**Abstract:** Wetlands are very important ecosystems from the ecological, productivity and conservation perspective. Economic valuation of ecosystem services provided by wetlands quantifies the various benefits derived from wetlands and puts a value on their conservation. One such wetland of importance is the Renuka wetland, which is a natural wetland located in the Western Himalayas, in the State of Himachal Pradesh of India. The article aims to assess and evaluate the wetland for its water purification service. The study is based on multisource data and conventional evaluation method. The results show that the average depth of the Renuka wetland is 6.01 m and average volume was determined as 1072530.176 m$^3$. The economic value of water purification service for Renuka wetland is estimated to be INR 31.9 million (0.44 million USD) thus identifying the Renuka wetland as a significant healthy ecosystem. The water purification value itself advocates its proper management and conservation.

**Keywords:** Valuation, Water Purification Service, Replacement Cost Method, Modified Normalized Difference Water Index, Wetland

**INTRODUCTION**

Wetlands are one of the highly productive ecosystems of the world, accounting for only about four per cent of the earth’s ice-free land surface (Bassi et al. 2014). They provide numerous goods and services to people living in their periphery, as well as people living outside the wetland area (Barbier et al. 1997) including regulating climate and global nitrogen cycle, purifying water, recreational and cultural services, flood regulation and providing habitat for wildlife (Zhang et al. 2017, Sharma et al. 2015). Wetlands are very important ecosystems from the ecological and conservation perspective. Although increasing in recognition, the need for their conservation continues to be lost throughout the world (Turner et al. 2000).

Water purification service of wetlands is defined as the capability of wetlands to remove sediments, nutrients, and other contaminants from water, which leads to the widespread utilization of wetlands for wastewater treatments. Wetlands contributes to improvement of water quality by immobilizing various pollutants and nutrients and plays important role in geochemical cycling (Radeva et al. 2019). Economic valuation of ecosystem services provide a mode for measuring the various benefits from wetlands and the costs for conservation (Groot et al. 2012). Monetary valuation can interpret the information obtained through qualitative and quantitative indicators into monetary figures. For example, the wastewa-
ter purification service provided by healthy wetlands can be valued in monetary terms through the equivalent cost of a wastewater treatment plant that would provide a similar service (Russi et al. 2013). With such understanding, degradation can be avoided and reduced (Zlatic et al. 2015). Further, these values can help policy-makers and stakeholders to take informed decisions. Thus, valuation can be an approach to assess the importance of wetlands. Water purification service of wetlands varies with different wetland types (Zhang et al. 2017). One such wetland of importance is the Renuka wetland, which is a natural wetlands located in the Western Himalayas, in the State of Himachal Pradesh of India. Owing to the compliance of criteria 3 & 4 of Ramsar convention, it was declared a Ramsar site on 8th November 2005 because of its unique biodiversity and ecological character. This natural wetland is believed to provide various ecosystem services like habitat for flora and fauna, water purification, nutrient cycling, cultural and recreational value (Gaur 2020). The aim of this study is to evaluate the wetland with respect to existing water quality of the lake.

It focuses on the assessment and estimation of the economic value of water purification service by Renuka wetland based on multisource data and conventional evaluation method. The evaluation results might help decision-makers to comprehend the status of the Renuka wetland and provide a scientific guidance for making strategic decisions for conserving the wetland Therefore; the study will provide a reference point to frame conservation strategies and wetland protection policies for the lake.

MATERIAL AND METHODS

Study Site

Renuka Lake, a natural wetland with an extended pond known as Parshuram Tal, is located in the Lesser Himalayas in the Sirmaur district of the State of Himachal Pradesh, India (Figure 1). It is fed by a small stream arising from lower Himalayan hills. Geographical coordinates of the lake are 31°36’34” N, 77°27’8” E and is situated at an elevation of 650 m above mean sea level. The

![Figure 1. Study Site (Source: Author)](image-url)
maximum length of the lake is 1706.7m, width is 132.5–246.8 m and the maximum depth is 0.3m–13 m (Diwate et al. 2020).

The surface area and perimeter of the Renuka Lake are 17.84 hectare (ha) and 3438.39 m, respectively. According to the rainfall data of India Meteorological Department from 1979 - 2018, the average rainfall varied from 279 mm (minimum) - 728 mm (maximum) during July to September (rainy season). The outlet of the wetland is towards Parshuram Tal (pond) from where water outflows into the Giri River in the west. The slopes around wetland are covered with dense sub-tropical forests.

Data

Multi-temporal Landsat image and high-resolution image from Google Earth is used for mapping of Renuka Wetland to determine the area of the lake. The LANDSAT8/OLI TIRS satellite image data was collected from the United States Geological Survey (USGS) Earth Explorer’s image database (https://earthexplorer.usgs.gov/). USGS provides radiometric and geometric corrected Landsat images. In order to ensure visual quality and accuracy in mapping, only cloud-free image were used. Taking both image quality and availability of images into account, post-monsoon season image of December 2019 with low cloud cover were selected to extract the information of lake water surface area. The details of the Landsat data used are given in Table 1.

The average depth of the Renuka lake is determined by the Bathymetry data generated by Diwate et al. 2020. According to the bathymetry survey results given by Diwate et al. 2020, the depth of Renuka wetland varies from a minimum of 0.03 m to a maximum of 13 m. Based on bathymetry contours, the wetland area is classified in to four depth zones as given in Table 2. The average depth of the Renuka wetland was determined by the weighted average method using Bathymetry data (Table 2)

Data pertaining to water quality were obtained from the annual data provided by the Central Pollution Control Board (CPCB), Ministry of Environment, Forest and Climate Change, Government of India under the National Water Quality Monitoring Programme and also from the research article by Kumar et al. 2019. CPCB’s primary water quality criteria for Class C water body (as designated best use of drinking water after conventional treatment and disinfection) and recommended water quality parameters for different uses by the Bureau of Indian Standards (BIS) (Standard IS 2296:1992) are used in this study (Table 3).

Table 1. List of Satellite Data

| S. No | Scene ID       | Path | Row | Date of Acquisition | Satellite/Sensor     | Spatial resolution |
|-------|----------------|------|-----|---------------------|----------------------|--------------------|
| 1     | LC81470392019349LGN01 | 147  | 39  | 15-12-2019          | LANDSAT8/OLI/TIRS    | 30m                |

(Source: Author)

Table 2. Bathymetry data

| S. No. | Zone                | Depth Class (m) | Area percentage |
|--------|---------------------|-----------------|-----------------|
|        |                     | Min  | Max |                   |
| 1.     | Peripheral zone     | 0.3  | 3   | 10                |
| 2.     | Extra-peripheral zone | 3   | 6   | 50                |
| 3.     | Sub-central zone    | 6    | 9   | 23                |
| 4.     | Central region      | 9    | 13  | 17                |

(Source: Diwate et al. 2020)
There are several methods for lake mapping using remote sensing analysis, such as the single band threshold value method, the band ratio method, the water index method and the Normalized Difference Water Index (NDWI) method. We have used the Modified Normalized Difference Water Index (MNDWI) for detecting water body from multispectral Landsat imagery in ArcMap 10.3 platform. Amongst other indices, this method, based on the spectral water index, represents a better approach for delineating wetland. MNDWI is a modified version of the NDWI proposed by the McFeeters 1996.MNDWI was developed by the Xu 2006 that is based on the principle that the water bodies have a stronger absorbability and built-up class has greater radiation in the Shortwave Infrared (SWIR). MNDWI uses green and SWIR bands and defines as:

\[
MNDWI = \frac{\text{Green band} - \text{SWIR band}}{\text{Green band} + \text{SWIR band}} \quad \text{(1)}
\]

The MNDWI index is most suitable for mapping water bodies. The water bodies generally absorb more SWIR waves and have greater positive values in MNDWI while, soil, vegetation and built-up classes reflect more SWIR waves than green light and have smaller negative values. The MNDWI mostly identifies the presence of water bodies more effectively (Sun et al. 2012). To achieve accuracy, best threshold value was set manually. MNDWI had been widely applied to produce water body maps at different scales in the last few years (Du et al. 2014, Rokni et al. 2014).

The pre-processing of the multispectral images was carried out before performing the MNDWI. Reflectance values were extracted from the Digital Number (DN) for the SWIR and thermal infrared radiometer (TIR) spectral ranges for Landsat 8 images. Water body exhibits a fine smooth texture in compare to the surrounding rough texture of the hills or land. Due to its high contrast values, water is one of the distinguished features to delineate on a satellite image. In combination with various image enhancements, visual pattern recognition is also considered in this analysis. The water body tone is light/dark blue or black in the satellite images. The water surface area of wetland was calculated using steps given in Figure 2.

After extracting reflectance values from the digital number image, the MNDWI were performed on the image to map the wetland. Water features were automatically mapped using the MNDWI with the manual threshold of 0.09 and the obtained raster data were converted into polygon shape file. Due to spectral reflection, some shadow areas were misclassified as water. Misclassified water boundaries were manually corrected through the visual interpretation of data. The obtained wetland boundary vector file was then converted to KML format and loaded into Google Earth Pro for visual examination.

To determine the average volume of the wetland weighted average method was used to find the average depth of the wetland by using data given in Table 2. Subsequently, the average depth was multiplied with the water surface area of wetland to calculate the average volume of the wetland.

### Table 3. Water quality data of Renuka Wetland

| S. No. | Water Quality Parameters          | Minimum | Maximum | Average | Quality Standards |
|--------|----------------------------------|---------|---------|---------|------------------|
| 1.     | Biological Oxygen Demand (mg/l)  | 0.5     | 2.8     | 1.65    | <3               |
| 2.     | Dissolved Oxygen (DO) (mg/l)     | 5.31    | 6.98    | 6.12    | >4               |
| 3.     | Nitrate (NO₃⁻)(mg/l)             | 1.26    | 3.25    | 2.66    | <50              |
| 4.     | Sulphate (SO₄²⁻) (mg/l)          | 155     | 168     | 159.8   | <400             |
| 5.     | Total dissolved solids (mg/l)     | 280     | 312     | 299.6   | <1500            |

(Source: CPCB, Kumar et al. 2019, BIS)
Water Purification service

Water purification service is defined as the improvement role of wetlands on water quality (Zhao et al., 2016). Wetlands are well known for their ability to remove sediments, nutrients, and other contaminants from water, which leads to the widespread utilization of wetlands for wastewater treatments (Almukhtar et al. 2018). Physicochemical parameters of any water body plays a very significant role in maintaining the various life forms (Kumar and Puri 2012). The water purification service is calculated as the concentration of Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Nitrate (NO₃⁻), Sulphate (SO₄²⁻) and Total Dissolved Solids (TDS) pollutants removed by the wetlands. 

Economists have resorted to use the cost of replacing the service as a valuation approach to value those ecosystem services, which are unique to a specific ecosystem and are difficult to value. This approach does not measure benefit derived from the wetland’s waste treatment service directly. It instead estimates it using the cost of providing the ecosystem service that people value (Dickie 2003). We have used the replacement cost method (Farber et al. 2002) to obtain the value of water purification service ($V_w$). Shabman and Batie, 1978 suggest that this method is reliable for estimating ecological services if the alternative considered during evaluation provides the same services or there are substantial evidence that the service would be demanded by society provided at least-cost alternative or both. The economic value of wetland’s water purification service calculated through the removal cost of pollutants using the following equations 2 and 3:

$$W_p = (\sum_{i=1}^{n} R_{pi}) \times W_v = (\sum_{i=1}^{n} (S_i - P_i)) \times (H \times A) \quad \ldots (2)$$

$$V_w = W_p \times P_t \quad \ldots \quad (3)$$

Where, $W_p$ is the amount of total pollutant removed by a wetland (t), $R_{pi}$ is the pollutant removal capacity of a wetland (mg/L), $W_v$ is the amount of stored water by a wetland (L), $S_i$ is the standard concentration of different pollutants (mg/L), $P_i$ is the concentration of pollutants (mg/L), $H$ represents the average water depth of the wetland (m) and $A$ is the area of the wetland (m²); $V_w$ is the total economic value of water purification service of wetland (INR), and $P_t$ is the treatment cost of pollutants (INR/t).

The removal cost of water pollutants was adopted through the primary survey of experts and personal communication with few water treatment plant authorities. Treatment cost of water in treatment plants was 20000 INR/ton.
RESULTS AND DISCUSSION

Surface area and Volume

Water surface area and perimeter of the Renuka wetland was determined as 178457.6 m² and the 3438.39m respectively. Figure 3 shows the LANDSAT False Color Composite (FCC) and MNDWI images of Renuka Wetland.

Average depth of the Renuka wetland is 6.01 m shown in Table 4. The average volume of the wetland was determined as 1072530.176 m³.

Water Purification service

The data of water quality acquired from secondary sources (Table 3) shows that the water quality standards for all the parameters i.e. DO, BOD, NO₃-, SO₄²- and TDS are within permissible limits. Estimates shows that the Renuka wetland can remove the 1599.58 tonnes of pollutants BOD, DO, NO₃-, SO₄²- and TDS (Table 5). Accordingly, the economic value of water purification service for Renuka wetland is estimated to be INR 31.9 million (0.44 million USD) with an average value of 179.3 INR/m².

It is observed that the economic value of the water purification service is directly dependent to the volume of the wetland. The water quality within permissible limits indicates the proper functioning of water purification process in the wetland. It also indicates that the wetland needs to be conserved because it holds great ecological and economical importance. The study suggests that replacement cost method may be used for assessing economic value of the wetland’s water purification service. The estimation by suggested method provides substantial evidence regarding the value and importance of natural resource. The results also reflects on the need of conservation of wetlands as it is playing an important role in water purification both ecologically as well as economically.

Table 4. Weighted Average Method

| Sr. No. | Depth class (m) | Area percentage | Area percentage (m²) | Midmark depth (m) | Weighted area (m²) |
|---------|-----------------|-----------------|----------------------|-------------------|-------------------|
| 1.      | 0.3 - 3         | 10              | 17845.76             | 1.65              | 29445.504         |
| 2.      | 3 - 6           | 50              | 89228.8              | 4.5               | 401529.6          |
| 3.      | 6 - 9           | 23              | 41045.248            | 7.5               | 307839.36         |
| 4.      | 9 - 13          | 17              | 30337.792            | 11                | 333715.712        |
| Total   |                 |                | 178457.6             |                   | 1072530.176       |

Average depth of the Lake (m) = (Total weighted area)/(Total actual area) = 6.01

(Source: Author)
CONCLUSION

Wetlands provide many important ecosystem services to humans, but at the same time wetlands are ecologically sensitive and adaptive systems (Sunkara et al. 2002). Therefore, there is a need to draw attention towards the preparation and operation of sustainable management strategies for wetlands. The study identifies Renuka wetland as a significant healthy ecosystem and needs proper management and conservation because of its contribution to water purification services. Therefore, there is a need to value such ecosystems irrespective of the non-existence of economic markets for ecosystem services. The study suggests that the combination of economic evaluation methods along with remote sensing based approaches such as MNDWI can help in identifying economic value of wetland and other natural ecosystems. Overall, evaluation of the water purification services of wetland ecosystems will help the policymakers for strategizing the sustainable development programs.

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