Research article

Erosion hotspot mapping using integrated morphometric parameters and Land use/land cover of Jigjiga Watershed, Ethiopia

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ARTICLE INFO

Keywords:
- Morphometric parameters
- Land use/land cover
- Jigjiga sub-watersheds
- Erosion hotspots

ABSTRACT

Integration of morphometric parameters (MPs) and Land use/land cover (LU/LC) is crucial to prioritise the sub-watershed for conservation management to control soil erosion. The main objective of this study is to develop erosion hotspot mapping using integrated MPs and the LU/LC of Jigjiga Watershed further precisely to map soil erosion hotspots using MPs, LU/LC types and mapping of erosion hotspots by average weightage of MPs and LU/LC types. The study used the digital elevation model data for MPs analysis to extract the areal, linear and relief aspects to determine erosion risk mapping further using ArcGIS 10.5 software. The Jigjiga watershed was subdivided into fifteen sub-watersheds and coded as JSW-1 to JSW-15. The MPs and LU/LC types computed values were used to rank and prioritise the sub-watersheds. Jigjiga Sub-watershed, LU/LC types were analysed for erosion risk area mapping using the Compound Priority method. The degree of prioritisation used for this study for the MPs and LU/LC types was very high, high, moderate, low, and very low. Accordingly, the erosion hotspots mapping results showed that the sub-watersheds JSW-15 and JSW-14 were categorised under a high priority based on MPs, whereas the JSW-14 was put under a very high priority by LU/LC. The JSW-1, JSW-5, JSW-9 and JSW-13 need high priority for natural resources conservation, both methods of MPs and mean weightage of LU/LC and MPs. The integration of erosion hotspot mapping from MPs and LU/LC parameters correlated for JSW-2, JSW-3, JSW-10, JSW-11, JSW-13 and JSW-14 common values of final erosion prioritisation. This research has provided information on land degraded areas for watershed managers, urban planners and decision-makers to manage the natural resources for sustainable watershed development.

1. Introduction

Soil erosion is one of the earth surface environmental problems (Ananda and Herath, 2003; Shi and Shao, 2000) favoured to lose top fertile soil that is the most important for agricultural productivity (Graves et al., 2015); unstable soil structure leads the infrastructure failure to not serve as design periods. Soil erosion disturbs the beauty of the landscape. Human and material transportation delayed by an eroded land surface such as a gully. Water distribution lines failed due to soil erosion agents; the supporting soil material has detached by water force.

Soil erosion removes topsoil material from its original place to another site by the combined velocity and unmeasured water force (Williams et al., 2009). In addition to soil erosion agents (Venkateswarlu, 1994; Lal, 2001), it is intensified by the human day to day activity on land surface initiation to soil erosion (Karydas et al., 2019). However, human and animal are the actors for soil erosion (FAO and ITPS, 2015). The climatic condition, soil type as well as its chemical and biological characteristics, topographical features like slope steepness, slope length and shape of the watershed, vegetation cover and the kind of erosion have studied by different researchers and summarized as soil erosion is a global problem (Kouli et al., 2009; Lal, 1998; Rahman et al., 2009; Shahid et al., 2021; Pande et al., 2021a, b, c).

Soil erosion hotspot mapping is a cost-effective way of reporting the eroded soil site using the ArcGIS 10.5 software for decision-makers, designers, urban or rural area administrators to further plan and manage watershed in the perspective of soil and water conservation (Skilodimou et al., 2003; Pande et al., 2021a, b, c; Pande et al., 2022a, b; Pande, 2020). Researchers worldwide reported several studies for erosion hotspot mapping or critical sub-watershed/prioritization (Vrieling, 2007; Baba and Yusof, 2001). Soil erosion has mapped using land use/land cover (LU/LC) and morphometric parameters (MPs) (Puno and Puno, 2019; Javed et al., 2011; Altaf et al., 2014; Pande et al., 2018).

GIS technology and Remote sensing data have been confirmed in research works related to natural resources studies, such as soil and water...
assessment and management (Khadri and Pande, 2016; Pande et al., 2022a, b; Ananda and Herath, 2003). Soil erosion mapping using the Remote sensing data like LU/LC and digital elevation model and MPs based on the method developed in ArcGIS10.5 software has been used by researchers (Jang et al., 2013; Petropoulos et al., 2015).

The MPs measure external dimensions of landforms’ using mathematical equations based on shape and size (Agarwal, 1998; Obi Reddy et al., 2002; Jang et al., 2013). MPs have been classified under linear, areal and relief aspects. The parameters are negatively or positively associated with soil erosion (Pradhan and Pirasteh, 2010; Thakkar and Dhirman, 2007; Ratnam et al., 2005). For instance, the higher hydrologic coefficient of the MPs showed resistance to soil erosion during high discharge (Tesema, 2021), while the minimum value is the risk of soil erosion. On the other hand, the maximum value for basin relief of MPs risks soil erosion, as reported in various research works (Farhan and Nawaysa, 2015; Bhatt and Ahmed, 2014; Alqahtani and Qaddah, 2019). In addition, authors have reported that soil erosion spatial distribution in different parts of the world using MPs (Aher et al., 2014; Ajaykumar et al., 2019; Patel et al., 2013; Chopra et al., 2005; Abdul Rahaman et al., 2015).

LU/LC is the combined land use and land cover of earth resources. Land use implies the people consumed the land resources, whereas land cover includes forest or waterbody. Hence, LU/LC is the earth environmental balance (Gaglio et al., 2017; Hasan et al., 2020; Pande et al., 2021a, b, c). Soil erosion is the output of land cover change (Mutua et al., 2006; Sharma et al., 2011; Fu et al., 2011). The land surface altered by a human is easily eroded by water or wind due to its LU/LC (Al-Seibh, 2006; IPCC, 2007). Based on this fact, researchers can prioritize the watershed following the erosion hotspots information (Petropoulos et al., 2015; Pandey et al., 2007; Aher et al., 2014). Accordingly, using LU/LC parameters, it is possible to map the erosion hotspot of the Jigjiga watershed. Therefore, this study aims to (1) map erosion hotspots using MPs, (2) erosion hotspot mapping using LU/LC parameters and (3) soil erosion hotspot mapping by average weightage of morphometric and LU/LC parameters.

2. Datasets and methods

2.1. Study area

Jigjiga watershed is located in Somali Regional State, in the eastern part of Ethiopia. The watershed is located in the Wabi Shebel river basin, around 100 km east of Harar and 60 km west of the border with Somaliland and geographically, bounded between 9.017’ N to 9.35’ N and 42’ E to 42.8’ E (Figure 1). The watershed has an average elevation of 1609 m above mean sea level. It has characterized by frequent semi-annual flash floods and semi-arid erosion risks. The watershed has a temperature of 12.3 °C and 27 °C minimum and maximum respectively, with minimum and maximum rainfall lying between 400mm and 800mm respectively, with an annual mean of 857mm (https://en.climate-data.org/africa/ethiopia/somali/jigiga-3651/). The study area is the most drought-prone due to high inter and intra-annual irregularity in rainfall and high variation coefficients. The rainy period in most of this area is from March to the end of June, primarily dry periods with rare precipitation.

2.2. Data collection

This study used two satellite data sources:

1. JAXA (Japan Aerospace Exploration Agency) was accessed to download ALOS (Advanced Land Observing Satellite) a 12.5m digital elevation model (DEM) resolution from the Alaska Satellite Facility (ASF) Distributed Active Archive Center (DAAC). An active microwave sensor Phased Array-Type L-Band Synthetic Aperture Radar (PALSAR) largely supports in reaching this high-resolution DEM products to the users free of charge. ALOS DEM has been using by...
Figure 2. General flowchart of research methodology.

Table 1. Linear aspects of JSW morphometric parameters.

| Parameters                  | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds | Jigjiga Sub-Watersheds |
|-----------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|-------------------------|
| A                           | 100                     | 62.7                    | 39                      | 92                      | 96.1                    | 157                     | 84.1                    | 83.7                    | 89.6                    | 62                      | 48.9                    | 163                     | 62                      | 32                      |
| P                           | 73                      | 44.5                    | 4’8                     | 65                      | 77.2                    | 102                     | 50.3                    | 75.1                    | 73.8                    | 38                      | 42.6                    | 74.5                    | 29                      | 38                      |
| Lb                          | 18                      | 13.8                    | 11                      | 17                      | 17.5                    | 23.2                    | 16.3                    | 16.2                    | 16.9                    | 14                      | 12                      | 23.7                    | 9.3                     | 13                      |
| Ll                          | 181                     | 130                     | 80                      | 162                     | 197                     | 324                     | 171                     | 172                     | 188                     | 138                     | 107                     | 355                     | 50                      | 95                      |
| Nu                          | 744                     | 534                     | 347                     | 632                     | 792                     | 777                     | 703                     | 556                     | 857                     | 419                     | 446                     | 1178                    | 313                     | 551                     |
| Highest Stream Order        | 5’th                    | 5’th                    | 5’th                    | 5’th                    | 5’th                    | 6’th                    | 7’th                    | 4’th                    | 5’th                    | 5’th                    | 4’th                    | 5’th                    | 4’th                    | 5’th                    |
| MRb                         | 2                       | 4.64                    | 1.9                     | 2.3                     | 1.93                    | 2.44                    | 1.73                    | 13.7                    | 5.08                    | 1.8                     | 1.73                    | 1.94                    | 1.5                     | 2.2                     |
| Rb                          | 7.8                     | 18.6                    | 7.6                     | 7                       | 7.73                    | 9.77                    | 6.93                    | 68.4                    | 30.5                    | 5.3                     | 6.92                    | 7.75                    | 4.5                     | 6.5                     |
| Rl                          | 2.5                     | 4.92                    | 2.5                     | 3.8                     | 3.25                    | 1.82                    | 2.01                    | 12.6                    | 8.27                    | 1.5                     | 3.01                    | 2.05                    | 1.9                     | 1.8                     |
| Run                         | 0.5                     | 0.98                    | 0.5                     | 0.9                     | 0.65                    | 0.36                    | 0.4                     | 2.11                    | 1.38                    | 0.4                     | 0.6                     | 0.41                    | 0.5                     | 0.5                     |
| Lsm                         | 0.3                     | 0.24                    | 0.3                     | 0.3                     | 0.24                    | 0.24                    | 0.25                    | 0.24                    | 0.2                     | 0.23                    | 0.23                    | 0.3                     | 0.3                     | 0.3                     |
| RHD                         | 0.3                     | 0.21                    | 0.3                     | 0.4                     | 0.34                    | 0.15                    | 0.23                    | 0.15                    | 0.27                    | 0.2                     | 0.35                    | 0.21                    | 0.3                     | 0.2                     |
| Lmn                         | 0.3                     | 0.27                    | 0.1                     | 0.2                     | 0.19                    | 0.35                    | 0.21                    | 0.24                    | 0.22                    | 0.3                     | 0.21                    | 0.28                    | 0.2                     | 0.1                     | 0.19                   |
researchers to study soil erosion (Niipele and Chen, 2019; Arabameri et al., 2019).

2. The Jigjiga watershed LULC 2020 downloaded from USGS with 30m resolution on 21/01/2020. The source of this data is Georeferenced Satellite Landsat 8 images (https://earthexplorer.usgs.gov/); it was validated with Ground truth values and Google Earth Pro data.

2.3. Data analysis

Using the methods and equations provided in Table S1, MPs were analysed from DEM for this particular study. The DEM has been extracted for the Jigjiga watershed for further parameter computation based on the study area shapefile map. The ArcGIS 10.5 of the spatial analysis tools component of hydrology procedures implemented to delineate sub-watersheds. This study computed the MPs values of linear, areal and relief aspects of parameters for erosion risk mapping analysis. Accordingly, the Jigjiga watershed has been divided into 15 sub-watersheds; and coded as JSW-1 to JSW-15 to simplify for attribute report in ArcGIS. Hence, JSW-1 stands for Jigjiga Sub-Watershed one while JSW-15 stands for Jigjiga Sub-Watershed fifteen.

Using ArcGIS 10.5 software spatial analysis tools, LU/LC 2020 was classified based on the unsupervised image classification method. Then, the classified LU/LC image is reclassified to change into polygon shapefiles to assign the nomenclature of LU/LC types. Based on Python programming in ArcGIS 10.5 software, the LU/LC attributed table has been set into six classes Agriculture, Forest, Bare soil, Shrubland, Urban Land and Waterbody. For example, Figure 5 showed JSW-1 to JSW-15 sub-watershed wised LULC type of the study area.

2.4. Jigjiga Sub-watershed (JSW) prioritization

Jigjiga sub-watershed prioritization was accomplished by dividing the main watershed into 15 sub-watersheds; Jigjiga sub-watershed coded from JSW-1 to JSW-15; JSW parameters have computed following these discretized sub-watersheds. Prioritization of watersheds focused on the linear and areal aspects of morphometric parameters direct and indirect erosion risk associations (Farhan and Nawaysa, 2015; Debelo et al., 2017). These include linear aspect parameters such as overland flow and bifurcation ratio; areal aspects Drainage density, circularity ratio, compactness coefficient, basin shape, drainage texture, stream frequency, form factor and elongation ratio. Prioritization was made by ranking parameters as a minimum value to a higher ranking for areal aspect parameters and maximum value to higher-order to linear parameters.

Prioritizing of the Jigjiga watershed was executed by the compound parameter value. Morphometric parameters were weighted equally. The correlation matrix was applied to this study to compute the weightage factor following the correlation sum and total parameters. Then, each sub-watershed compound parameter constants were developed from the prioritization Eq. (1) given below

\[
C_p = \frac{x_1}{y} (p_1) + \frac{x_2}{y} (p_2) + \ldots + \frac{x_n}{y} (p_n) 
\]

Where, \(C_p\) is compound parameter, \(x\) is correlation sum, \(y\) is grand total, \(p\) is morphometric parameters, 1, 2, \ldots, \(n\) are subscripts.

Based on the above equation, \(P\) values of minimum were considered the priority to JSW among 15 sub-watersheds using morphometric parameters.

Figure 3. Areal aspects of MPs of JSW
Prioritization of watersheds using LU/LC has a significant role in watershed management options. For Jigjiga watershed LU/LC was analyzed to evaluate the erosion risk area of sub-watersheds (Farhan and Nawaiya, 2015). Accordingly, LU/LC of Jigjiga watershed has been categorized into six (6) classes as Agriculture, Bare Soil, Forest, Shrubland, Urban Land and Waterbody. Compared to morphometric analysis, the ranked the LU/LC types used to identify the impact of causing erosion risk prioritization. Following the ranks and correlation sums, JSW were prioritized based on the LU/LC impacts on soil erosion.

In this study, the flowchart (Figure 2) showed the integrated MPs and LU/LC parameters applied to evaluate the erosion hotspots of JSW. The integration was accomplished by averaging each parameter’s weightage for further analysis of JSW in erosion hotspots. Then, the JSW has mapped according to erosion hotspots prioritization.

3. Results and discussions

Erosion hotspot mapping provides watershed information based on the various land surface process and dissimilar land surface systems regarding the erosion status in sub-watersheds wise (Ifabiyi and Enilorunda, 2012; Pande and Moharir, 2017). The hotspot mapping has been conducted by the integrated parameter values of morphometry and LU/LC from JSW. Computation of MPs analysis derived from linear, areal and relief aspects of Jigjiga watershed. Erosion analysis from LU/LC determined based on the assigned LU/LC parameters for each JSW (Table 4 and Figure 7).

3.1. MP analysis for erosion risk analysis

3.1.1. Linear aspects

Linear aspects of morphometric parameters play a significant role in the erosion area assessment, especially during data insufficiency (Table 1). Watershed/sub-watershed drainage network analysis relies on linear aspects parameters (Aher et al., 2014). Area (A) and basin length (Lb) have direct relations with runoff, flood risk, erosion and peak discharge. The higher these parameters produce, the higher runoff, flood risk, erosion and peak discharge. Stream orders linked with the surface water potential and in Table 1 except JSW-8, JSW-9, JSW-10, JSW-13 and JSW-14, all sub-watersheds the highest stream order is 5th while the watershed maxim stream order is 7th. The higher the length of the stream (Lu) has many tributaries that contribute water and pollutant flow to the main channel (Chang, 2005; Vittala et al., 2004). The highest stream length has been observed in JSW-12, while the smallest is JSW-13 (Table 1). Stream Number (Nu) is negatively associated with the watershed’s local rainfall pattern and hydrological characteristics. The largest Nu has the higher watershed response to hydrology such as sedimentation, erosion and runoff; therefore, JSW provides JSW-12 the largest Nu and JSW-13 the smallest (Table 1). Table 1 justifies the direct relations between the Nu and Lu. The bifurcation ratio (Rb) measures the complication of the watershed stream network (Mesa, 2006). The stream networks of JSW have disturbed 4th stream orders for JSW-15 and JSW-8; the estimated value of Rb of this sub-watershed is higher than the range (Figure 5 and Table 1), which implies that there is structural
Researchers reported that the Rb reflects higher permeability (Hajam et al., 2013; Manu and Anirudhan, 2008). Mean bifurcation ratio (MRb) and Rb directly related to the geomorphological analysis. The stream length ratio (RL) of JSW is the highest for JSW-8 and smallest for JSW-10 (Table 1); this indicates that high surface runoff, discharge and erosion events (Sreedevi et al., 2009; Pandey and Das, 2016).

### 3.1.2. Areal aspects

Areal aspects of morphometric parameters have been used worldwide for erosion risk area prioritization (Aher et al., 2014; Altaf et al., 2014; Said et al., 2018). They have direct relations to erosion events such as drainage density (Dd), drainage texture (Dt) and stream frequency (Figure 3) and indirect ties to erodibility factor including circularity ratio (Rc), elongation ratio (Re), form factor (Ff) and channel compactness (Cc).

Stream frequency (Fs) is associated with the drainage networks and flow characteristics passing through the flow channel (Bali et al., 2011). Hydrologically, Fs is inversely related to the watershed’s permeability and infiltration capacity (Montgomery and Dietrich, 1989). In the description of JSW, the highest Fs is the lowest permeability and infiltration capacity; for example, JSW-13, JSW-14, JSW-9, JSW-11, JSW-3 and JSW-15 satisfied the criteria. Therefore, these sub-watersheds show the highest erosion susceptibility to erosion (Figure 5).

The characteristics of Dd include lack of infiltration and percolation due to impermeable rocks and soil types of the watershed; in such geologically formed watersheds, immediate flow discharge could happen towards the main channel. In the Jigjiga watershed, JSW-9 to 12 indicated the erosion power of water around the main channel.

In erosion susceptibility mapping, Figure 5 showed that the sub-watershed drainage texture increases with increasing soil erosion. Dl is the drainage spacing of the watershed and depends on soil type, vegetation and climate (Horton, 1945; Smith, 1950; Kale and Gupta, 2001). Accordingly, JSW-15, JSW-12, JSW-14 and JSW-7 provided high drainage texture of sub-watersheds (Figure 3), and it has conveyed that it should have priority of conservation to these sub-watersheds. Moreover, according to Smith (1950), JSW has been categorized into a moderate texture including JSW-3, JSW-4, JSW-6 and JSW-8; except JSW-12 and 15 is extra fine, all the others are fine drainage textural classes.

The circularity ratio (Rc) is directly related to the watershed area, and its maximum value is 1 for circular watershed shape (Miller, 1953). As showed in Figure 3, JSW characterized as an elongated shape except for JSW-10, which has reflected moderate elongation. JSW-10 is hydrological; peak discharge has observed than the other sub-watersheds. Elongated sub-watersheds characterized by high infiltration capacity and low discharge of runoff (Malik et al., 2019; Puno and Puno, 2019).

The elongation ratio (Re) is directly proportional to the watershed area and inversely proportional to its maximum length (Schumm, 1956). The higher the elongation ratio of the watershed indicates high infiltration capacity and low runoff (Yadav et al., 2014). The elongation ratio values generally vary from 0.6 to 1.0 (Rudraiah et al., 2008). Jigjiga sub-watershed has also agreed with the variation of the previous study’s elongation ratio (Figure 3). Table 3 showed that the form factor (Ff) values are uniform, with an approximate value estimated to 0.3.

Channel compactness (Cc) is affected by the watershed slope and the area of the watershed. Cc is independent of the size of the watershed. The sub-watersheds JSW-1, JSW-3, JSW-5, JSW-6, JSW-8 and JSW-9 have provided the maximum Cc value (Figure 3), and these sub-watersheds Cc...
value are inverse to the erosion risk of the watershed. Conversely, JSW-2, JSW-10, JSW-13, JSW-14 and JSW-15 required the first priority to manage the erosion degradation.

3.1.3. Relief aspects

Relief aspects are a central aspect in understanding and indicator of the watershed water or pollutant flow direction. Watershed relief is an elevation difference between the watershed's upstream point and the outlet of the watershed. The contour of the watershed plays a significant role in determining the elevation difference for the relief parameter.

Basin relief ($B_h$) used to determine the stream gradient and sediment accumulation in the stream (Hadley and Schumm, 1961). In JSW, the $B_h$ ranges from 0.9 to 2.33km (Figure 4). Relief ratio ($R_h$) describes the slope characteristics of the watershed. The relief aspects of JSW based on relief ratio are flat slope in degrees for sub-watersheds except for JSW-4, JSW-7, JSW-8, JSW-9, JSW-10, and JSW-13 have $R_h$ values more than 0.1 (Figure 4); these sub-watersheds characterized as underlain resistance rock (Vittala et al., 2004).

Ruggedness number ($R_n$) is the production values of basin relief and drainage density (Strahler, 1958). The highest $R_n$ value of the sub-watersheds indicates the highest soil erosion degree (Vijith and Sateesh, 2006). Accordingly, in the current study, sub-watersheds JSW-6 to 10 showed these sub-watersheds are prone to erosion while the others are moderately affected.

3.1.4. Mapping of MPs selected for erosion risk analysis

In Figure 5, spatial mapping of MPs of JSW presented. The first five (5) $R_p$, $F_w$, $D_d$, $D_t$ and $L_g$ were directly related to erosion risk, while the others are inversely related to soil erosion (Figure 5). Accordingly, the red colours reflect the sub-watersheds affected by erosion risk, and green is low erosion, which describes high erosion control management and

![Figure 6](image-url). Areal and area percentage of LU/LC parameters on erosion risk analysis of Jigjiga Sub-Watershed (JSW).
minimum erosion control management. Assessment of soil erosion based on the MPs has been applied throughout the world using a compound parameter (Farhan et al., 2017; Hembram and Saha, 2018; Nitheshnirmal et al., 2019).

3.2. Jigjiga Watershed LU/LC analysis

Watershed can be affected by the coverage area of LU/LC. Watershed management interconnected with LU/LC’s important parameters found
Table 3. Correlation matrix (CM) of MPs of JSW.

| CM  | Ff | Rs | Dd | Rr | Ds | Fi | Rs | CS | Lg | WS1  | CF  | P  |
|-----|----|----|----|----|----|----|----|----|----|------|-----|----|
| Ff  | 1.00| -0.10 | -0.34 | 0.36 | 0.31 | 0.62 | 0.62 | -0.36 | 0.36 | JSW-1 | 4.92 | 2  |
| Rs  | -0.10| 1.00 | 0.08 | -0.04 | -0.34 | -0.24 | -0.24 | 0.37 | -0.12 | JSW-2 | 10.04 | 12|
| Dd  | -0.34| 0.08 | 1.00 | -0.15 | -0.19 | -0.25 | -0.24 | 0.22 | -0.04 | JSW-3 | 10.21 | 13|
| Rr  | 0.36 | -0.04 | -0.15 | 1.00 | 0.58 | 0.29 | -0.29 | -0.66 | 0.15 | JSW-4 | 7.09 | 7 |
| Ds  | 0.31 | -0.34 | -0.19 | 0.58 | 1.00 | 0.35 | 0.35 | -0.98 | 0.25 | JSW-5 | 5.26 | 4 |
| Fi  | 0.62 | -0.24 | -0.25 | -0.29 | 0.35 | 1.00 | 1.00 | -0.32 | 0.29 | JSW-6 | 5.64 | 5 |
| Rs  | 0.62 | -0.24 | -0.24 | -0.29 | 0.35 | 1.00 | 1.00 | -0.32 | 0.29 | JSW-7 | 8.67 | 9 |
| CS  | -0.36 | 0.37 | 0.22 | -0.66 | -0.98 | -0.32 | -0.32 | 1.00 | -0.26 | JSW-8 | 8.01 | 8 |
| GT  | 0.31 | 0.05 | -0.11 | 0.09 | 0.17 | 0.27 | 0.27 | -0.17 | 0.12 | JSW-9 | 5.09 | 3 |
| CB  | 2.46 | 0.37 | -0.87 | 0.68 | 1.33 | 2.16 | 2.17 | -1.33 | 0.97 | JSW-10 | 15.35 | 15|
| WS  | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | JSW-11 | 11.15 | 14|
| UL  | 0.31 | 0.05 | -0.11 | 0.09 | 0.17 | 0.27 | 0.27 | -0.17 | 0.12 | JSW-12 | 6.05 | 6 |
| SW1 | -0.36 | 0.37 | 0.22 | -0.66 | -0.98 | -0.32 | -0.32 | 1.00 | -0.26 | JSW-13 | 10.03 | 11|
| CS  | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | 7.94 | JSW-14 | 8.75 | 10|
| GT  | -0.36 | 0.37 | 0.22 | -0.66 | -0.98 | -0.32 | -0.32 | 1.00 | -0.26 | JSW-15 | 3.75 | 1 |

Table 4. Correlation matrix (CM) of LU/LC of JSW.

| CM  | Agr | BS | FR | SHL | UL | WB | JSW  | CF  | P  |
|-----|-----|----|----|-----|----|----|------|-----|----|
| Agr | 1.00 | 0.87 | 0.01 | -0.87 | 0.04 | -0.04 | SW1  | 6.15 | 10 |
| BS  | 0.87 | 1.00 | 0.10 | -0.85 | 0.05 | -0.05 | SW2  | 7.34 | 13 |
| FR  | 0.01 | 0.10 | 1.00 | -0.26 | 0.02 | -0.18 | SW3  | 5.23 | 8  |
| SHL | -0.87 | -0.85 | -0.26 | 1.00 | -0.44 | -0.25 | SW4  | 7.00 | 12 |
| UL  | 0.04 | 0.05 | 0.02 | -0.44 | 1.00 | 0.82 | SW5  | 2.33 | 3  |
| WB  | -0.04 | -0.05 | -0.18 | -0.25 | 0.82 | 1.00 | SW6  | 8.30 | 15 |
| CS  | 1.01 | 1.11 | 0.69 | -1.67 | 1.50 | 1.30 | SW7  | 4.76 | 6  |
| GT  | 3.94 | 3.94 | 3.94 | 3.94 | 3.94 | 3.94 | SW8  | 6.64 | 11 |
| WF  | 0.26 | 0.28 | 0.18 | -0.42 | 0.38 | 0.33 | SW9  | 4.04 | 5  |
| Agr= | Agriculture | BS= | Bare Soil | FR= | Forest | SHL= | Shrubland | UL= | Urban Land | JSW= | Jigjiga Sub-watershed |
| SW1 | 8.08 | 14 |
| SW2 | 5.09 | 7  |
| SW3 | 6.09 | 9  |
| SW4 | 0.19 | 2  |
| SW5 | -3.49 | 1  |
| SW6 | 3.25 | 4  |

in the boundary (Javed et al., 2011; Sastry et al., 2004). Unsuitable land-use system and deforestation of land cover make a favourable environment for water and wind erosion. Practically, semi-arid regions like the Jigjiga watershed caused by water and wind erosion (Du et al., 2016).

In Figure 6, LU/LC categories used for erosion risk analysis were agriculture (Agr), Bare Soil (BS), Forest (FR), Shrubland (SHL), Urban Land (UL) and Waterbody (WB). Agriculture has the highest percentage area coverage for JSW-13, and the lowest was JSW-6 (Figure 6). Agriculture contributes higher soil erosion by water and wind (Zhang et al., 2016). Bare soil was maximum for JSW-14, whereas the last was JSW-1, which has indicated minimum priority. The lowest area coverage of the forest means the watershed highly degraded by erosion. Accordingly, Figure 6 reported that except JSW-15, JSW-7, JSW-10, JSW-4 and JSW-1, all the other Jigjiga sub-watersheds need soil conservation as a result of forest deforestation soil has been degrading. JSW-6, JSW-2 and JSW-12 were the highest, which informs Shrubland’s priority, while JSW-15 and JSW-13 placed on the last focus. The watershed ranked under the 1st priority of watershed management, excluding JSW-8, JSW-9 and JSW-10, due to urbanization stress (Figure 6). Lastly, water body conservation in this analysis requests priority for the whole watershed (Figure 6). Similar studies were reported by researchers on watershed soil erosion assessment using LU/LC parameters (Altaf et al., 2014; Sujatha et al., 2014; Chauhan et al., 2016). On the other hand, Figure 7 provided the spatial distribution of LU/LC of the JSW. Accordingly, Shrubland covers the maximum land surface of the watershed. Urbanization shows early expansion, which has covers JSW-8, JSW-9 and JSW-10. Water shortage is long time problems of the JSW; it has located only at JSW-9, nearest to Jigjiga city (Figure 7).

3.3. Morphometric and LU/LC parameter based prioritized JSW

Watersheds characterised by different or uniform hydrological and hydraulic natural behaviours. The watersheds characteristics identification for prioritisation is significantly useful for watershed management based on the erosion control mechanism. In this study, the watershed has divided into fifteen sub-watersheds, coded as JSW-1 to JSW-15. Using morphometric parameters such as stream frequency, form factor,
The bifurcation ratio, drainage density, circulatory ratio, elongation ratio, drainage texture, compactness constant and overland flow were used to prioritise JSW for watershed management regarding erosion hotspots. The research articles reported that areal parameters like stream frequency, drainage density, and drainage texture are directly related to erosion responses. Compactness constant and overland flow show a negative correlation with runoff and soil erosion, while the other linear parameters show a positive correlation with soil erosion (Thakkar and Dhiman, 2007).

The 1st rank given to the highest value of stream frequency, bifurcation ratio, drainage density, drainage texture and overland flow, and the minimum value was 15th or minimum priority for each JSW. Accordingly, using the Fs parameter, JSW-13 is prioritised first, and the last focus has given to JSW-6 (Table 2). In Table 2, JSW-8 needed first to consider using the Rb parameter, and JSW-13 was the last in the erosion hotspot mapping reports to control soil erosion. The Chronology of JSW-10 and 11 was 1st and 2nd ranking in prioritising sub-watersheds, the minimum priority given to JSW-13. The 1st and the 2nd rank of priority assigned for JSW-15 and JSW-12 using the Dt parameter and the last priority given to JSW-3 (Table 2).

The parameters like form factor (Ff), circulatory ratio (Rc), elongation ratio (Re) and compactness constant (Cc) have inverse relations with soil erosion risk of sub-watersheds. The minimum value of the sub-watershed parameter ranked 1st, and the same procedure has done until the highest parameter value or the last rank of priority. Hence, in Table 2, Rc was ranked 1st and 2nd for JSW-12 and JSW-6, respectively. Compactness constant (Cc) was ranked the 1st for JSW-10 and 2nd JSW-14, the last rank assigned to JSW-8.

To properly execute the weightage average of MPs and LU/LC, Eq. (1) was applied, and Eqs. (2) and (3) below were developed. Using Eq. (2), Sub-watershed wised of the JSW of erosion risk was computed using the product of WF and each parameter values (Table 3). Based on the CF values, the watershed P of the watershed has prioritized the erosion risk report (Table 3). Moreover, in this study, Eq. (3) used for erosion risk analysis based on卢/LC parameters provided in Table 4 and Figure 7.

$$CP = 0.31Fs + 0.05Rb - 0.11Dd + 0.09Dt + 0.17Rc + 0.27Ff + 0.27Re - 0.17Cc + 0.12Lg$$

(2)

$$CP = 0.26Agr + 0.28BS + 0.18Fr - 0.42SHL + 0.38UL + 0.33WB$$

(3)

Prioritise the Jigjiga watershed for erosion hotspot mapping CP value was implemented (Figure 8 (c)). First, hotspot mapping of the JSW conducted using morphometry. Following this, JSW-14 and 15 placed on the 1st consideration to manage soil erosion. The 2nd or high degree of priority has reported by morphometry values were JSW-1, JSW-5, JSW-9 and JSW-13 (Figure 8 (a)). These sub-watersheds existed on the intermittent streams passing through Jigjiga city. In Figure 8 (a), moderate considerations for sub-watershed management provided by this study using morphometry were JSW-4, JSW-6, JSW-7 and JSW-12. Based on morphometry’s priority only, more than eighty percent of the watershed area required moderate to very high watershed management to control soil erosion. Watershed prioritisation by morphometric parameters was a crucial solution in ungauged watershed (Javed et al., 2009; Gajbhiye, 2015).
In this study, the other parameter analysis was LU/LC for erosion hotspot mapping. According to LU/LC parameters, a very high degree of land degradation by soil erosion is shown in Figure 8 (b) of on JSW-14, followed by JSW-13, high erosion signature. While JSW-5 and JSW-15 moderately eroded (Figure 8 (b)). The higher priority the sub-watershed showed a high degree of soil erosion which implies that soil and water conservation for sustainable use of the watershed resources (Mehram and Sharma, 2015).

Watershed priority produced from the MPs and LU/LC parameters’ integration value for erosion hotspot mapping of JSW reported in Figure 8 (c). The mean value of the watershed prioritisation shifted to MPs parameter values rather than LU/LC parameters to identify erosion hotspot mapping of the sub-watersheds (Figure 8 (c)). A similar study prioritised watershed for soil conservation (Puno and Puno, 2019; Javed et al., 2009; Sujatha et al., 2014).

4. Conclusions

The most significant conclusion of this study is that the utilization of satellite-based DEM of Jigjiga watershed for MPs analysis in an ArcGIS environment for evaluating the influence of MPs and LU/LC of 2020 with its category of land use and land cover types used in soil erosion hotspots mapping is a more suitable approach at the data scarcity area to prioritize of the watershed.

Based on MPs assessment for erosion hotspots mapping, the linear and areal aspects were the most influencing erosion risk assessment parameters. The overland flow, bifurcation ratio, drainage density, drainage texture, and stream frequency have identified as the erosion risk assessment parameters and linear aspect parameters. The compound priority and weightage average methods prioritize the watershed for ranking the most degraded sub-watersheds. The MPs resulted in approximately 14.5% of the watershed area affected by erosion and required immediate treatment; these include JSW-14 and 15 categorized under very high priority. The Jigjiga watershed, around 24.44% was classified under high erosion prioritization, including JSW-1, JSW-5, JSW-9 and JSW-13; these sub-watersheds need the second immediate consideration. Regarding LU/LC parameters for erosion risk prioritization, only JSW-14 (4.4%) required an immediate soil erosion control mechanism followed by JSW-13 (2.23%). Whereas JSW-5 and 15 need moderate erosion management that is around 17.44 % of the watershed area. The other JSW-1, JSW-2, JSW-3, JSW-4, JSW-6, JSW-7, JSW-8, JSW-9, JSW-10 and JSW-11 approximately 75% of the watershed was categorized under low priority.

Based on the integration of MPs and LU/LC parameters, the erosion hotspot mapping provides the result which has 100% shifted to MPs erosion risk prioritization. Generally, MPs are more scientifically provides accurate result than LU/LC. Designers could use this study, planners, agriculturists, decision-makers and administrators to select the most appropriate erosion control mechanisms and sustainable management.

Declarations

Author contribution statement

Tesfu Abebe Tesema: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2022.e09780.

Acknowledgements

The author would like to say thanks to Mikiyas Gonfa, PhD candidate at the University of Manchester and the Water Resources and Irrigation Engineering department staff at Jigjiga University. The author also is very grateful to the anonymous reviewers for their comments and critical suggestions that significantly helped improve the quality of the manuscript.

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