Soil Erosion Status of Nepal

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DOI: 10.3126/nutaj.v8i1-2.44109

Abstract
Soil erosion is one of the problems in Nepal because about 73 percent of the land surface is mountainous and still tectonically active where 60.43 percent people involved in agricultural activities. The paper assesses the soil erosion status based on ecological region and watershed boundary with population density. The ecological region determined based on elevation and the watershed boundary of Nepal was generated using the Advanced Spaceborne Thermal Emission and Reflection Radiometer–ASTER, 30m resolution Digital Elevation Model (DEM) of NASA’s Earth Observing System (EOS) on May 14, 2010. The DEM data was processed using remote sensing technique then hydrological analysis conducted using remote sensing and geographic information system to delineate the watershed boundary. The study generates 19 watersheds based on available soil erosion data. The soil erosion rate of ecological zone and watershed are assessed with population data of Nepal from central bureau of statistic, 2011. There is below 50 people per square kilometer watersheds have average soil erosion rate (about 20 t ha⁻¹/ y⁻¹) and 100 to 500 people per square kilometer watersheds have high soil erosion rate ranges from 27 to 102 t ha⁻¹/ y⁻¹. The main causes of soil erosion of Nepal Himalaya are Himalaya energy and its people activities. These scenarios partial follow the theory of Himalayan degradation. So that there is still environmental degradation is observed and it is needed in detail field based study of Himalaya degradation.

Keywords: GIS, RS, Soil, Soil Erosion, Watershed

Introduction
A soil is a naturally occurring earth body of minerals and organic matter that exists on the earth's surface. It is an essential part of the natural environment which is composed of several physical, chemical, and biological components having a wide range of interactions when it comes to plant growth, with its properties constantly changing as a result of chemical reactions and biophysical processes. In Nepal, Soil types are varied due to many factors, such as geology, physiography, climate, and vegetation types (Gurung, 2020). There has been very little research on soil types and erosion in Nepal (Shah, 1995, Chalise, Kumar & Kristainsen, 2019 and Gurung, 2020).
Soil erosion involves the breakdown, separation, transport, and redistribution of soil particles by powers of water, wind, or gravity (Carson, 1985; USDA, 2006; 2022). Similarly, DesInventar (n.d.),
defined soil erosion as washing away of soil down the outer layer of slope inclines or mass movement due to storm water flow during extraordinary rains or winds and can cause sedimentation in streams/rivers and areas at the toe of the hill slopes. According to Oldeman (1992), soil erosion take place on globally and under every single climatic condition and is assessed 1094 M/ha universally, though 441 M/ha in Asian mainland, which is 59% of the world. This exploration has led under UNEP's task 'Worldwide Evaluation of Soil Debasement' (GLASOD) by the Global Soil Reference and Data Center (ISRIC). The finding depends on 21 territorial correlator's database. Likewise, FAO (2015) and (2017) had assessed throughout the last ten years, the figures distributed for water disintegration range over a significant degree of ca. 20 Gt/y\(^{-1}\) to north of 200 Gt y\(^{-1}\).

Soil erosion is a problem in Nepal. Because more than 73 percent of the land is mountainous (Gurung, 2004) and still tectonically active, and agriculture is the primary source of income for more than 60.43 percent of the population of the country (CBS, 2014). As a result of increased population pressure on agriculture, soil and forest resources have degraded (Chalise, Kumar & Kristainsen 2019). Understanding the spatial behavior of resources and hazards requires mapping soil erosion (Pourghasemi, Kariminejad, and Amirri) (2020). As a result, the current study analyzed soil erosion status based on ecology and watershed using a geographic information system and remote sensing techniques.

**Material and Methods**

This study is based on previously published documents on ecological and large and small watershed soil erosion condition of Nepal, such as books, reports, and articles, which develop ideas about it. Similarly, the internet provided the majority of the information about Nepal's soil erosion. The ecological region determined based on elevation and the watershed boundary of Nepal was generated using the Advanced Spaceborne Thermal Emission and Reflection Radiometer – ASTER, 30m resolution Digital Elevation Model (DEM) of NASA's Earth Observing System (EOS) on May 14, 2010. The DEM data was processed using remote sensing technique then hydrological analysis conducted using remote sensing and geographic information system to delineate the watershed boundary. The study generates 19 watersheds based on available soil erosion data. The soil erosion rate of watershed is assessed with population data of Nepal from central bureau of statistic, 2011.

**Study Area**

In terms of geography, Nepal lies within the coordinates 26° 12' to 30° 27' North and 80° 4' to 88° 12' East. It extends from East to West (885 km) on the continent of Asia and north-south width ranges from 145 to 241 km, with an average of 193 km. It's bordered by China to the north and by India to the east, west, and south (buffer state). So that it is a landlocked country surrounded on all sides by land. Its physiography is characterized by the local relief, geological structure, altitude, and geographical distribution. In general, Nepal is divided into Hills and Mountain zones, Tarai and Inner Tarai, occupying roughly 77 and 23 percent of its land respectively (LRMP, 1986). These can be further divided into Tibetan Mountain Ranges, Inner Himalayas, Great Himalayas, Midland Valleys, Mahabhart Lekhs and Chre Ranges. Similarly, Tarai and Inner Tarai regions also can be divided into Inner Terai, Bhabar zone and Main Terai (see Fig. 1a).
Subtropical, warm temperate, cool temperate, alpine or cold, and tundra or cold desert climates are the most common in Nepal. Up to 1200 meters above sea level, the climate is subtropical. The weather is hot and humid. In this climatic zone, temperatures range from 150°C to 350°C, with rainfall ranging from 1000mm to 2000mm. The warm temperate climate, which can be found between 1200 and 2100 meters above sea level, is a healthy climate. The temperature ranges from 100 to 300 degrees Celsius, with rainfall ranging from 1000 to 2000 millimeters. The cool temperate climate, which ranges in elevation from 2100m to 3300m, is also healthy, but it is a little cooler. The temperature ranges from 50 to 200 degrees Celsius, and rainfall occurs at a height of nearly 1000 meters, with snowfall in the winter (see Fig. 1b).

Results

Soil Erosion

Soil erosion, landslides, and flooding are the most common causes of land degradation in Nepal (Hegen, 1961; Jhonson, Olson and Manandhar, 1982; Carson, 1985; Karan Iijma, 1985; Biot, Blaikie, Jacson, Jones, 1989; ADB, 2015; MOPE, 2015; Chalise, Kumar, and Kristiansen, 2015 and 2019). The main causes of environmental degradation in this region are population growth, deforestation, and rapid development. Joshi, Shrestha, and Joshi (2003) discovered that the ecology was the most important factor in determining the types of land degradation. They discovered that the high Himalayan region experienced rockslides, avalanches, and glacier lake outburst floods above 5000 meters (GLOF), gully erosion, surface erosion (rill and inter rill), and river bank cutting are all examples of mass wasting (slumping, gully, landslide, and rock fall) (table 1).
Table 1: Types of Erosion in Nepal

| Degradation Type          | Affected Area as % of Total Land Area of Nepal | Affected Areas (Million Ha.) |
|---------------------------|------------------------------------------------|-----------------------------|
| Water erosion             | 45.4                                          | 6.7                         |
| Wind erosion              | 4.0                                           | 0.6                         |
| Chemical deterioration    | 1.7                                           | 0.3                         |
| Physical deterioration    | 1.3                                           | 0.2                         |

Sources: Ministry of Population and Environment, 2016.

Water erosion is the most common form of erosion in Nepal, which is caused by the country's mountainous terrain and monsoon system, which affects 45.4 percent of the country's total area and 6.7 million hectares of land. Similarly, wind erosion, chemical, and physical deterioration have occurred, all of which share 4.17 and 1.3 percent, respectively, and 0.6, 0.3, and 0.2 million hectares of land were severely affected by water erosion, with an erosion rate of 40-200 t ha\(^{-1}\)/y\(^{-1}\) and approximate soil loss ranges of 182.38 to 707.91 t ha\(^{-1}\)/y\(^{-1}\) of Nepal year-round, with only snowfall and snow storms occurring on rare occasions. This area is also known as the world's third pole.

Figure 2: Soil Erosion by Ecological Region in Nepal

Source: Joshi, 1996 (Joshi, J., Bhattarai, T. N., Sthapit, K. M., and Omura, N., 1998) and Central Bureau of Statistics (A Compendium on Environment Statistics 1998 Nepal)

Soil Erosion by Ecological Region

Nepal's ecological soil erosion was presented by Joshi in 1996. In Shiwalik (Chure) ecological region, erosion rate was 20 – 40 ton/ha\(^{-1}\)/yr\(^{-1}\), in Mahabharat ecology, erosion rate was 30 – 40 ton/ha-1/yr-1,
and Middle mountain ecology loss was 20 – 50 ton/ha-1/y-1. Similarly, CBS (1998) estimated soil erosion rates for Siwalik (Chure), Mahabharat Lekh, and Middle Mountain at 7.8 to 40, 31.5 to 420, and 8 to 570 ton/ha-1/y-1, respectively. According to CBS (1998), the most soil has been lost from Nepal's Middle Hill (Table 2 and Fig 8).

### Table 1: Soil Erosion by Ecological Region

| Ecological Region      | Erosion Rate (ton/ha-1/y-1) |
|------------------------|----------------------------|
| Siwalik Range (Chure)  | 20 - 40                    |
| Mahabharat Lekh        | 30 - 40                    |
| Middle Mountain        | 20 - 50                    |

Source: Joshi, J., Bhattarai, T. N., Sthapat, K. M., and Omura, N., 1998 and Central Bureau of Statistics (A Compendium on Environment Statistics 1998 Nepal)

### Soil Erosion in Large Watershed

WECS (2003) analyzed the soil erosion status of Nepal at the large watershed level based on the work of various authors. As shown in table 3, different authors calculated watershed boundaries in different ways depending on the rate of sediment yield.

### Table 3: Large Watersheds Soil Erosion in Nepal

| Large Watersheds | Watersheds Area in sqkm | Sediment Transport (ton/ha-1/y-1) |
|------------------|--------------------------|-----------------------------------|
| Tamor            | 5770 (1), 5700 (6), 5900 (4), 5770 (5) | 38.0 (1), 70.0 (6), 80.0 (4), 38.0 (5) |
| Sunkoshi         | 18985 (1), 19000 (3), 19000 (4) | 21.0 (1), 65.0 (3), 45.0 (4) |
| Bagmati          | 585 (6), 1388 (3) | 45.0 (6), 46.0 (3) |
| Trisuli          | 4100 (6), 4110 (3) | 18.0 (6), 18.5 (3) |
| Karnali          | 42890 | 21.0 (9) |
| Ganges           | 1076000? | 13.5 (8) |
| Saptakoshi       | 59280 (1), 62000 (1), 61000 (7), 59280 (5) | 15.0 (1), 27.7 (8), 31.0 (7), 15.0 (5) |
| Arun             | 34525 (1), 36000 (7), 36533(4), 34525 (5) | 7.6 (1), 16.0 (7), 4.7, 7.6 (5) |

Reference : 1, Williams-1977; 2, Sherchan-1991; 3, Schaffner-1987; 4, Upadhyaya-et.al. 1991; 5, Ries-1994; 6, Maskey and Joshy-1991; 7, Karver-1995; 8, Erl – 1988; 9, HPC-1989.

Source: Water and Energy Commission Secretariat/ CIDA.(Himalayan Sediment, Issue and Guidelines, 2003).

The soil erosion rate of Tamor, Sunkoshi, Saptakoshi and Arun are ranges from 38-80, 21-65, 15-31 and 7.6-16 ton/ha-1/y-1 respectively. The average erosion rate of Bagmati, Trishuli, Karnali and Ganges are 45.5, 18.25, 21 and 13.5 ton/ha-1/y-1 respectively. Saptakoshi river system and Bagmati are high sediment yield river of Nepal.
Similarly, Shankar, (1989) had estimated average soil erosion of Surnagad, Karnali, Seti, Saradaa, Babai, west and east Rapti, Kaligandaki, Seti, Trisuli, Narayani, Lothar, Bagmati, Kulekhani, Bagmati, Kamala, Tamur, Saptakosi, and Kankaimai watersheds ranges from only 1.74 to 102.05 t ha$^{-1}$/y$^{-1}$ with an average of 31 t ha$^{-1}$/y$^{-1}$ (Chalise and Khanal, 1997).

**Soil Erosion in Small Watershed**

WECS (2003) shows the small watershed or rives soil erosion status of Nepal. The area of water shed is less than or equal to 12500 sqkm and greater than or equal to 8 sqkm. The lowest sediment yield from Surma Khola watershed (2.1 t ha$^{-1}$/y$^{-1}$ ) and the highest sediment transported from Chhukarpo Khola Up stream was 29.8 t ha$^{-1}$/y$^{-1}$. There is no differences of sediment yield between small and large watershed (see table 4).
Table 4 Small Watershed Erosion Status of Nepal

| Small Watersheds | Watersheds in sqkm | Sediment Transport (t ha⁻¹/ y⁻¹) |
|------------------|--------------------|---------------------------------|
| Lahore River     | 63                 | 6.8 (1)                         |
| Bamti Khola      | 8                  | 13.3 (2)                        |
| Chhukarpo Khola (upstream) | 23.5        | 29.8 (2)                        |
| Chhukarpo Khola (downstream) | 369          | 3.7 (2)                         |
| Surma Khola      | 570                | 2.1 (2)                         |
| Harpan Khola (Phewa Lake) | 12000          | 8.9 (9)                         |
| Kukhuri khola    | 75                 | 17.0 (11)                       |
| Anderi Khola     | 540                | 15.0 (11)                       |
| Jhikhu           | 11141              | 11.0 (11)                       |
| Sunsardizal      | 1553               | 12.9 (3)                        |
| Godavari         | 1231               | 3.3 (3)                         |
| Bishnumati       | 614                | 10.7 (3)                        |
| Mahabharat       | 19                 | 29.0 (4)                        |
| Kulekhani (re-1993) | 12500           | 20.45 (10)                      |
| Jhikhu           | 111.41             | 22.5 (12)                       |
| Yarsha           | 53.38              | 26.33 (12)                      |

Reference: 1, Impat-1979;  2, Sherchan-1991;  3, Schaffner-1987;  4, Upadhaya-et.al. 1991;  9, Laban-1978;  10, Mulder-1978; 11, Carson-1985. 12, Merz-2004.
Source: Water and Energy Commission Secretariat/CIDA (Himalayan Sediment, Issue and Guidelines 2003).

Figure 3: Small Watershed Soil Erosion of Nepal

Reference: Shankar, 1989;  Source: Chalise and Khanal, 1997
Discussion

Monsoon climatic systems play the vital role to occur water erosion in the Himalaya (Pal, 2009). As a Himalayan country, Nepal faces water erosion severely and erosion rate is varying with ecological zone (Biot, Blakie, Jacson and Jones, 1989; Gabet, Burbank, Sitaula, Putkonen and Bookhasen, 2008 and Chalise, Kumar and Kristainsen, 2019). According to the theory of Himalayan degradation (THD), growing population need agriculture land to feed the people so that it lead to deforestation and faced severe soil erosion in the Himalaya (Ives, 1987).

Table 5 shows the soil erosion and population density of river watershed of Nepal. Among the 19 watershed, Kulekhani watershed has the minimum area which is 126 sqkm and the Saptakoshi has maximum area which is 59400 sqkm. The average area of watershed is 10187 sqkm. Similarly minimum number of population live in Lother and Kulekhani watershed which are around 80000 population. The maximum about 4.6 million population live in Narayani watershed. The average population of the watershed is about one million. The soil erosion status of the watersheds are as follow: minimum average soil erosion rate (1.74 t ha⁻¹/y⁻¹) take place in Kulekhani watershed whereas maximum soil erosion (102.05 t ha⁻¹/y⁻¹) take place in Tamor watershed. The average soil erosion rate is 20.25 t ha⁻¹/y⁻¹.

Table 5 Population Density Vs Soil Erosion

| Watershed          | Area sqkm | Soil Erosion t ha⁻¹/y⁻¹ | Population | Population Density |
|--------------------|-----------|------------------------|------------|--------------------|
| Kulekhani          | 126       | 1.74                   | 81547      | 647                |
| Saradha            | 816       | 5.07                   | 280012     | 343                |
| Karnali (Asarghat) | 19260     | 8.62                   | 578686     | 30                 |
| Trisuli            | 4640      | 9.70                   | 93888      | 20                 |
| Surnagad           | 188       | 12.00                  | 164682     | 876                |
| Bagmati (Karmaiya) | 2720      | 14.77                  | 2602558    | 957                |
| Bagmati (Chobhar)  | 585       | 14.77                  | 2375229    | 4060               |
| Karnali (Chisapani)| 42890     | 20.12                  | 1822432    | 42                 |
| Saptakosi          | 59400     | 24.40                  | 2876273    | 48                 |
| West Rapti         | 5150      | 27.96                  | 1140348    | 221                |
| Seti               | 7460      | 28.02                  | 845770     | 113                |
| Kamala             | 1550      | 32.30                  | 746090     | 481                |
| Lothar             | 169       | 36.37                  | 81228      | 481                |
| Babai              | 3000      | 37.00                  | 636367     | 212                |
| Kaligandaki        | 7130      | 41.73                  | 477216     | 67                 |
| Kankaimai          | 1148      | 48.36                  | 351930     | 307                |
| Seti               | 582       | 52.86                  | 347191     | 597                |
| Narayani           | 31100     | 56.84                  | 4604567    | 148                |
| Tamur              | 5640      | 102.05                 | 662494     | 117                |

Source: Water and Energy Commission Secretariat/CIDA (Himalayan Sediment, Issue and Guidelines 2003 and CBS, 2011.)
The minimum population density of the watersheds are Trishuli, Karnali, and Saptakoshi which are below 50 people per square kilometer and maximum population density occupy in Bagmati watershed which is 4060 people per square kilometer. The average population density of the watershed is 514 people per square kilometer.

Fig. 4 Population Density and Soil Erosion in Nepal

Figure 4 show the population density and soil erosion by watersheds of Nepal. There is below 50 people per square kilometer watersheds have average soil erosion rate (about 20 t ha\(^{-1}\)/y\(^{-1}\)) and 100 to 500 people per square kilometer watersheds have high soil erosion rate ranges from 27 to 102 t ha\(^{-1}\)/y\(^{-1}\). These scenarios partial follow the theory of Himalayan degradation. So that there is still environmental degradation is observed and it is needed in detail study of Himalaya degradation.

Conclusion

Soil is an important natural resource of Nepal Himalaya. The country is facing soil erosion from last century. The water erosion is main soil erosion process of Himalaya and triggered by Monsoon system. It is varying with ecological zone of Nepal Himalaya. The study shows the population pressure on land resources is one of the strongly reason of soil erosion which partially follow the theory of Himalayan degradation. So that there is still environmental degradation is observed and it is needed in detail field based study of Himalaya degradation. The main causes of soil erosion of Nepal Himalaya are Himalaya energy and its people activities.
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