Sub-watershed prioritization inferred from geomorphometric and landuse/landcover datasets in Sari Watershed, Sumbawa Island, Indonesia

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Abstract. Sub-watershed prioritization based on erosion propensity plays essential roles in decision making in implementing management practices, especially in the sensitive semiarid regions. Geomorphometric and landuse/landcover datasets are crucial in terms of sub-watershed prioritization for integrated watershed management. Our study was held in Sari Watershed, Sumbawa Island, which needs to be given proper consideration of prioritizing sub-watersheds that need immediate handling. Integration of Principal Component Analysis (PCA) and Weighted Sum Approach (WSA) was used to determine the final sub-watershed prioritization. The use of PCA aimed to define significant parameters, while WSA was employed to determine the weights for significant parameters and calculate the compound values for priority ranking. The result showed that the integration of PCA and WSA was robust enough to define significant and more effective parameters with their weighted values for the sub-watershed prioritization. The adopted methodology in this study can be applied to different susceptibility in sub-watershed prioritization, such as a flash flood. This study also provides essential information for watershed managers to prioritize the program's implementation in the prioritized sub-watershed.

1. Introduction
Several watersheds in Indonesia, especially in the semiarid region, are categorized as to be rehabilitated watersheds. In general, these watersheds are under a critical condition with land degradation due to soil erosion as the main issue [1]. One of the semiarid watersheds in Indonesia is Sari watershed located in Sumbawa Island, West Nusa Tenggara Province. Critical land due to erosion is the main issue in Sari watershed that is classified as to be rehabilitated watershed [2]. Implementation of land and water management in the frame of integrated watershed management is needed to guarantee sustainable benefits and natural resources of the watershed [3]. On the other hand, it is tough to implement all the programs of watershed management in one term because of some biophysics and socio-economics conditions [4]. Therefore, prioritization for the area, such as sub-watershed, is an essential need while implementing the management programs. The prioritization uses the central issue of the watershed problem, including erosion, as the principal consideration.

Various studies over the latest years have used geomorphometric parameters (i.e., linear, areal, and relief aspect) to define priority level using Geographical Information System (GIS) and Remote Sensing (RS) application [5][4][6]. For example, Mangan et al. [7] employed geomorphometric characteristics to study and prioritize the sub-watershed of Nanganji Watershed, Tamil Nandu, India. They used the correlation matrix to understand the inter-relationship of geomorphometric variables. Siddiqui et al. [8] studied the morphometry of the Nagmati River basin using RS and GIS. The prioritization of sub-watersheds in this study is based on soil erosion potential area inferred from morphometric parameters. Sangma and Guru [9] applied the geomorphometric parameters in the watershed prioritization of the Lower Subansiri basin. The study concluded that the geomorphometric
parameters were practicable parameters to comprehend the hydrological feature of the watershed. Youssef et al. [10] utilized geomorphometric and satellite imagery to analyse and prioritize the area of Katherine Road, Southern Sinai, Egypt, based on flash flood risk. According to all studies above, understanding of geomorphometric characteristics provides a sound knowledge related to the process within the watershed, especially the hydrological process. Furthermore, the geomorphometric analysis also gives evidence on lithology, soil properties, permeability, and flood peak [9]. All this knowledge is useful in the prioritization process.

The use of geomorphometric parameters in prioritization analysis mostly indicates the natural characteristic of the watershed, which is related to the central issue of interest. The addition of management characteristics probably could be more comprehensive in terms of the analysis process. Pandey et al. [11] suggested integrating geomorphometric parameters with other thematic maps to define the suitable region for soil and water conservation as well as watershed prioritization. Additional thematic maps represent the management characteristics, which are mostly anthropogenic entity. Landuse has been considered as a management factor for prioritization since the change of landuse influences the hydrological process, particularly in an acceleration of soil erosion [12][13]. Puno and Puno [14] used the integration of geomorphometric and landuse/landcover to prioritize watershed for conservation purposes in Philippine. Javed et al. [15] studied the sub-watershed prioritization with RS and GIS approaches and used geomorpometric and landuse/landcover as parameters.

Regarding the analysis method in prioritization, previous studies were predominantly carried out using a standard compound value that is determined by the average calculation of initial ranks of priority for all parameters [16]. A few studies have been informed using Principal Component Analysis (PCA) and Weighted Sum Approach (WSA) [17][18][19]. For example, Aher et al. [16] employed WSA of geomorphometric parameters in the prioritization of sub-watershed for Pimpalgaon Ujjaini watershed, India. Application of PCA by Sharma et al. [20] and Mesram and Sharma [21] concluded that the method reduced the dimensionality of the dataset based on the correlation among the used parameters for sub-watershed prioritization. These studies inferred that PCA and WSA were more efficient and lively than that standard compound values method. The standard compound values method assumed that all the used parameters have equal importance in determining final prioritization. In reality, the importance of parameters may not be the same due to each sub-watershed has its specific characteristics. Therefore, the combination of PCA and WSA exhibited a promised approach for watershed prioritization.

The objective of the current study is to prioritize sub-watersheds inferred from data integration of geomorphometric parameters and landuse in Sari watershed. The integration of PCA and WSA approach was applied to be capable of ranking the sub-watershed lastly.

### 2. The study area

This study was conducted in Sari watershed, a watershed in the semiarid region in West Nusa Tenggara (figure 1.). Sari Watershed is located at 08°23'51.3"S-08°37'41.8"S and 118°42'32.9"E-118°55'22.8"E, geographically. Administratively, it is located in Bima District, West Nusa Tenggara Province. It covers 260,10 km² of drainage area with a length of 31 km and a width of 12.92 km. The climate of Sari watershed is classified into three groups based on climate classification by Schmidt Fergusson, namely C (almost wet), D (fair), and E (almost dry). The average annual rainfall varies from 1110.6 mm to 1834 mm according to four rain gauge stations across the watershed area. The rainy season occurs mostly between November and April, while the dry season falls from May to October. The dominant soil was complex brown mediteran and lithosols (52.54%), followed by complex lithosols and brown mediteran (26.73%), brown alluvial (13.9%), and complex brown mediteran and reddish-brown mediteran (6.83%) [2].
Figure 1. Study area map of Sari Watershed, Sumbawa Island, West Nusa Tenggara Province.

Based on the Monitoring and Evaluation Management of Sari Watershed [2], the main issue of Sari watershed is the increase of critical land due to high erosion. Data analysis in 2018 showed that the actual erosion in Sari watershed was 165.33 ton ha$^{-1}$, and it was above the tolerable erosion of only 20.12 ton ha$^{-1}$. A 31.72% steep slope area dominates Sari watershed. The vegetation coverage of Sari watershed in 2018 was only 29.95% of the total area. Forest and shrubs were spread in the upper stream of the watershed. This condition also increases the susceptibility of watersheds to erosion [2].

3. Methods

3.1. Data used and collection

The Digital Elevation Model (DEM) data used in the study were generated from the topographic maps of 1:25.000 scale with 12.5m of spatial resolution. The boundary of Sari watershed was extracted from the West Nusa Tenggara Watershed map. Determining the stream network and delineating the sub-watershed employed the DEM data along the watershed boundary. Sub-watershed subdivision based on water divide, the ridgelines, and other supporting morphological entities. Seven sub-watershed was obtained and then named labels SW1, SW2, SW3, SW4, SW5, SW6, and SW7 from the upstream to the watershed outlet. The stream network of each sub-watershed was assigned a number in sequence from the first order following Horton's law [22].

According to the sub-watershed boundary and their stream orders, the basic geomorphometric was determined using GIS software, including stream number ($N_u$), stream length ($L_u$), sub-watershed area ($A$), sub-watershed perimeter ($P$), and sub-watershed length ($L_b$). Geometric parameters used in the sub-watershed prioritization consisted of three aspects, namely linear, areal, and relief. The linear
parameter used in the analysis were stream length ($L_u$), bifurcation ratio ($B_r$), and the average length of overland flow ($L_g$). There were seven parameters of the areal aspect employed for prioritization: form factor ($F_f$), drainage texture ($D_t$), compactness coefficient ($C_c$), circularity ratio ($R_c$), elongation ratio ($R_e$), Drainage density ($D_d$), and stream frequency ($F_s$). Further, the parameter of the relief aspect used in the analysis was relief ratio ($R_{hl}$), relative relief ratio ($R_{hp}$), gradient ratio ($G_r$), and ruggedness number ($R_n$). All the geomorphometric parameters were obtained and calculated based on basic geomorphometric parameters and DEM data with GIS software and mathematical formula developed by [22][23][24][25](Table 1).

| Table 1. Formula and references used to calculate geomorphological parameters |
|---------------------------------|-----------------|-----------------|
| Morphometric Parameters         | Formula          | References       |
|---|---|---|
| **Basic aspect**                |                 |                 |
| Area of Basin ($A$) (km$^2$)    | The region enclosed by the watershed boundary | [24] |
| Perimeter of Basin ($P$)(km)    | Perimeter of watershed | [24] |
| Number Stream order ($N_u$)     | $N_u=N_1+N_2+N_3+...+N_n$ | [22] |
| Basin Length ($L_b$)(km)        | Distance from outlet to the farthest point of boundary | [24] |
| **Linear aspect**               |                 |                 |
| Stream Length ($L_u$)           | $L_u=L_1+L_2+...+L_n$ | [22][23] |
| Bifurcation ratio ($B_r$)       | $R_b = N_u /N_u + 1$ | [24][23] |
| Length of overland flow ($L_g$)(km) | $L_g = 1/2 D_d$ | [22] |
| **Areal aspect**                |                 |                 |
| Form factor ($F_f$)             | $F_f = A/L_b^2$ | [22] |
| Drainage Texture ($D_t$)        | $D_t = Nu/P$ | [23] |
| Compactness coefficient ($C_c$) | $C_c = 0.282 x P/\sqrt{A}$ | [22] |
| Circularity ratio ($R_c$)       | $R_c = 4 \pi x A/P^2$ | [25] |
| Elongation ratio ($R_e$)        | $R_e = 1.129 x \sqrt{A/L_b}$ | [24] |
| Drainage density ($D_d$) (km/km$^2$) | $D_d = L_u/A$ | [23] |
| Stream frequency ($F_s$)(no./km$^2$) | $F_s = Nu/A$ | [22] |
| **Relief aspect**               |                 |                 |
| Relief Ratio ($R_{hl}$)         | $R_{hl}=H/L_b$, | [24] |
| Relative Relief Ratio ($R_{hp}$) | $R_{hp}=H*100/P$ | [24] |
| Gradient Ratio ($G_r$)          | $G_r=(Z-z)/L_b$ | [26] |
| Ruggedness number ($R_n$)       | $R_n=D_d*(H/1000)$ | [23] |

Landuse/landcover data of Sari watershed was obtained by supervised interpretation and classification of remotely sensed data of SPOT 2016. Landuse/landcover categories employed a classification system proposed by BSN with the Maximum Likelihood Method application [27]. Three generalized important landuse/landcover was defined according to a strong influence on the hydrological process in the watershed: forest, shrub, and agriculture. Other landuse/landcover were excluded due to small areas and be assumed not to affect the prioritization significantly.

3.2. Geomorphometric and landuse/landcover analysis
Geomorphometric and landuse/landcover analysis aimed to assign Preliminary Rank (PR) for each parameter and sub-watershed based on the relationship of the parameter to soil erodibility. Geomorphometric parameters that have a direct influence on soil erodibility included $L_u$, $R_b$, $L_g$, $D_t$, $D_d$, $F_s$, $R_{hl}$, $R_{hp}$, $G_r$, and $R_n$. While $F_f$, $C_c$, $R_c$, and $R_e$ were the parameters that have an inverse relationship to soil erodibility [17][28][29]. The geomorphometric parameters which have a direct effect on soil arodibility were assigned rank 1 for the highest value, rank 2 for second-highest value, and so on for all sub-watershed. A higher value of the direct effect parameter implied more potential of soil erodibility. The ranking process for inverse effect parameters to soil erodibility was started by assigning rank 1 from the lowest value, and so on for all the sub-watershed. The high potential of soil erodibility was indicated by the lower value of inverse relationship parameters [30][31].

The preliminary rank for landuse/landcover was assigned based on the method employed from a previous study [15]. The method was applied by determining the first rank to the highest percentage
of agriculture and shrub. The lowest percentage of the forest was also defined as the highest
preliminary rank as well.

3.3. Principal Component Analysis and Weighted Sum Approach
PCA was used in this study to define significant parameters, both geomorphometric and
landuse/landcover. As the multivariate statistical method, PCA is employed to simplify the parameters
dimensionally. Because the parameters had different scales, it was needed to standardized the dataset
before PCA calculation using the z-score method [8][32]. PCA produces two or more principal
components as the result of data conversion from the original. Principal components with eigenvalues
> 1 were selected based on Kaiser criterion and varimax rotation of factor loading [33]. The factor
loading rotation was performed in order to get a better correlation in defining the most significant
parameters [3].

WSA was applied subsequently to the most significant parameters obtained from PCA. The
weighted value of significant parameters (Wsp) was determined through cross-correlation analysis that
was expressed as [3]:

\[ Wsp = \frac{\text{Sum of correlation coefficient}}{\text{Total of correlation}} \] (1)

The final priority ranking used the compound values (CV) that were determined based on Wsp and PR
of significant parameters. The CV calculation was employ following mathematical formula [3][8][34]:

\[ CV = PRsp \times Wsp \] (2)

where \( CV = \) compound value; \( PRsp = \) preliminary ranking of significant parameter; and \( Wsp = \) weight
of significant parameter. The lowest value \( CV \) was considered as the priority rank 1, the second-
lowest value was given the priority rank 2, and so on for all sub-watershed.

4. Result and discussion
4.1. Geomorphometric and landuse/landcover analysis
The geomorphometric analysis of the seven SW of Sari watershed employed the GIS software to
evaluate the characteristics of the sub-watershed. The computation of morphometric consisted of linear (i.e., \( Lu, Rb, Lg \)), areal (i.e., \( Ff, Dt, Cc, Rc, Re, Dd, Fs \)), and relief (i.e., \( Rhl, Rhp, Gr, Rn \)). The quantitative values of geomorphometric parameters are shown in table 2.

| Sub Watershed (SW) | Linear (km) | Areal (km²) | Relief (km²) |
|-------------------|------------|-------------|-------------|
| Lu                | Rb         | Lg          | Fr          | Dt         | Cc          | Rc          | Re          | Dd          | Fs          | Rhl         | RHp         | Gr          | Rn          |
| SW1               | 61.851     | 3.220       | 0.203       | 0.394      | 4.583       | 1.632       | 0.381       | 0.708       | 2.459       | 5.249       | 0.119       | 3.298       | 0.119       | 2.336       |
| SW2               | 60.605     | 4.546       | 0.199       | 0.529      | 3.054       | 2.065       | 0.238       | 0.820       | 2.513       | 4.519       | 0.102       | 1.936       | 0.102       | 1.736       |
| SW3               | 80.827     | 4.601       | 0.193       | 0.230      | 2.842       | 2.146       | 0.220       | 0.542       | 2.587       | 3.841       | 0.111       | 3.051       | 0.111       | 3.332       |
| SW4               | 85.654     | 4.021       | 0.217       | 0.179      | 3.107       | 2.354       | 0.183       | 0.477       | 2.302       | 4.220       | 0.093       | 2.644       | 0.093       | 3.076       |
| SW5               | 124.069    | 5.565       | 0.216       | 0.165      | 2.998       | 2.742       | 0.135       | 0.459       | 2.311       | 3.949       | 0.077       | 1.966       | 0.077       | 3.213       |
| SW6               | 48.991     | 4.241       | 0.188       | 0.390      | 3.090       | 1.908       | 0.279       | 0.705       | 2.663       | 4.838       | 0.050       | 1.184       | 0.050       | 0.908       |
| SW7               | 132.004    | 5.804       | 0.228       | 0.203      | 3.627       | 2.312       | 0.190       | 0.509       | 2.192       | 3.802       | 0.061       | 1.666       | 0.061       | 2.306       |

The sub-watersheds of Sari watershed generally have a fifth-order of stream order, yet the stream
length (\( Lu \)) varies. The sub-watershed, which have the greatest and the lowest total stream length is
SW7 (132.0 km) and SW6 (48.9km), respectively. The length of the stream segment of all sub-
watershed is maximum for the first stream order and declines following the stream order sequence.
The bifurcations ratio ($R_b$) has a strong correlation with the hydrological process in the watershed. High overland flow is an indication of the high value of $R_b$, and it influences the level of erosion potential [35]. The level of structural disturbance also controls the value of $R_b$. The higher of structural disturbance in the watershed, the higher the structural disturbance control [36]. The SW7 of Sari watershed retains the highest soil erodibility potential in terms of $R_b$ value. The average length of overland flow ($L_g$) designated the flow length of water on the land surface prior to entering the stream [37]. Based on Table 2, SW7 is the highest susceptibility to erosion indicated by $L_g$ value. Ali and Ikbal [38] confirmed that the higher value of $L_g$ provides more time for overland flow and erosion process. This study also concluded that the $L_g$ value lesser than 0.2 offers a very low amount of water for runoff and infiltration.

The sub-watershed form factor ($F_f$) value of Sari watershed ranges from 0.165 to 0.529, implying a more elongated shape, lower peak, and longer duration of flow. The value of $F_f$ is the ratio of watershed area to the area of square based on watershed length [15]. Among all sub-watersheds, the SW2 has the highest chance of erosion, while the SW5 is the lowest. Drainage texture ($D_t$) describes a relative interval of streamlines in the watershed. Drainage texture is controlled by lithology, surface material, vegetation, and relief [39]. The highest value of $D_t$ in Sari watershed is belonging to SW2. Circularity ratio ($R_c$) is the expression of the roundedness of the watershed. It has a strong correlation with stream discharge. The calculation formula for $R_c$ is the ratio of the watershed area and the circle area having the same perimeter with the watershed [25]. The $R_c$ values of all sub-watershed indicate a more elongated shape with the value ranging from 0.135 to 0.381 [40]. Based on the elongation ratio ($R_e$) of the sub-watersheds, the SW5 is more susceptible to erosion and a more elongated shape [14] as represented by its higher value. The drainage density ($D_d$) has more related to how long the water takes time across the watershed [15]. It also describes the permeability of subsurface material that influence erosion. The highest value of $D_d$ in Sari watershed is SW 6. This condition reflects the SW6 is more disposed to soil erosion [41]. The stream frequency ($F_s$) expresses the number of streams for every unit area of a watershed [22]. The stream frequency has a high relation to permeability, infiltration, and relief. The lowest $F_s$ value is observed in SW7, while the highest value is observed in SW1.

The relief aspect of geomorphometric has been studied as the essential parameters in comprehending geomorphometric and erosion relationships [42]. Relief ratio ($R_h_l$) is used to describe the erosion intensity of the hillslope. The low value of $R_h_l$ reflects lesser soil erodibility because of lower slope and resistant basement rock [17]. This study was observed that the SW6 and SW1 were the lowest and the highest of $R_h_l$, respectively. This condition implies that SW1 is more susceptible to erosion than SW1. Regarding the relative relief ratio ($R_h_p$), it was observed that the SW6 and SW1 were the lowest and the highest of $R_h_l$ value, respectively. The $R_h_p$ also describes the terrain characteristic of watersheds. A high value of $R_h_p$ indicates a high relief with a steeper slope that is more susceptible to erosion [42]. Another relief parameter is ruggedness number ($R_n$) that is a result of drainage density and relief or the ratio between relief and horizontal distance. The watershed tends to be prone to erosion, indicated by the high value of $R_n$ [42]. In this study, the sub-watershed, which is more susceptible to erosion, is SW3. Gradient ratio ($G_r$) describes the stream channel slope and uses it to evaluate the volume of runoff. It is positively correlated with erosion [26]. In this study, the SW1 was the most susceptible sub-watershed to erosion.

The landuse/landcover of Sari watershed was generalized into three crucial types, namely forest, shrub, and agriculture. The unit used in landuse/landcover classification is a percentage, as the ratio of specific landuse/landcover type area to sub-watershed area. Table 3 shows the percentage of landuse/landcover for each sub-watershed in Sari watershed.
Table 3. The percentage of landuse/landcover of sub-watershed

| Sub Watershed (SW) | Forest (%) | Shrub (%) | Agriculture (%) |
|--------------------|------------|-----------|-----------------|
| SW1                | 34.5       | 7.0       | 58.1            |
| SW2                | 3.4        | 2.8       | 92.5            |
| SW3                | 17.8       | 13.9      | 65.8            |
| SW4                | 16.5       | 18.4      | 63.2            |
| SW5                | 32.3       | 13.2      | 51.6            |
| SW6                | 0.1        | 6.0       | 71.3            |
| SW7                | 14.8       | 10.0      | 68.0            |

Based on the relationship of geomorphometric parameters and landuse/landcover with erosion potential, all the sub-watershed have been assigned the preliminary rank (PR). PR was determined according to the direct or inverse relationship of the parameters and erosion. Table 4 and table 5 present the PR of sub-watersheds corresponding to geomorphometric and landuse/landcover parameters, respectively.

Table 4. Preliminary rank (PR) of sub-watersheds based on morphometric parameters

| Sub Watershed (SW) | Linear | Areal | Relief |
|--------------------|--------|-------|--------|
|                    | Lu     | Rb    | Lg     | Ff    | Dt    | Cc    | Re    | Re    | Dd    | Fs    | Rhl   | RHp   | Gr    | Rn    |
| SW1                | 5      | 7     | 4     | 6     | 1     | 1     | 7     | 6     | 4     | 1     | 1     | 1     | 1     | 4     |
| SW2                | 6      | 4     | 5     | 7     | 5     | 3     | 5     | 7     | 3     | 3     | 3     | 5     | 3     | 6     |
| SW3                | 4      | 3     | 6     | 4     | 7     | 4     | 4     | 4     | 2     | 6     | 2     | 2     | 2     | 1     |
| SW4                | 3      | 6     | 2     | 2     | 3     | 6     | 2     | 2     | 6     | 4     | 4     | 3     | 4     | 3     |
| SW5                | 2      | 2     | 3     | 1     | 6     | 7     | 1     | 1     | 5     | 5     | 5     | 4     | 5     | 2     |
| SW6                | 7      | 5     | 7     | 5     | 4     | 2     | 6     | 5     | 1     | 2     | 7     | 7     | 7     | 7     |
| SW7                | 1      | 1     | 1     | 3     | 2     | 5     | 3     | 3     | 7     | 7     | 6     | 6     | 6     | 5     |

Table 5. Preliminary rank (PR) of sub-watersheds based on landuse/landcover

| Sub Watershed (SW) | Landuse | Forest (%) | Shrub (%) | Agriculture (%) |
|--------------------|---------|------------|-----------|-----------------|
| SW1                | 7       | 5          | 6         |
| SW2                | 2       | 7          | 1         |
| SW3                | 5       | 2          | 4         |
| SW4                | 4       | 1          | 5         |
| SW5                | 6       | 3          | 7         |
| SW6                | 1       | 6          | 2         |
| SW7                | 3       | 4          | 3         |

4.2. Principal component analysis (PCA) and Weighted sum approach (WSA)

The PCA for all parameters, geomorphometric and landuse/landcover, aimed to calculate the correlation among parameters, to define a principal component, and to reduce the dimension of parameters that, in turn, find out the most important parameters. The correlation matrix among all parameters is shown in table 6. The strong correlation (coefficient correlation ($r \geq 0.9$) is observed between $Dd$ and $Lg$, $Re$ and $Ff$, $Re$ and $Cc$, $RHp$ and $Rhl$, $Gr$ and $RHp$, and $Gr$ and $Rhl$. The good correlation ($0.75 \leq r \leq 0.9$) occurs between $Rb$ and $Lu$, $Lg$ and $Lu$, $Ff$ and $Lu$, $Cc$ and $Lu$, $Re$ and $Lu$, $Dd$
and $Lu$, $Fs$ and $Lu$, $Cc$ and $Rb$, $Re$ and $Rb$, $Fs$ and $Rb$, $Re$ and $Cc$, shrub and $Ff$, and shrub and $Re$. Some moderate correlation ($0.60 \leq r \leq 0.75$) exist between $Dd$ and $Re$, $Fs$ and $Re$, $Re$ and $Re$, $Fs$ and $Dt$, $Re$ and $Lg$, $Cc$ and $Ff$, $Re$ and $Ff$, $Dt$ and $Ff$, $Fs$ and $Ff$, $Fn$ and $Ff$, $Ff$ and $Lg$, $Re$ and $Lg$, agriculture and $Ff$, and agriculture and $Re$. The existence of correlation among parameters indicates that information could present in more than one parameter [17]. Therefore, it possible to reduce parameter dimension for practical purposes using PCA to the correlation matrix.

**Table 6. Correlation matrix of parameters of Sari watershed**

|   | Lu  | Rb  | Lg  | Fs  | Dd  | Cc  | Rc  | Re  | Ds  | Rhl | RHp | Gr  | Rn  | Forest | Shrub | Agriculture |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|--------|--------------|
| Lu| 1.000 |     |     |     |     |     |     |     |     |     |     |     |     |         |        |              |
| Rb| 0.818 | 1.000 |     |     |     |     |     |     |     |     |     |     |     |         |        |              |
| Lg| 0.855 | 0.527 | 1.000 |     |     |     |     |     |     |     |     |     |     |         |        |              |
| Fs| -0.768 | -0.472 | -0.617 | 1.000 |     |     |     |     |     |     |     |     |     |         |        |              |
| Dd| -0.092 | -0.454 | 0.185 | 0.218 | 1.000 |     |     |     |     |     |     |     |     |         |        |              |
| Cc| 0.788 | 0.772 | 0.595 | -0.710 | -0.592 | 1.000 |     |     |     |     |     |     |     |         |        |              |
| Rc| -0.719 | -0.796 | -0.5217 | 0.653 | 0.727 | -0.965 | 1.000 |     |     |     |     |     |     |         |        |              |
| Re| -0.788 | -0.499 | -0.642 | 0.998 | 0.246 | -0.751 | 0.694 | 1.000 |     |     |     |     |     |         |        |              |
| Ds| -0.844 | -0.502 | -0.999 | 0.607 | -0.196 | -0.594 | 0.513 | 0.634 | 1.000 |     |     |     |     |         |        |              |
| Fs| -0.774 | -0.818 | -0.494 | 0.709 | 0.608 | -0.813 | 0.883 | 0.731 | 0.479 | 1.000 |     |     |     |         |        |              |
| Rhl| -0.294 | -0.546 | -0.189 | 0.214 | 0.295 | -0.325 | 0.372 | 0.210 | 0.145 | 0.217 | 1.000 |     |     |         |        |              |
| RHp| -0.134 | -0.548 | -0.042 | -0.122 | 0.394 | -0.272 | 0.348 | -0.108 | 0.006 | 0.136 | 0.902 | 1.000 |     |         |        |              |
| Gr| -0.294 | -0.546 | -0.189 | 0.214 | 0.295 | -0.325 | 0.372 | 0.210 | 0.145 | 0.217 | 0.956 | 0.902 | 1.000 |     |         |        |              |
| Rn| 0.561 | 0.200 | 0.442 | -0.733 | -0.138 | 0.560 | -0.479 | -0.747 | -0.465 | -0.596 | 0.466 | 0.631 | 0.466 | 1.000 |     |         |        |              |
| Forest| 0.411 | -0.069 | 0.397 | -0.446 | 0.503 | 0.174 | 0.056 | -0.442 | -0.426 | -0.003 | 0.447 | 0.631 | 0.447 | 0.671 | 1.000 |     |         |        |              |
| Shrub| 0.489 | 0.149 | 0.446 | -0.895 | -0.289 | 0.589 | -0.563 | -0.897 | -0.451 | -0.579 | 0.063 | 0.362 | 0.063 | 0.807 | 0.387 | 1.000 |     |         |        |              |
| Agriculture| -0.450 | -0.028 | -0.351 | 0.732 | -0.264 | -0.304 | 0.109 | 0.710 | 0.357 | 0.120 | 0.009 | -0.347 | 0.009 | -0.573 | -0.806 | -0.627 | 1.000 |     |         |        |              |

PCA application in this study resulted four principal components (PC) (table 7). These principal components were able to explain 94.78% of the original data variance with the eigenvalues greater than 1.

**Table 7. The total variance of principal components for Sari watershed**

| Principal Component | Initial Eigenvalues | Extraction Sums of Squared Loadings | Rotation Sums of Squared Loadings |
|---------------------|---------------------|-----------------------------------|----------------------------------|
|                     | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1                   | 8.229 | 48.408 | 48.408 | 8.229 | 48.408 | 48.408 | 4.379 | 25.757 | 25.757 |
| 2                   | 4.587 | 26.984 | 75.392 | 4.587 | 26.984 | 75.392 | 4.116 | 24.214 | 49.971 |
| 3                   | 2.007 | 11.804 | 87.197 | 2.007 | 11.804 | 87.197 | 3.920 | 23.060 | 73.031 |
| 4                   | 1.290 | 7.591 | 94.788 | 1.290 | 7.591 | 94.788 | 3.699 | 21.757 | 94.788 |
| 5                   | 0.558 | 3.283 | 98.071 |        |        |        |        |        |        |
| 6                   | 0.328 | 1.929 | 100.000 |        |        |        |        |        |        |
| 7                   | 5.8E-16 | 3.2E-15 | 100.000 |        |        |        |        |        |        |
| 8                   | 4.0E-16 | 2.3E-15 | 100.000 |        |        |        |        |        |        |
| 9                   | 2.2E-16 | 1.3E-15 | 100.000 |        |        |        |        |        |        |
| 10                  | 2.0E-16 | 1.2E-15 | 100.000 |        |        |        |        |        |        |
| 11                  | 3.5E-17 | 2.0E-16 | 100.000 |        |        |        |        |        |        |
| 12                  | -8.0E-17 | 4.7E-16 | 100.000 |        |        |        |        |        |        |
| 13                  | -1.7E-16 | 9.9E-16 | 100.000 |        |        |        |        |        |        |
| 14                  | -2.2E-16 | 1.3E-15 | 100.000 |        |        |        |        |        |        |
| 15                  | -3.7E-16 | 2.2E-15 | 100.000 |        |        |        |        |        |        |
| 16                  | -5.8E-16 | 3.4E-15 | 100.000 |        |        |        |        |        |        |
| 17                  | -8.5E-16 | 5.0E-15 | 100.000 |        |        |        |        |        |        |

PCA also generates the first factor-loading matrix that explains the correlation among parameters in each principal component (table 8). The first PC had a strong correlation ($r \geq 0.9$) with $Lu$, $Ff$, $Cc$, and $Re$; good correlation ($0.75 \leq r \leq 0.9$) with $Lg$, $Re$, $Dd$, $Fs$, and shrub; and moderate correlation
(0.60 ≤ r ≤ 75) with Rb and Rn. The second PC was strongly correlated with \(R_{hp}\); good correlated with \(R_{hl}, Gr,\) and forest; and moderately correlated with \(Rn\). The third and fourth PC was only correlated moderately with \(Dt\) and agriculture, respectively.

**Table 8. First factor-loading matrix of all parameters**

| Parameters | Principal Component 1 | 2 | 3 | 4 |
|------------|-----------------------|---|---|---|
| Lu         | -0.920*               | -0.031 | 0.256 | 0.230 |
| Rb         | -0.724***              | -0.525 | 0.032 | 0.274 |
| Lg         | -0.762**               | 0.092 | 0.467 | 0.354 |
| Ff         | 0.917*                 | -0.190 | -0.001 | 0.316 |
| Dt         | 0.333                  | 0.536 | 0.757*** | 0.110 |
| Cc         | -0.900*                | -0.220 | -0.189 | 0.080 |
| Re         | 0.852**                | 0.359 | 0.320 | -0.118 |
| Re         | 0.938*                 | -0.176 | 0.015 | 0.273 |
| Dd         | 0.754**                | -0.129 | -0.455 | -0.371 |
| Fs         | 0.845**                | 0.205 | 0.360 | -0.188 |
| Rh         | 0.279                  | 0.821** | -0.359 | 0.343 |
| RHp        | 0.070                  | 0.961* | -0.221 | 0.054 |
| Gr         | 0.279                  | 0.821** | -0.359 | 0.343 |
| Rn         | -0.696***              | 0.630*** | -0.331 | 0.066 |
| Forest     | -0.361                 | 0.796** | 0.301 | -0.036 |
| Shrub      | -0.756**               | 0.369 | -0.269 | -0.339 |
| Agriculture| 0.530                  | -0.523 | -0.309 | 0.646*** |

*Strong correlation (r > 0.90), ** Good correlation (0.90 ≥ r > 0.75), *** Moderate correlation (0.75 ≥ r > 0.60)

According to the first factor-loading matrix, some parameters were strongly correlated with PC, some good correlated, some moderately correlated, and some did not correlate with any principal components. Therefore, it is hard to define the most significant parameters of each PC. The rotation of the first factor-loading matrix is necessary to provide better correlation and significant parameters. Table 9 shows the rotated factor-loading matrix. The strong correlation for the first PC, second PC, third PC, and fourth PC was \(Dt\), agriculture, \(Lg\), and \(Gr\), respectively. These parameters are also considered as the important parameters and utilized for WSA and sub-watershed prioritization.

**Table 9. Rotated factor-loading matrix of all parameters**

| Parameters | Principal Component 1 | 2 | 3 | 4 |
|------------|-----------------------|---|---|---|
| Lu         | -0.387                | -0.366 | 0.815** | -0.129 |
| Rb         | -0.615                | 0.016 | 0.575 | -0.409 |
| Lg         | -0.116                | -0.267 | \textbf{0.920*} | -0.049 |
| Ff         | 0.418                 | 0.815** | -0.365 | 0.058 |
| Dt         | \textbf{0.914*}       | -0.052 | 0.316 | 0.211 |
| Cc         | -0.744***             | -0.331 | 0.460 | -0.162 |
| Re         | 0.865**               | 0.202 | -0.374 | 0.203 |
| Dd         | 0.453                 | 0.790** | -0.392 | 0.049 |
| Fs         | 0.109                 | 0.267 | -0.918* | 0.007 |
| Rh         | 0.846**               | 0.215 | -0.399 | 0.033 |
| RHp        | 0.142                 | 0.063 | -0.110 | 0.980* |
| Gr         | 0.142                 | 0.063 | -0.110 | \textbf{0.981*} |
| Rn         | -0.430                | -0.591 | 0.304 | 0.609*** |
| Forest     | 0.294                 | -0.611*** | 0.403 | 0.483 |
| Shrub      | -0.456                | -0.795 | 0.119 | 0.204 |
| Agriculture| -0.176                | \textbf{0.938*} | -0.189 | -0.039 |

*Strong correlation (r > 0.90), ** Good correlation (0.90 ≥ r > 0.75), *** Moderate correlation (0.75 ≥ r > 0.60)
The final sub-watershed prioritization used the \( CV \) value that was calculated based on the preliminary rank and weight of important parameters (\( Dt \), agriculture, \( Lg \), \( Gr \)). The determination of the weight of important parameters employed cross-correlation analysis between the four parameters (table 10). According to the weighted sum of the important parameters, the \( CV \) was calculated using the following equation.

\[
CV = (0.361 \times PR \ of \ Dt) + (0.117 \times PR \ of \ Agriculture) + (0.192 \times PR \ of \ Lg) + (0.331 \times PR \ of \ Gr)
\]

**Table 10.** The cross-correlation between the important parameters of Sari watershed

| Parameters | Dt   | Agriculture | Lg    | Gr    |
|------------|------|-------------|-------|-------|
| Dt         | 1.000| -0.264      | 0.185 | 0.295 |
| Agriculture| -0.264| 1.000      | -0.351| 0.009 |
| Lg         | 0.185| -0.351      | 1.000 | -0.189|
| Gr         | 0.295| 0.009       | -0.189| 1.000 |
| **Sum**    | 1.216| 0.394       | 0.645 | 1.115 |
| **Grand total** | 3.369| 3.369       | 3.369 | 3.369 |
| **WSA**    | 0.361| 0.117       | 0.192 | 0.331 |

4.3. Prioritization of sub-watershed using PCA-WSA

The priority rank of sub-watershed based on \( CV \) values is presented in table 11. Figure 2 illustrates the spatial distribution of priority rank for sub-watershed of Sari watershed. The SW1 is considered as the highest priority with the lowest of \( CV \) value (2.162). Besides, the lowest priority was the SW6 that had the highest \( CV \) value.

**Table 11.** The final priority rank for sub-watersheds of Sari watershed

| Sub Watershed | Compound Value (CV) | Priority Rank |
|---------------|---------------------|---------------|
| SW1           | 2.162               | 1             |
| SW2           | 3.875               | 4             |
| SW3           | 4.809               | 5             |
| SW4           | 3.376               | 3             |
| SW5           | 5.216               | 6             |
| SW6           | 5.339               | 7             |
| SW7           | 3.251               | 2             |
Figure 2. Priority rank map for sub-watersheds of Sari watershed

The final priority rank was assigned the priority category based on CV values. The priority category has been divided into three groups, namely low (CV > 4.300), medium (3.301 ≤ CV ≤ 4.300), and high (VC < 3.300). Table 12 presents the SW1 and SW7 as the high category; SW2 and SW4 as the medium category; and SW3, SW5, and SW6 as low category. The high category occupies approximately 8,582.35 ha area of Sari watershed. Figure 3 shows the map of the priority category for Sari watershed.

Table 12. The priority category for sub-watershed of Sari watershed

| No | Compound Value (CV) | Priority Category | Sub Watershed (SW) | Area (ha) | Percentage of area (%) |
|----|---------------------|-------------------|--------------------|-----------|------------------------|
| 1  | <3.300              | High              | SW1, SW7           | 10,397.12 | 41.34                  |
| 2  | 3.301-4.300         | Medium            | SW2, SW4           | 6,170.71  | 24.54                  |
| 3  | >4.300              | Low               | SW3, SW5, SW6      | 8,582.35  | 34.12                  |
The high category of prioritization also depicts a higher degree of erosion potential and the potential area for applying soil and water conservation [21]. On the other hand, the low category indicated to have a good enough geomorphometric characteristic and existing landuse/landcover. The mitigation efforts for the high category include structural soil and water conservation techniques to minimize the sub-watershed susceptibility to erosion. In addition, maintenance and protection of the present vegetation coverage and revegetation in the high category are recommended as well. The medium category sub-watersheds have a moderate risk to erosion requiring vegetative soil and water conservation to inhibit erosion, particularly sheet and rill erosion [14].

5. Conclusions
Sari watershed, with its ‘to be rehabilitated’ status, has various programs to reduce land degradation by soil erosion. The implementation of the programs needs prioritization spatially in the sub-watershed unit due to bio-physics and socio-economic limitations. This current study formulated the

**Figure 3.** Priority category map for sub-watersheds of Sari watershed
prioritization of sub-watersheds based on ‘natural’ characteristics represented by geomorphometric properties, and ‘management’ characteristic represented by landuse/landcover. The method for the calculation was the integration of PCA and WSA. The PCA was capable of extracting the most important parameters (i.e., Dt, agriculture, Lg, and Gr). The WSA application was successful in defining the weight of each important parameter. It is in line with the real condition that the contribution of parameters is not equal to the natural process, including erosion. The integration PCA-WSA offers more dynamic, effective, and efficient results over the common prioritization techniques that use many parameters in a complex way and assumes the equal contribution among parameters.

According to the methodology applied in the sub-watershed of Sari watershed, the high priority is given to SW1 and SW7. The SW2 and SW4 are assigned the medium priority, while the low priority belongs to SW3, SW5, and SW6. This valuable information can be utilized by decision-makers of Sari watershed in the implementation of the management practices to reduce and prevent land degradation.

For future work, it is recommended to consider socio-economic parameters in the prioritization process. The use of various parameters (biophysics, social-economics) for prioritization is expected a more reliable result and intuitive point of view. The adopted methodology of this study can also be applied to different susceptibility or main issues, such as flash flood, groundwater potential, and drought.

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Conceptualization, O.S. and R.N.; Field observation and measurement, O.S. and R.N.; Software and data analysis, O.S.; Writing, review, and editing manuscript, O.S. and R.N. Both authors read and approved the final manuscript.

Conflicts of Interest
The authors declare no conflict of interest.

References
[1] Arami SA, Alvandi E, Frootandanesh M, Tahmasebipour N, Karimi Sangchini E. 2016 Prioritization of watersheds in order to perform administrative measures using fuzzy analytic hierarchy process Seyyed. J Fac For Istanbul Univ., 67(1):13–21.
[2] Moyosari BD. 2018 Monitoring dan Evaluasi Pengelolaan DAS Sari [Monotoring and evaluation management of Sari watershed] (Dirjen PDAS dan HL, KLHK, Mataram)
[3] Malik A, Kumar A, Kushwaha DP, Kisi O, Salih SQ, Al-Ansari N, et al. 2019 The implementation of a hybrid model for hilly sub-watershed prioritization using morphometric variables: Case study in India. Water (Switzerland), 11(6).
[4] Gajbhiye S, Mishra SK, Pandey A. 2014 Prioritizing erosion-prone area through morphometric analysis: an RS and GIS perspective. Appl Water Sci., 4(1):51–61.
[5] Kadam AK, Jaweed TH, Kale SS, Umrikar BN, Sankhua RN. 2019 Identification of erosion-prone areas using modified morphometric prioritization method and sediment production rate: a remote sensing and GIS approach. Geomatics, Nat Hazards Risk., 10(1):986–1006.
[6] Syed NH, Rehman AA, Hussain D, Ishaq S, Khan AA. 2017 Morphometric analysis to prioritize sub-watershed for flood risk assessment in Central Karakoram National Park using GIS / RS approach. In: ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences. p. 367–710.
[7] Mangan P, Haq MA, Baral P. 2019 Morphometric analysis of watershed using remote sensing and GIS—a case study of Nanganji River Basin in Tamil Nadu, India. Arab J Geosci., 12(6).
[8] Siddiqui R, Said S, Shakeel M. 2020 Nagmati River Sub-watershed Prioritization Using PCA, Integrated PCWS, and AHP: A Case Study. *Nat Resour Res.*, https://doi.org/10.1007/s11053-020-09622-6

[9] Sangma F, Guru B. 2020 Watersheds Characteristics and Prioritization Using Morphometric Parameters and Fuzzy Analytical Hierarchal Process (FAHP): A Part of Lower Subansiri Sub-Basin. *J Indian Soc Remote Sens.*, 48(3):473–96.

[10] Youssef AM, Pradhan B, Hassan AM. 2011 Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS based morphometry and satellite imagery. *Environ Earth Sci.*, 62(3):611–23.

[11] Pandey A, Chowdary V.M. MBC. 2004 Morphological analysis and watershed management using geographic information system. *Hydrol J.*, 27:71–84.

[12] Javed A, Khanday MY, Ahmed R. 2009 Prioritization of sub-watersheds based on morphometric and land use analysis using Remote Sensing and GIS techniques. *J Indian Soc Remote Sens.*, 37(2):261–74.

[13] Malik MI, Bhat MS. 2014 Integrated Approach for Prioritizing Watersheds for Management: A Study of Lidder Catchment of Kashmir Himalayas. *Environ Manage.*, 54(6):1267–87.

[14] Puno GR, Puno RCC. 2019 Watershed conservation prioritization using geomorphometric and land use/land cover parameters. *Glob J Environ Sci Manag.*, 5(3):279–94.

[15] Javed A, Khanday MY, Rais S. 2011 Watershed prioritization using morphometric and land use/land cover parameters: A remote sensing and GIS based approach. *J Geol Soc India.*, 78(1):63–75.

[16] Aher PD, Adinarayana J, Gorantiwar SD. 2014 Quantification of morphometric characterization and prioritization for management planning in semi-arid tropics of India: A remote sensing and GIS approach. *J Hydrol*, 511:850–60.

[17] Meshram SG, Sharma SK. 2017 Prioritization of watershed through morphometric parameters: a PCA-based approach. *Appl Water Sci.*, 7(3):1505–19.

[18] Adhami M, Sadeghi SH. 2016 Sub-watershed prioritization based on sediment yield using game theory. *J Hydrol*, 541:977–87.

[19] Farhan Y, Anbar A, Al-Shaikh N, Mousa R. 2017 Prioritization of Semi-Arid Agricultural Watershed Using Morphometric and Principal Component Analysis, Remote Sensing, and GIS Techniques, the Zerqa River Watershed, Northern Jordan. *Agric Sci.*, 08(01):113–48.

[20] Sharma SK, Gajbhiye S, Tignath S. 2015 Application of principal component analysis in grouping geomorphic parameters of a watershed for hydrological modeling. *Appl Water Sci.*, 5(1):89–96.

[21] Meshram SG, Sharma SK. 2018 Application of Principal Component Analysis for Grouping of Morphometric Parameters and Prioritization of Watershed. *Hydrol Model.*, 447–458.

[22] Horton RE. 1945 Erosion development in stream and their drainage basins. *Geol Soc Am Bull.*, 56(1):275–370.

[23] Strahler A. 1957 Quantitative Analysis of Watershed Geomorphology. *American Geophysical, Vol 8.*

[24] Schumm S. 1956 Evolution of drainage systems and slopes in badlands at Perth Amboy. New Jersey. *Geol Soc Am Bull.*, 67:597–646.

[25] Miller VC. 1953 Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee. *Technical report (Columbia University. Department of Geology) no. 3.* (FAO of The UN)

[26] Badan Standardisasi Nasional. 2010 Klasifikasi Penutup Lahan. Sni 7654, 1–28.

[27] Chandniha SK, Kansal ML. 2017 Prioritization of sub-watersheds based on morphometric analysis using geospatial technique in Piperiya watershed, India. *Appl Water Sci.*, 7(1):329–338.

[28] Varade AM, Khare YD, Mondal NC, Muley S, Wankawar P, Raut P. 2013 Identification of Water Conservation Sites in a Watershed (WRJ-2) of Nagpur District, Maharashtra using
Geographical Information System (GIS) Technique. *J Indian Soc Remote Sens.*, **41**(3):619–630.

[29] Khan MA, Gupta VP, Moharana PC. 2001 Watershed prioritization using remote sensing and geographical information system: A case study from Guhiya, India. *J Arid Environ.*, **49**(3):465–475.

[30] Thakkar AK. 2012 Morphometric analysis and prioritization of miniwatersheds in Rongli watershed, Sikkim (India) using remote sensing and GIS techniques. *Int J Fundam Appl Sci.*, **1**(3):61–6.

[31] Subrahmanym PDS, Ahmed S. 2005 The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environmental Geology*, **47**:412–420.

[32] Spitale D, Mair P. 2017 Predicting the distribution of a rare species of moss: The case of buxbaumia viridis (bryopsida, buxbaumiaceae). *Plant Biosyst.*, **151**(1):9–19.

[33] Kaiser HF. 1958 The varimax criterion for analytic rotation in factor analysis. *Psychometrika.*, **23**(3):187–200.

[34] Aher PD, Adinarayana J, Gorantiwar SD. 2013 Prioritization of watersheds using multi-criteria evaluation through fuzzy analytical hierarchy process. *Agric Eng Int: CIGR Journal*, **15**(1):11–8.

[35] Kanth T, Hassan Z. 2012 Morphometric Analysis and Prioritization of Watersheds for Soil and Water Resource Management in Wular Catchment Using Geo-Spatial Tools. *Int J Geol Earth Environ Sci*, **2**(1):30–41.

[36] Kadam AK, Umrikar BN, Sankhua RN. 2016 Geomorphometric Characterization and Prioritization of Watershed from Semi-Arid Region, India for Green Growth Potential. *J Environ Res Dev.*, **11**(02):417–432.

[37] Rama VA. 2014 Drainage basin analysis for characterization of 3rd order watersheds using Geographic Information System (GIS) and ASTER data. *J Geomatics.*, **8**(2):200–210.

[38] Ali SA, Ikbal J. 2015 Prioritization based on geomorphic characteristics of Ahar watershed, Udaipur district, Rajasthan, India using Remote Sensing and GIS. *J Environ Res Dev.*, **10**(1):187–200.

[39] Altaf F, Meraj G, Romshoo SA. 2013 Morphometric Analysis to Infer Hydrological Behaviour of Lidder Watershed, Western Himalaya, India. *Geogr J.*, **2013**:1–14.

[40] Thomas J, Joseph S, Thrivikramji KP, Abe G. 2011 Morphometric analysis of the drainage system and its hydrological implications in the rain shadow regions, Kerala, India. *J Geogr Sci.*, **21**(6):1077–1088.

[41] Choudhari PP, Nigam GK, Singh SK, Thakur S. 2018 Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India. *Geol Ecol Landscapes*, **9508**:1–12.

[42] Ali U, Ali SA, Ikbal J, Bashar M, Fadhil M, Ahmad M, et al. 2018 Soil Erosion Risk and Flood Behaviour Assessment of Sukhnag catchment, Kashmir Basin: Using GIS and Remote Sensing. *J Remote Sens GIS.*, **07**(01):1–8.