lian Y 2021 *Journal of Hydrology* 593
[10] Altdorff D, Galagedara L, and Adian U 2017 *Journal of Water and Climate Change* 613
[11] Sudarmadji 2013 *Springs: Hydrological and Environmental Perspectives* (Yogyakarta: UGM Graduate School)
[12] Griebler C and Avramov M 2015 *J. Freshwater Science.* 34 355-367
[13] Stevens L, Schenk E R, and Springer A E 2021 *J Ecological Applications.* 31 1-28
[14] Meinzer O E 1923 *outline of ground-water hydrology* *J Geological Survey.* 494
[15] Deutsche Gesellschaft fur Internationale Zusammenarbeit (DGIZ) Gmbh and Indonesian Ministry of Environment and Climate Change 2012 *Integrating Ecosystem Services into Development Planning* (Germany: Bonn and Eschborn)
[16] Supangat S 2005 *Study of Water System Balance in the Framework of Spatial Planning in the Cirasea Sub-watershed Area.* (ITB Bandung: Urban and Regional Planning Study Program)
[17] Minister of the Environment Number 115/2003 concerning Guidelines for determining the status of water quality

Acknowledgments

The author would like to thank for the support from the Faculty of Environmental Sciences, Universitas Gadjah Mada: Dr. Tjahjo Nugroho Adjii, S.Si., M.Sc. Tech., Dr. Langgeng Wahyu Santosa, S.Si., M.Sc., Dr. Nur Mohammad Farda, S.Si., M.Cs., Faisal Arsyad, Fluorddy N., and all of my friend from MPL 36, thank you for the support from the Faculty of Forestry and Dr. eng. Ngadisih, STP., M.Sc. from the Faculty of Agricultural Technology, Universitas Gadjah Mada