Article

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Abstract: The Southwest Alpine Canyon Area of China was one of the regions in the world that suffered from severe soil erosion. The focus of this research was to understand the response of land use change on soil loss by water erosion in alpine canyon on Southeast Tibet, we analyzed the characteristics of temporal and spatial dynamics of land use in the Niyang River Basin from 1990 to 2020 using GIS and statistical methods, assessed the spatial and temporal change characteristics of soil erosion in the Niyang River Basin using RUSLE model. For this purpose, the meteorological, soil, topographic, remote sensing data were collected. The results showed the area of cropland and construction land in the Niyang River Basin increased to 2.4 and 6.1 times the original from 1990 to 2020, respectively, the area of forest and water continued to decrease. Grassland, unused land and forest have always been the dominant land types in the Niyang River Basin. Tolerable soil erosion was distributed in the flat areas of the valley terraces in the main stream and its tributaries, slight soil erosion was mainly distributed in the flat areas at high altitudes, and moderate, severe, very severe and destructive soil erosion was sporadically distributed in the Niyang River Basin. The areas of tolerable and slight soil erosion exceeded 82% of the total area, The area of severe, very severe and destructive soil erosion was less than 6%, but the total soil loss amount of severe, very severe and destructive erosion was more than 27%. From 1990 to 2020, the soil erosion area decreased from 9219.34 km2 to 8,090.84 km2 in Niyang River Basin, more than 85% of the soil erosion class has not changed, and the change of total soil loss amount also shows a significant reduction trend as a whole. 99% of the total soil loss amount in the Niyang River basin is generated by grassland, forest and unused land. The conversion of various land use types to cropland will cause the enhancement in soil erosion grade. We recommend that the focus of soil erosion control in the Niyang River Basin is to protect grassland, forest and carry out scientific farming.

Keywords: soil loss; water erosion; land use change; RUSLE; Niyang River Basin

1. Introduction

The global average soil erosion rate is 240 t km−2 a−1 [1]. Soil erosion causes annual loss of 25-40 billion tons of topsoil in the world, which is one of the ten most serious environmental problems in the world, it not only causes land degradation and food production reduction, but also brings ecological and environmental problems such as collapse, landslide, debris flow, flood and water pollution [2–4].

Land use and land cover change (LUCC) not only objectively recorded the spatial pattern of human changing the features of the Earth's surface, but also reproduced the spatio-temporal dynamic change process of the Earth's surface landscape [5], is the most significant area of global environmental change. Since its launch in 1995 by the International Geosphere–Biosphere

Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP), the land use and land cover change research programme has gradually become a hot spot in the study of global change [6,7]. Land use and land cover change has a profound impact on the structure, function and evolution of ecosystems [8], it will cause soil erosion [9–11], surface runoff change [12], soil property variation [13,14], Changes in vegetation cover [15], biodiversity change [16–18] and so on. Experts in various fields generally believe that human beings and their activities are the main causes of soil erosion, and that unreasonable land use patterns and the reduction of vegetation cover have magnifying effects on soil erosion [11,19–21]. Exploring the relationships between land use and soil erosion is a frontier research field and a hot spot topic in contemporary physical geography [10].

In the early stage of soil erosion assessment and monitoring, the standard runoff plots [22] and sand-collecting tables [23,24] were set up at monitoring stations to measure the amount of soil loss in order to evaluate the overall erosion status of the study area, it is difficult to characterize the spatial trend of soil erosion. Since Wischeier [25,26] proposed the term erosivity index, which is defined as the product of the kinetic energy of rainfall and the maximum rainfall intensity in 30 minutes, and applied to the general soil loss equation USLE [27], USLE has been widely used in many countries.

The USLE, or the lateral RUSLE model, is a universally accepted method that can be used as the best fitted model for monitoring soil erosion because its applicability has been proven over the last decades, and the reliability of the results are indisputable [28–30]. In China, the cultivated cropland average soil erosion rate is 500 t km^{-2} a^{-1} [31], significantly exceeding the global average soil erosion rate. The Loess Plateau in China was one of the regions in the world that suffered from severe soil erosion. In recent years, RUSLE has been applied in the study of the possible influences of land use change on soil erosion in the Chinese Loess Plateau. Fu et al. [32]evaluated the soil erosion control and the land cover changes from 2000 to 2008, found that ecosystem soil erosion control service has been improved as a result of vegetation restoration. Liu et al. [33] reported that the sensitivity of soil erosion reduced significantly from 2000 to 2007. The sensitivity of soil erosion in the southeast region was higher than the northwest region. It was mainly caused by the frequent regional human activities and the unscientific farming. Zhang et al. [34] found that positive measures aimed to increase plantation of shrubberies have dammed the soil shipment is essential. Sun et al. [30] reported that Forest, shrub and dense grassland provided the best protection from erosion, the decadal trend of reduced soil erosion was greater for the lower vegetation cover of woodland and moderate and sparse grassland on the Loess Plateau in China using the Revised Universal Soil Loss Equation (RUSLE).

As a fragile ecosystem with global significance, the Qinghai-Tibet plateau had significant differences in topography, climate and vegetation, including almost all types of soil erosion on land [35]. Southeast Tibet was a region where the edge of the Qinghai-Tibet plateau has been cut violently and was in transition to a lowland. The vertical drop was huge, formed the most densely-packed v-shaped alpine canyons on the Qinghai-Tibet plateau. The soil in the region was loose, and local heavy rainfall was frequent, landslides, debris flows and other natural disasters often occurred [36]. This area was the highest sensitivity to soil loss by water erosion [37]. Since the 1980s, the Niyang River Basin has experienced continuous population growth, rapid economic development and frequent land use changes, it is an ideal region to study soil erosion and land use change in alpine valley of Southeast Tibet. Therefore, this study chooses the Niyang River Basin in Tibet as the research area, based on the basic principles of the Revised Universal Soil Loss Equation (RUSLE), this research took advantage of rainfall erodibility, undulating terrain, soil texture, vegetation cover, analyzed the spatial difference of soil erosion, and assessed the change of soil erosion with changing land cover. It is expected that the results could help us understand the soil erosion change and relationship between land use and soil erosion, and further provide scientific supports for the ongoing ecological construction and regional high-quality development.

2. Materials and Methods

2.1. Study Area

The study area specifically focuses on the Niyang River Basin of Southeast Tibet. The Niyang River is a first-class tributary of the Yarlung Tsangpo River, originating from the valley of ancient glaciation in the west of Mila Mountain, with an elevation of about 5,000 m. It flows from west to east through the Gongbo'gyamda County, Bayip District. joins the Yarlung Tsangpo River near Zemen in Bayip District. The Niyang River has a length of 307.5 km, a drop of 2,273 m, an average longitudinal drop of 7.39%, an average flow rate of 538 m^3s^{-1}, and an annual runoff of 22 billion m^3, which ranking second among the tributaries of the Yarlung Tsangpo River, second only to the Palung Tsangpo River. The Niyang River Basin (29°23'–30°37' N, 92°09'–94°40'E) is bounded by the Nyechingtanggula Mountains on its north and east, the remnants of the Gangdise Mountains on its west, and the Yarlung Tsangpo River on its south, with the overall terrain tilting from north-west to south-east (Figure 1). The basin is 240 km east to west and 140 km north to south, covering an area of 17,783 km² [38]. It is located in the mid-latitude zone, belongs to the plateau temperate semi-humid climate zone. Its altitude is high, air is thin, solar radiation is strong, annual mean temperature is 8℃, and annual precipitation is 600–900 mm [39]. The upper and middle reaches of the Niyang River Basin is the temperate coniferous forest region, which is the transition zone between the humid-semi-humid forest area in eastern Tibet and the semi-arid scrub area in the west, and the lower reaches is the humid mountainous coniferous forest region in the middle and lower reaches of the Yarlung Tsangpo River, with a wide variety of vegetation types [40].

Tibetan ancient Niang tribe had lived in the Niyang River Basin for a long time, so the Niyang River is also known as Niangqu. The term "Nyingchi" (name of the largest city in the Niyang River Basin) is derived from the combined name of the Niang and Chi tribes living in the Niyang River Basin [41]. Nowadays, the Niyang River Basin covers 126 villages of three counties including Gongbo´gyamda, Bayipp and Gyaca. In 2019, the registered population of the Niyang River Basin is 80,300, the resident population reaches 112,500, of which 49.5 thousand rural population [42]. Farmers and herdsmen plant barley, wheat and other food crops, raise cattle, sheep, pigs and other livestock, pick Chinese Caterpillar Fungus and Pine Mushrooms, run homestays, do business and transportation, and also go out to work. The Niyang River Basin is the most economically active area in Southeast Tibet and even in Tibet. The capital city of Nyingchi, Gongbo'gyamda county city is located in the valley terraces of the main stream of the Niyang River. Large hydroelectric power stations in southeast Tibet, such as Xueka Power Station, Laohuzui Power Station and Dobu Power Station, are located on the main stream and tributaries of the Niyang River. National Highway 318 and the La-lin Highway follow the Niyang River upstream and extend to Lhasa.
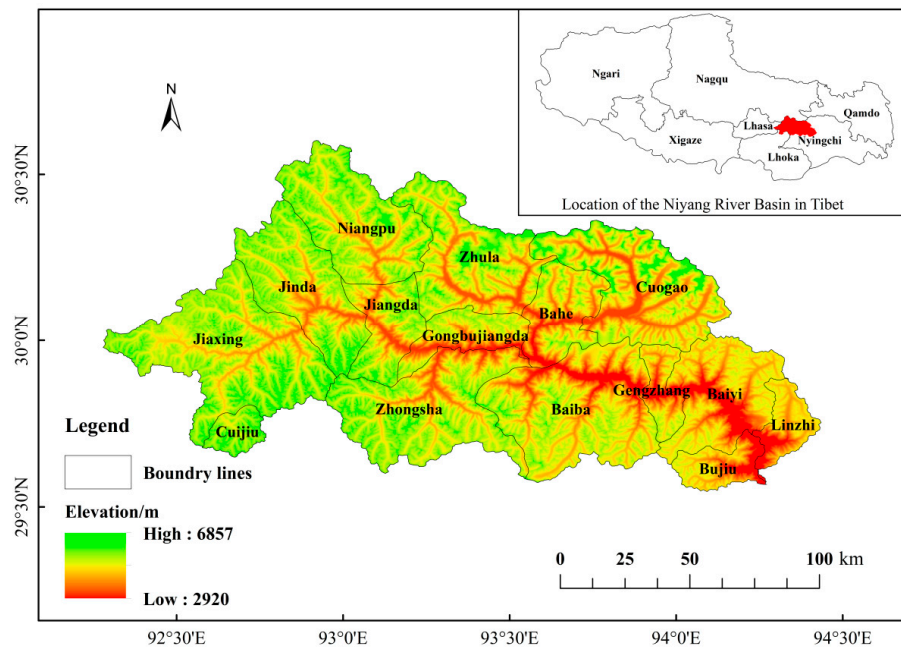
Figure 1. Location of the study area.

2.2. Data Collection

The remote sensing data (30 m×30 m) from Geospatial Data Cloud (https://www.gscloud.cn/), included 4 views of Landsat 5 TM in 1990, landsat-7 ETM+ in 2000, landsat-7 ETM+ in 2010 and landsat-8 OLI in 2020. Using ENVI5.1 to preprocess the remote sensing data with radiometric calibration, atmospheric correction, cropping, etc., combined with the actual situation of the study area, and based on the Standard for Current land use classification (GB/T 21010-2017), the current land use is classified as grassland, cropland, construction land, forest, waters and unused land using the supervisory classification method.

Meteorological data were obtained from the National Meteorological Information Centre of the China Meteorological Data Service Centre (http://data.cma.cn), soil data were obtained from the Soil Subcenter of the National Earth System Science Data Center of China (http://soil.geodata.cn), the digital elevation model (DEM) and the Normalized Difference Vegetation Index (NDVI) were obtained from the Geospatial Data Cloud (https://www.gscloud.cn).

2.3. RUSLE Model

The estimation of soil loss rate was conducted using the Revised Universal Soil Loss Equation (RUSLE):

$$A_i = R \cdot K \cdot L \cdot S \cdot C \cdot P \tag{1}$$

where A_i is the computed annual soil loss rate in year i, in units of t km^{-2} a^{-1}; R is the rainfall-runoff erosivity factor; K is a soil erodibility factor; L is a slope length factor; S is a slope steepness factor; C is a cover-management factor; and P is a supporting and conservation practices factor.

2.3. R Factor

Zhang et al. (2003) [43] found that daily rainfall data can provide richer information on rainfall characteristics, and the erosive power of rainfall can be estimated more accurately by using daily rainfall data than monthly or annual rainfall data. This study is based on day-to-day rainfall data from six meteorological stations in and around the Niyang River Basin. the methods developed by Xie et al. [44] and Zhang et al. (2002) [45] were employed to calculate the R factor, which is represented by the following equations:

5

$$R_i = \alpha \sum_{j=1}^{n} D_j{}^{\beta} \tag{2}$$

$$\alpha = 21.586\beta^{-7.1891} \tag{3}$$

$$\beta = 0.8363 + 18.144 D_{d_{12}}{}^{-1} + 24.455 D_{y_{12}}{}^{-1} \tag{4}$$

where R_i is the rainfall-runoff erosivity force in year *i*, in units of (MJ mm)/(ha^{-1}h^{-1}a^{-1}); D_j is the daily rainfall of day *j* with soil erosion threshold caused, mm; *n* is the days with rainfall ≥12 mm in each year, d; $D_{d_{12}}$ is the average daily rainfall of several years with ≥12 mm required, mm; $D_{y_{12}}$ is the average annual rainfall with daily rainfall above 12 mm, in units of mm; and α and β are the model parameters.

2.4. K Factor

In this study, we use the EPIC model proposed by Williams et al. [46] to calculate the K value. The formula is as following:

$$K = (0.2 + 0.3\exp(-0.0256 Sa(1 - \frac{Si}{100}))) \cdot (\frac{Si}{Ci - Si})^{0.5} \cdot (1 - \frac{0.25C}{C + \exp(3.72 - 2.95C)}) \cdot (1 - \frac{0.75Si}{Si + \exp(-5.51 + 22.95Si)}) \tag{5}$$

where K is the soil erodibility factor; Sa, Si, and Ci are the soil sand, silt, and clay content in %, respectively. The C is soil organic carbon content in %.

2.5. L and S Factors

In this study, the L and S factors were calculated by combining the topography and geomorphology of the Niyang River Basin with the formulas proposed by Williams et al. [27] and Liu et al. [47]. The formulas are as follows:

$$L = (\lambda / 22.13)^m \tag{5}$$

$$m = \begin{cases} 0.2, & \theta \leq 1° \\ 0.3, & 1° \langle \theta \leq 3° \\ 0.4, & 3° \langle \theta \leq 5° \\ 0.5, & \theta \rangle 5° \end{cases} \tag{6}$$

$$S = \begin{cases} 10.8 \sin\theta + 0.036 & \theta \langle 5° \\ 16.8 \sin\theta - 0.5 & 5° \langle \theta \langle 10° \\ 21.9 \sin\theta - 0.96 & \theta \geq 10° \end{cases} \tag{7}$$

where L is the slope length factor; λ is the slope length, m; m is the model parameter of slope length; θ is the slope angle (gradient), in units of °; and S is the steepness factor.

2.6. C Factor

Vegetation cover and management factor C refers to the ratio of soil loss on land with specific vegetation cover or field management to soil loss on bare recreational land with clear-cutting or no vegetation cover under the same soil, slope and rainfall conditions, and its value is between 0 and 1. The larger the C value, the greater the amount of soil erosion caused by this type of land use. Therefore, in this study, we used the Normalized Difference Vegetation Index (NDVI), which is currently the most widely used method, to estimate the vegetation coverage, and then calculated the vegetation cover and management factors using the model proposed by Tsai et al. [48]. The formulas are as follows:

$$C = \begin{cases} 1, & f = 0 \\ 0.6508 - 0.3461 \lg f & 0 \langle f \langle 78.3\% \\ 0, & f \geq 78.3\% \end{cases} \tag{8}$$

$$f = (NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min}) \tag{9}$$

where C is the vegetation cover and management factor; f is the the vegetation coverage, in units of %; $NDVI$ is the Normalized Difference Vegetation Index; $NDVI_{min}$ is the minimum values in the Normalized Difference Vegetation Index; $NDVI_{max}$ is the maximum values in the Normalized Difference Vegetation Index.

2.7. P Factor

The conservation practice factor P represents the ratio of soil loss achieved with a specific conservation practice compared to the soil loss without specific conservation practice under the same conditions. On the basis of the actual investigation of the study area, combined with previous research and experience [49,50], the values were assigned to different land use types. The P factors for forest, grassland, construction land, water, cropland and unused land were 1.00, 1.00, 0, 0, 0.35 and 1, respectively.

2.8. Soil Erosion Classification

According to the Standards for classification and gradation of Soil Erosion (SL190-2007) [51], the study area was categorized into six erosion classes (Table 1).

Table 1. Classification criteria for soil erosion intensity (Unit: t km-2a-1).

Gradation of Soil Erosion	Tolerable	Slight	Moderate	Severe	Very Severe	Destructive
thresholds	(0, 500]	(500, 2500]	(2500, 5000]	(5000, 8000]	(8000, 15000]	>150000

3. Results

3.1. Land Use Changes from 1990 to 2020

The Niyang River Basin is a typical alpine valley with obvious vertical zonation. Cropland and construction land were distributed in flat valley terraces at lower elevations. Forest, grassland and unused land were distributed sequentially with the increase in elevation, and waters were scattered all over (Figure 2).

From 1990 to 2000, the area of various types of land in the Niyang River Basin changed slightly, and the proportion of various land use type remained the same; after 2000, the proportion of forest and water continued to decrease (Figure 3). The proportion of forest decreased from 31.95% in 2000 to 27.77% in 2010 and then to 27.63% in 2020; the proportion of water area decreased from 5.44% in 2000 to 3.07% in 2010 and then to 3.03% in 2020. Unused land and grassland increased and then decreased, with the proportion of unused land increased from 28.10% in 2000 to 28.15% in 2010, and then decreased to 28.04% in 2020; the proportion of grassland increased from 33.99% in 2000 to 40.00% in 2010, and then decreased to 39.97% in 2020. Construction land and cropland showed a continuous increase, with the proportion of cropland increased from 0.48% in 2000 to 0.94% in 2010, and then to 1.17% in 2020; construction land increased from 0.03% in 2000 to 0.06% in 2010, and then to 0.17% in 2020 (Table 2). Grassland, unused land and forest have always been the dominant land types in the Niyang River Basin.
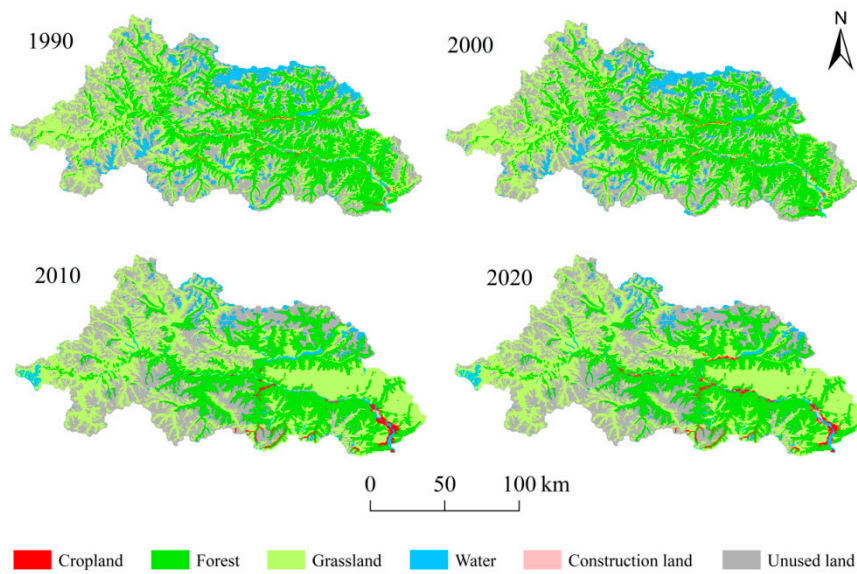
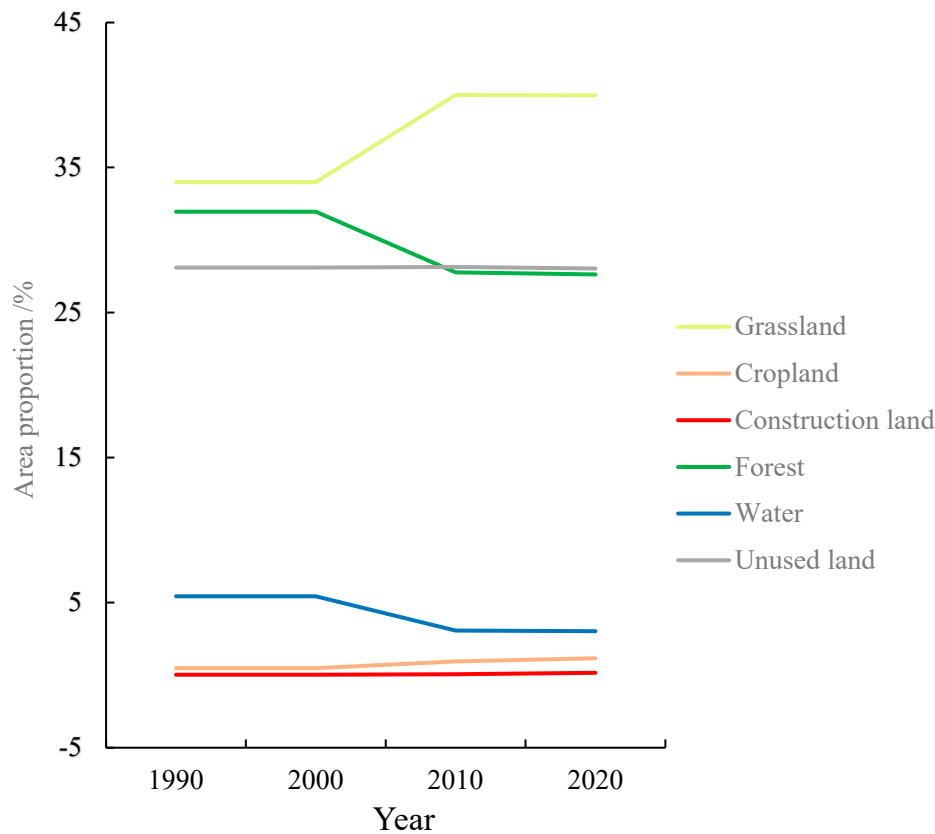**Figure 2.** Types of land use in the Niyang River Basin in 1990, 2000, 2010 and 2020.

Figure 3. Proportion changes of different land use types in the Niyang River Basin from 1990 to 2020.

Table 2. Area and proportion of land use types in the Niyang River Basin from 1990 to 2020.

Land use types	1990		2000		2010		2020	
	Area(km²)	Proportion (%)	Area (km²)	Proportion (%)	Area (km²)	Proportion (%)	Area (km²)	Proportion (%)
Cropland	84.60	0.48	84.51	0.48	166.47	0.94	206.51	1.16
Forest	5,621.13	31.61	5,620.26	31.60	4,886.64	27.48	4,861.62	27.34
Grassland	6,097.91	34.29	6,098.53	34.29	7,145.87	40.18	7,140.03	40.15
Water	946.87	5.32	946.82	5.32	531.88	2.99	523.87	2.95
Construction land	4.87	0.03	4.86	0.03	10.88	0.06	29.57	0.17
Unused land	5,027.79	28.27	5,028.20	28.28	5,041.44	28.35	5,021.59	28.24

3.2. Spatio-Temporal Changes of Soil Erosion

3.2.1. Temporal Variation of Soil Erosion

The average value of soil loss rate by water erosion in the Niyang River Basin decreased from 1,625.46t $km^{-2}a^{-1}$ in 1990 to 1,254.99t $km^{-2}a^{-1}$ in 2000, then increased to 1,357.03t $km^{-2}a^{-1}$ in 2010, and finally decreased to 961.03t $km^{-2}a^{-1}$ in 2020, where the minimum value was 0 and the maximum value was 238,581.47t $km^{-2}a^{-1}$ in 2010 (Table 3).

Table 3. Soil erosion modulus in the Niyang River Basin in different years (Unit: t $km^{-2}a^{-1}$).

Types	1990	2000	2010	2020
Minimum	0.00	0.00	0.00	0.00
Maximum	327,727	232,783.16	238,581.47	110,343.13
Mean	1,625.46	1,254.99	1,375.03	961.03

The areas affected by slight, moderate, severe, very Severe, and destructive erosion has been increasing and then decreasing. From 1990 to 2010, the soil erosion area increased continuously from 9,219.34 km² to 9,703.65 km², with an increase of 484.31 km², or 5.25%, and the percentage of erosion area increased continuously from 52.76% to 55.53% (Table 4). Subsequently, the area of soil erosion decreased to 8,090.84 km² in 2020, a decrease of 1,612.81 km², a decrease of 16.62%, and the percentage of soil erosion area decreased to 46.65% (Table 4). It shows that the local ecological environmental protection policy is effective and soil erosion has been effectively treated.

The sum of the areas of tolerable and slight erosion exceeds 82% of the total area (Table 4). The proportion of moderate erosion, severe erosion, very severe erosion and destructive erosion decreased in order, and showed a decreasing trend year by year. It shows that the natural environment of the Niyang River Basin is healthy and getting better.

Table 4. Area and proportion of soil erosion in the Niyang River Basin in 1990, 2000, 2010 and 2020.

Gradation of Soil Erosion	1990		2000		2010		2020	
	Area(km²)	Proportion (%)	Area(km²)	Proportion (%)	Area(km²)	Proportion (%)	Area(km²)	Proportion (%)

Tolerable	8,253.65	47.24	8,082.02	46.24	7,769.40	44.47	9,253.75	53.35
Slight	6,211.61	35.55	7,574.83	43.34	7,652.67	43.80	6,825.89	39.35
Moderate	2,114.54	12.10	1,242.01	7.11	1,406.97	8.05	857.33	4.94
Severe	458.83	2.63	287.12	1.64	305.43	1.75	223.69	1.29
Very Severe	283.38	1.62	201.93	1.16	236.24	1.35	141.05	0.81
Destructive	150.99	0.86	88.88	0.51	102.34	0.59	42.87	0.25

From 1990 to 2020, the total soil loss amount decreased from 27.46Mt to 21.98Mt, showed a significant reduction, of which the total soil loss amount increased from 2000 to 2010, from 21.77Mt to 24.11Mt. The area of tolerable and slight soil erosion was more than 44%, but the total soil loss amount of tolerable and slight soil erosion was less than 4%. The area of severe, very severe and destructive soil erosion was less than 6%, but the total soil loss amount of severe, very severe and destructive erosion was more than 27%, up to 38.7% (Figure 4).
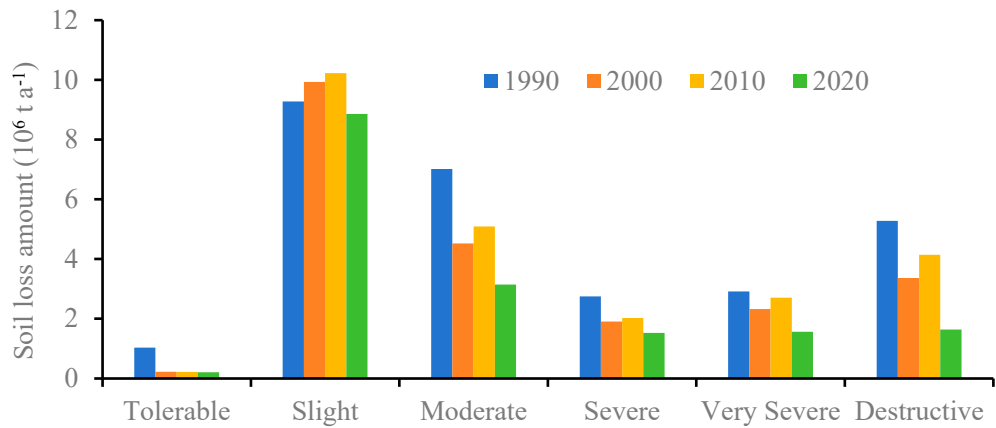

Figure 4. Change of soil loss amount in the Niyang River Basin from 1990 to 2020.

From 1990 to 2020, more than 85% of the soil erosion classes in the Niyang River Basin remained unchanged, and except for the period 2000-2010, when the number of soil erosion classes enhanced was greater than the number of soil erosion classes weakened; in the other two periods, the number of soil erosion classes weakened was greater than the number of soil erosion classes enhanced (Table 5).

Table 5. Proportion of soil erosion class change types in the Niyang River Basin (Unit: %).

Types of Change	1990-2000	2000-2010	2010-2020
weakened	10.96	2.39	11.83
unchanged	86.25	92.74	85.93
enhanced	1.98	4.87	2.24

3.2.2. Spatial Variation of Soil Erosion

Tolerable soil erosion was distributed in the flat areas of the valley terraces of the main stream and its tributaries, slight soil erosion was mainly distributed in the flat areas at high altitudes, and moderate, severe, very severe and destructive soil erosion was sporadically distributed in the Niyang River Basin (Figure 5). Bujiu Township, Linzhi Township, Bayi Township, Gengzhang Township was located in the lower reaches of the Niyang River at low altitude valleys there were very few moderate,

severe, very severe and destructive grades of erosion (Figure 5). Very severe and destructive soil erosion did not exist in Bujiu township. In 2020, 71.38% of the area of destructive soil erosion was concentrated in Jiaxing Township, Niangpu Township, Baiba Township and Cuogao Township, which were characterized by high erosion intensity because of their undulating topography and abundant precipitation (Figure 5).
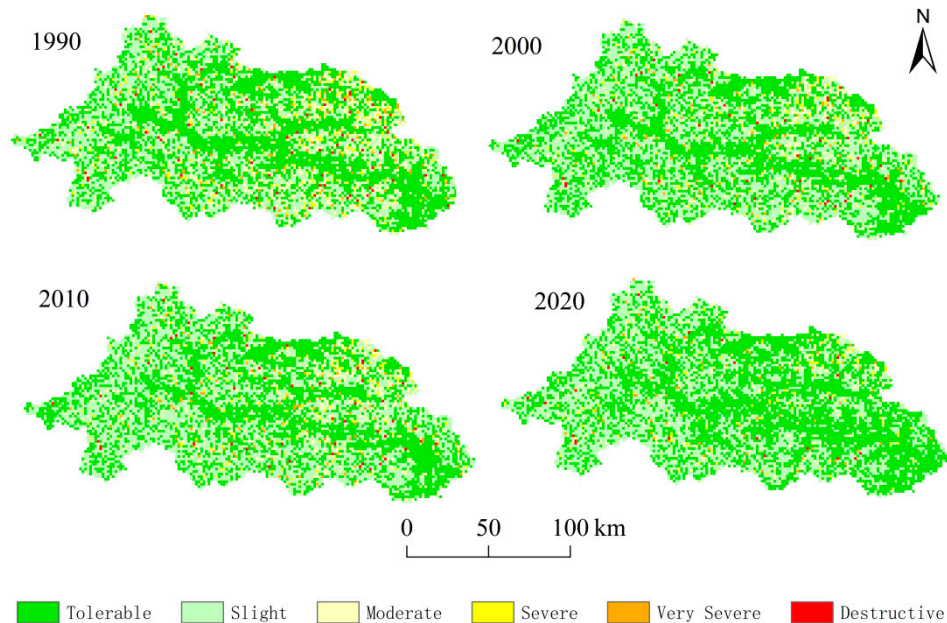

Figure 5. Gradation of soil erosion in the Niyang River Basin in 1990, 2000, 2010 and 2020.

From 1990 to 2000, the areas with enhanced soil erosion intensity were mainly distributed in the valley terraces of the main stream and its tributaries, and the other areas showed an overall positive trend. The intensive human farming activities in the valley in this period were the main reason for the deterioration of soil erosion (Figure 6). From 2000 to 2010, the area of soil erosion enhancement expanded significantly, showing the characteristics of scattered distribution (Figure 6). From 2010 to 2020, the trend of soil erosion deterioration was significantly curbed, the deterioration area retreated to a small number of sporadic distributions, and soil and water conservation in the eastern part of the Niyang River Basin as a whole tended to improve (Figure 6).
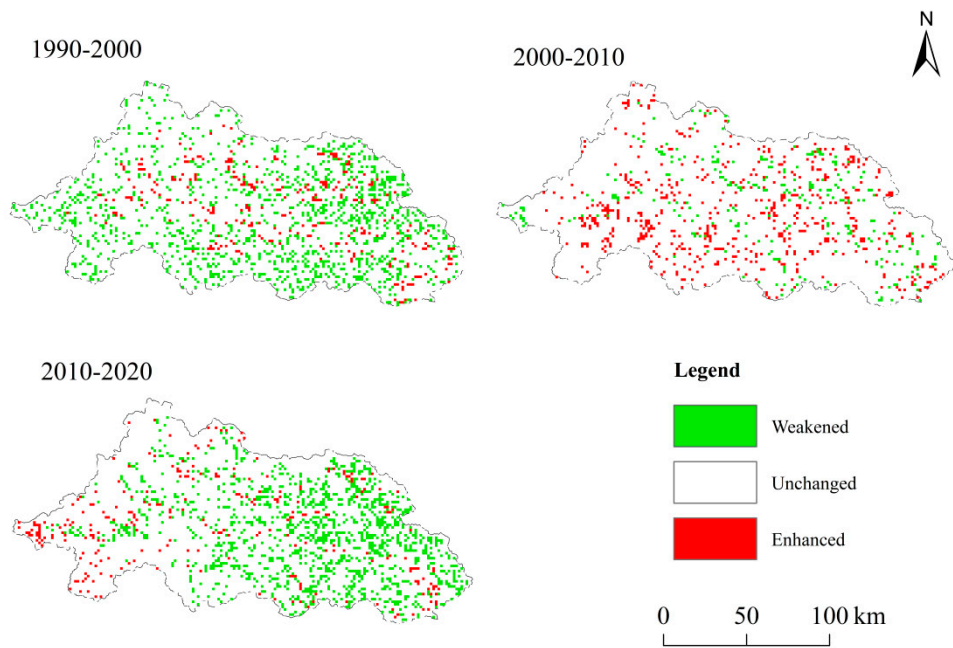
1990-2000

2000-2010

N

2010-2020

Legend

Weakened

Unchanged

Enhanced

0   50   100 km

Figure 6. Spatial change of soil erosion Gradation in the Niyang River Basin.

3.3. Soil Erosion Characteristics of Different Land Use Types and Their Variability

3.3.1. Soil Erosion Characteristics of Different Land Use Types

In 2020, the soil erosion of different land use types in the Niyang River Basin was shown in Table 6, 61.54% of the area of unused land undergoes soil erosion. Soil erosion was present in 49.6% of the area of grassland, 29.86% of the area of forest and of 27.42% of the area of cropland. There was no significant erosion, i.e., tolerable erosion, of waters such as rivers, lakes, glaciers and perpetual snow, and of construction land such as urban residential land and transportation land (Table 6).

Table 6. Proportion of soil erosion area in different land use types in the Niyang River Basin in 2020 (Unit: %).

Gradation of Soil Erosion	Grassland	Cropland	Construction land	Forest	Water	Unused land
Tolerable	50.40	72.76	100	70.14	100	38.46
Slight	42.64	23.09	0.00	23.87	0.00	52.24
Moderate	4.60	2.18	0.00	3.67	0.00	6.87
Severe	1.34	1.49	0.00	1.07	0.00	1.41
Very Severe	0.72	0.48	0.00	0.96	0.00	0.87
Destructive	0.30	0.00	0.00	0.29	0.00	0.15
The total	100	100	100	100	100	100

From 1990 to 2020, with the increase in the area of grassland and cropland, the area share of each grade of soil erosion in grassland and cropland also gradually increased; with the decrease in the area of forest, the area share of each grade of soil erosion in forest also gradually decreased. There was little change in the area of unused land, but there was a significant increase in the area of moderate, severe, very severe, and destructive soil erosion of unused land.

49.51% of the area of destructive soil erosion occurs in grassland, which is much higher than the proportion of the area of grassland in all land use types in the same period (40.15%); 33.18% and 31.47% of the area of very severe and destructive soil erosion occurs in forest, which is higher than the proportion of the area of forest in all land use types in the same period (27.34%) (Tables 2 and 7). In the future, for the management of the severest soil erosion, attention should be paid to grassland and forest.

Table 7. Proportion of land use area in different soil erosion intensities in the Niyang River Basin in 2020 (Unit: %).

Land Use Types	Tolerable	Slight	Moderate	Severe	Very Severe	Destructive
Grassland	37.85	43.48	37.53	41.97	35.19	49.51
Cropland	1.60	0.69	0.52	1.36	0.68	0.00
Construction land	0.27	0.00	0.00	0.00	0.00	0.00
Forest	36.88	18.04	20.91	23.30	33.18	31.47
Water	3.42	0.00	0.00	0.00	0.00	0.00
Unused land	19.98	37.79	41.04	33.37	30.95	19.02
The total	100	100	100	100	100	100

99% of the total soil loss amount in the Niyang River Basin was generated by grassland, forest and unused land. From 1990 to 2020, with the increase of grassland area, but its corresponding soil loss amount fluctuated from 9.91Mt to 9.63Mt; with the reduction of the area of forest, its corresponding soil loss amount decreased from 10.01Mt to 6.83Mt; the amount of soil loss generated by the unused land was also fluctuating and decreased from 7.54Mt to 5.37Mt. with the significant increase of cropland area, the corresponding soil loss amount increases from 0.01Mt to 0.16Mt (Table 8). Although the amount of soil loss generated by cropland accounts for a small percentage, it showed a continuous and rapid increase that is worthy of attention and is the focus of local soil erosion control.

Table 8. The total amount and proportion of soil loss in the Niyang River Basin in 1990, 2000, 2010 and 2020.

Land Use Types	1990		2000		2010		2020	
	Amount (Mt)	Proportion (%)	Amount (Mt)	Proportion (%)	Amount (Mt)	Proportion (%)	Amount (Mt)	Proportion (%)
Grassland	9.91	36.09	7.91	36.32	9.66	40.07	9.63	43.80
Cropland	0.01	0.04	0.04	0.20	0.14	0.57	0.16	0.71
Forest	10.01	36.43	8.26	37.94	8.21	34.04	6.83	31.06
Unused land	7.53	27.43	5.56	25.53	6.10	25.32	5.37	24.44

3.3.2. Soil Erosion Characteristics of Land Use Changes

From 1990 to 2020, more than 84% of the area with no change in soil erosion class in the Niyang River Basin occurred in grassland, forest and unused land, due to the fact that these were the main land use types (Table 9). Changes in soil erosion class fall into two categories: enhancement and weakening. From 1990 to 2000 and from 2010 to 2010, less than 1% of the area of soil erosion class enhancement or reduction in the Niyang River Basin occurred in various types of land use change,

and the rest occurred in forest, grassland, unused land and cropland where there is no change in land use type, of which the proportion of the area of soil erosion class enhancement in the forest to the total area of soil erosion class enhancement was 68.08% and 42.57%, respectively, both of which were much higher than the proportion of the forest area in all land use types in the same period; the proportion of the area of soil erosion class enhancement in the cropland to the total area of soil erosion class enhancement was 0.61% and 1.17%, respectively, both of which were much higher than the proportion of the cropland area in all land use types in the same period (Table 9).

From 2010 to 2020, less than 1% of the area of soil erosion class reduction in the Niyang River Basin caused by the conversion of grassland to cropland, cropland to grassland, cropland to forest, forest to grassland, forest to cropland and unused land to cropland. Nearly 3% of the area of soil erosion class enhancement caused by conversion of grassland to cropland, cropland to grassland, forest to grassland, forest to cropland, water to cropland, water to forest, and unused land to cropland (Table 9). It can be seen that the conversion of grassland, forest, unused land to cropland and cropland and forest to grassland caused bidirectional variation in soil erosion grade, and the possibility of soil erosion grade enhancement was higher than soil erosion grade weakening; the conversion of water to forest and cropland caused soil erosion grade enhancement, and the conversion of cropland to forest will caused soil erosion grade weakening.

Table 9. The proportion of soil erosion class change areas in land use change types in three phases (Unit: %).

Land Use Change Types	1990-2000		2000-2010		2010-2020	
	weakened	enhanced	weakened	enhanced	weakened	enhanced
Unchanged grassland	35.37	28.17	29.83	31.84	40.97	44.93
Unchanged forest	34.88	68.08	57.96	42.57	48.37	28.83
Unchanged unused land	29.51	3.13	11.56	24.42	9.26	18.20
Unchanged cropland	0.23	0.61	0.65	1.17	1.04	5.13
Grassland to cropland	0.00	0.00	0.00	0.00	0.04	0.52
Cropland to grassland	0.00	0.00	0.00	0.00	0.01	0.18
Cropland to forest	0.00	0.00	0.00	0.00	0.04	0.00
Forest to grassland	0.00	0.00	0.00	0.00	0.19	0.21
Forest to cropland	0.00	0.00	0.00	0.00	0.08	0.35
Water to cropland	0.00	0.00	0.00	0.00	0.00	1.51
Water to forest	0.00	0.00	0.00	0.00	0.00	0.01
Unused land to cropland	0.00	0.00	0.00	0.00	0.01	0.14

4. Discussion

Grassland, unused land and forest were the dominant land types in the Niyang River Basin. From 1990 to 2000, the area of various types of land in the Niyang River Basin changed slightly. From 2000 to 2010, as the resident population in the Niyang River Basin increased by 207,00 people and investment in fixed assets increased by 2.07 billion CNY [52], the area of cropland and construction land increased to 2 times the original, respectively, and forest and water decreased, percentage of grassland area increased from 33.99% to 40.00%, which aligns well with a previous study by Wang et al. [53]. According to their findings, the overall trend on vegetation coverage emerged as an approximate stability with a little increasing, among which the valley regions increased significantly in Bayip District. This change is closely related to human activities. From 2010 to 2020, the resident population increased by 32,500 people, investment in fixed assets increased by 29.44 billion CNY, and

cropland and construction land continued to increase, while all other types of land use decreased slightly [54].

Tolerable soil erosion was distributed in the flat areas of the valley terraces of the main stream and its tributaries, slight soil erosion was mainly distributed in the flat areas at high altitudes, and moderate, severe, very severe and destructive soil erosion was sporadically distributed in the Niyang River Basin. The valley terraces at the bottom of the Niyang River Basin canyon were flat, warm and humid, suitable for plantation and urban construction [55], and human activities were more intensive, but no significant soil erosion occurred in this region. This is because water, construction land and cropland were the dominant land types in the valley terraces, there was tolerable erosion of water and construction. In addition, there was no significant soil erosion of cropland with a gentle topography and very small amounts. The residual planation surface was an excellent summer pasture [55], there was slight soil erosion because gentle topography. In other areas, the vertical drop was huge, the soil in the region was loose, and localized heavy rainfall was frequent [36], so soil erosion was more serious.

The areas of tolerable and slight erosion exceeded 82% of the total area, it shows that the natural environment of the Niyang River Basin was healthy. The proportion of moderate erosion, severe erosion, very severe erosion and destructive erosion decreased in order, and showed a decreasing trend year by year. It shows that the natural environment of the Niyang River Basin was healthy and getting better. The area of tolerable and slight soil erosion was more than 44%, but the total soil loss amount of tolerable and slight soil erosion was less than 4%. The area of severe, very severe and destructive soil erosion was less than 6%, but the total soil loss amount of severe, very severe and destructive erosion was more than 27%, the area of different grades of soil erosion in Niyang River Basin and the corresponding soil loss amount were inverted, which aligns well with a study by Guo et al. [56]. Therefore, the severest soil erosion should be the key area to be treated.

From1990 to 2020, the resident population of the Niyang River Basin increased by 70,700 people, while the population urbanization level increased from 27.12% to 56%. This means that a large number of human activities were concentrated on construction land. Therefore, the change of soil erosion area showed a trend of increase and then decrease, more than 85% of the soil erosion class had not changed, and the change of total amount of soil loss also showed a significant reduction trend as a whole. It shows that the local government of Tibet attached importance to the construction of ecological civilization, actively promoted the protection and construction of ecological security barrier, and the policy of ecological environmental protection was effective.

Because grassland, unused land and forest were the dominant land types in the Niyang River Basin, 99% of the total soil loss amount in the Niyang River basin was generated by grassland, forest and unused land, which aligns well with a previous study by Ding et al. [57]. The proportion of very severe and destructive soil erosion areas in grassland and forest was much higher than the proportion of grassland and forest areas in all land use types. From 2010 to 2020, nearly 3% of the enhancement in soil erosion grade was caused by changes of cropland, forest, and grassland, and in particular, the conversion of various land use types to cropland caused the enhancement in soil erosion grade, which aligns well with previous studies by Liu et al. [33], Jiang et al. [50], Guo et al. [56], Ding et al. [57] and Cao et al. [58], but the amount of soil loss was not significant. This was due to the fact that the Niyang River Basin was sparsely populated, and limited human activity activities were concentrated on construction land in the gentle valley terraces, and the utilization of cropland has not had a significant impact on soil erosion. Therefore, the focus of soil erosion control in the Niyang River River Basin is to protect grassland, forest and carry out scientific farming.

5. Conclusions

Grassland, unused land and forest were the dominant land types in the Niyang River Basin. From 1990 to 2000, the area of various types of land in the Niyang River Basin changed slightly. From 2000 to 2020, the proportion of forest and water continued to decrease, the proportion of unused land decreased volatility, the proportion of grassland increased volatility, and the proportion of construction land and cropland continued to increase.

The areas of tolerable and slight erosion exceeded 82% of the total area, The area of severe, very severe and destructive soil erosion was less than 6%, but the total soil loss amount of severe, very severe and destructive erosion was more than 27%. Tolerable soil erosion was distributed in the flat areas of the valley terraces of the main stream and its tributaries, slight soil erosion was mainly distributed in the flat areas at high altitudes, and moderate, severe, very severe and destructive soil erosion was sporadically distributed in the Niyang River Basin.

From 1990 to 2020, the change of soil erosion area showed a trend of increase and then decrease, more than 85% of the soil erosion class had not changed, and the change of total amount of soil loss also showed a significant reduction trend as a whole.

99% of the total soil loss amount in the Niyang River basin was generated by grassland, forest and unused land. The proportion of very severe and destructive soil erosion areas in grassland and forest was much higher than the proportion of grassland and forest areas in all land use types. The conversion of various land use types to cropland caused the enhancement in soil erosion grade.

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