

Article

Climate Change Impacts on Soil Erosion and Sediment Yield in a Watershed

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Abstract: This study analyzed the influence of climate change on sediment yield variation, sediment transport and erosion deposition distribution at the watershed scale. The study was based on Gaoping River basin, which is among the largest basins in southern Taiwan. To carry out this analysis, the Physiographic Soil Erosion Deposition (PSED) model was utilized. Model results showed a general increase in soil erosion and deposition volume under the A1B-S climate change scenario. The situation is even worsened with increasing return periods. Total erosion volume and total sediment yield in the watershed were increased by 4–25% and 8–65%, respectively, and deposition volumes increased by 2–23%. The study showed how climate change variability would influence the watershed through increased sediment yields, which might even worsen the impacts of natural disasters. It has further illustrated the importance of incorporating climate change into river management projects.

Keywords: climate change; soil erosion; sediment yield; PSED Model

1. Introduction

Due to the increasing severity of global warming and climate change effect in recent years, extreme hydrographic phenomena have frequently been observed. Climate change has increased precipitation concentration, volume and intensity, which has significantly impacted runoff and soil erosion in many watersheds [1–3]. The sediments generated from watershed erosion are transported to rivers via surface runoff, and they are the main composition of river sediments and a major source of reservoir or river dam sediment deposition [4]. The degree of soil erosion has a significant impact on the evolution of river channels, influencing river stability, flood prevention safety and river remediation planning. Hence, the control of sediment yield is crucial in watershed management, especially since it usually involves high costs. In a review of sediment management strategies in Taiwan and the barriers to their implementation, Wang et al. [5] highlighted how technical barriers are driven primarily by engineering and costs. This was in reference to methods such as construction of upstream sediment structures and hydraulic and mechanical dredging. Moreover, in some regions, climate change is projected to decrease the overall soil erosion potential due to decrease in rainfall [6].

Several studies have focused on the impacts of climate change on precipitation volume, runoff volume, erosion volume and sediment yield. General Circulation Models (GCMs) have been applied to analyze the impacts of climate change on precipitation characteristic [7–9] and river runoff [10,11]. The Soil and Water Assessment Tool (SWAT) model seems to be the most favored by researchers when evaluating the impacts of climate change on flow rate, soil erosion and sediment yield in a

watershed area [12,13]. Thodsen et al. [14] applied the High Resolution Limited Area Model (HIRHAM) regional climate model to investigate the impact of climate change on suspended load transport rate of Danish rivers. In modeling flow rate and sediment yield for high flow-rate rivers under the A2 scenario in the rain season of 2050, Phan et al. [15] showed an increase of 11.4% and 15.3%, respectively. Cousino et al. [16] utilized SWAT to provide hydrological insights for the Maumee River watershed, showing a reduction by 10% in flow, while sediment yield increased by 11%. Most recently, Zhou et al. [17] used the SWAT model to evaluate the impacts of climate change on flow and sediment yield in northeast China. In northern Iran, Azari et al. [18] reported an annual increase of 5% in annual streamflow and more than 35% in sediment yield. Zhang et al. [19] generated climatic conditions for future periods 2020–2039, 2050–2069 and 2080–2099, and their results demonstrated an increase of 13% in sediment yield.

The abovementioned methods do not couple the computations of slope erosion and river sediment transport. Instead, watershed erosion is calculated first based on slope information, followed by watershed sediment yield based on sediment delivery ratio, a river sediment transport model or runoff volume with a flow rate-sediment transport rating curve. The estimation of slope erosion, regardless of applying the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE) [20] or Modified Universal Soil Loss Equation (MUSLE), is carried out by empirical model. Empirical models are established based on erosion data of the initial location via inductive analysis. Therefore, they have application and location limitations. Moreover, the erosion volume estimated by empirical models is the total erosion volume rather than the time-dependent or spatial-dependent erosion volume. Furthermore, watersheds and river systems are complex and sediment boundary conditions for carrying out river sediment transport simulations by the abovementioned models cannot be obtained directly. Typically, sediment transport volume is estimated by the flow rate-sediment transport rating curves established through hydrological observation stations. Nonetheless, sediment transport rates estimated by rating curves have large uncertainties, especially with high discharge values [21].

To understand the impacts of climate change on erosion volume, sediment yield and erosion distribution for a watershed, this study utilized a Physiographic Soil Erosion-Deposition (PSED) model proposed by Chen, Tsai and Tsai [4]. Unlike empirical models, the PSED model has physical mechanisms that enable simultaneous computation of slope erosion and river sediment transport. Additionally, this model does not require the flow rate-sediment rating curve as a boundary condition, thus eliminating uncertainties that come with their adoption. Findings from this study will serve as a useful reference for decision-making authorities in planning appropriate strategies and corresponding measures to prevent water- and soil-related disasters.

2. Materials and Methods

2.1. Study Area

Gaoping River, which is the largest river in Taiwan, was used for the analysis. It is located in the southwest of Taiwan and has a total length of 171 km, covering 3257 km². It originates from west of the Central Mountain Range near Yushan. The upstream end is connected to Laonong River, and its main branches include Qishan, Ailiao and Zhuokou (Figure 1). The topographic height varies significantly, descending along the direction from northeast to southwest, with a maximum difference of nearly 4000 m. The area above 1000 m accounts for 47.45% of the total drainage basin, that between 100 and 1000 m accounts for 32.38% and finally, the area below 100 m accounts for 20.17%. The average slope of the river bed is approximately 1/150, with 1/15, 1/100 and 1/1000 for the upstream, midstream and downstream sections, respectively. Additionally, the sections' lengths are 37, 68 and 66 km for the upstream, midstream and downstream sections, respectively.

Time- and location-based precipitation distribution in the basin varies widely. Near the Central Mountain Range it is large (~3400 mm), whereas in the plain and coastal areas it is significantly smaller

(~2000 mm). Precipitation is concentrated from May to October, which accounts for 90% of the annual precipitation. Average annual runoff volume is ~8.45 billion m³, of which 7.69 billion m³ (91%) occur in the wet season. The average annual sediment transport volume is 35.61 million tons, with 10,934 tons of sediment transport per km² of drainage basin area.



Figure 1. The drainage network in the Gaoping River basin.

The Gaoping River basin is among the worst basins in Taiwan in terms of sediment yield and is highly vulnerable to sediment deposition. Statistical data from the Water Resources Agency of Taiwan, MOEA, estimate a total dredging sediment volume of 94,780,000 m³ for Gaoping River basin between 2009 to 2014 [22]. The major contributions to such high rates include the high-slope landform and concentrated precipitation. The geological map in Figure 2 shows that the watershed mainly constitutes sand gravel and sandstone, rendering it vulnerable to erosion. Stefanidis and Stathis [6], in their assessment of soil erosion in a catchment, showed that vulnerable geological subsoil and the steep slopes favor the development of erosion phenomena. At Gaoping, about 80% of the annual precipitation is from an average of 3–4 typhoons per year [21], which fall between June and September each year. Precipitation in these events is characterized by high intensity and short duration, leading to enormous volumes of sediment yield. The situation is even worsened by additional factors, such as climate change, which has caused drastic changes in precipitation [23].

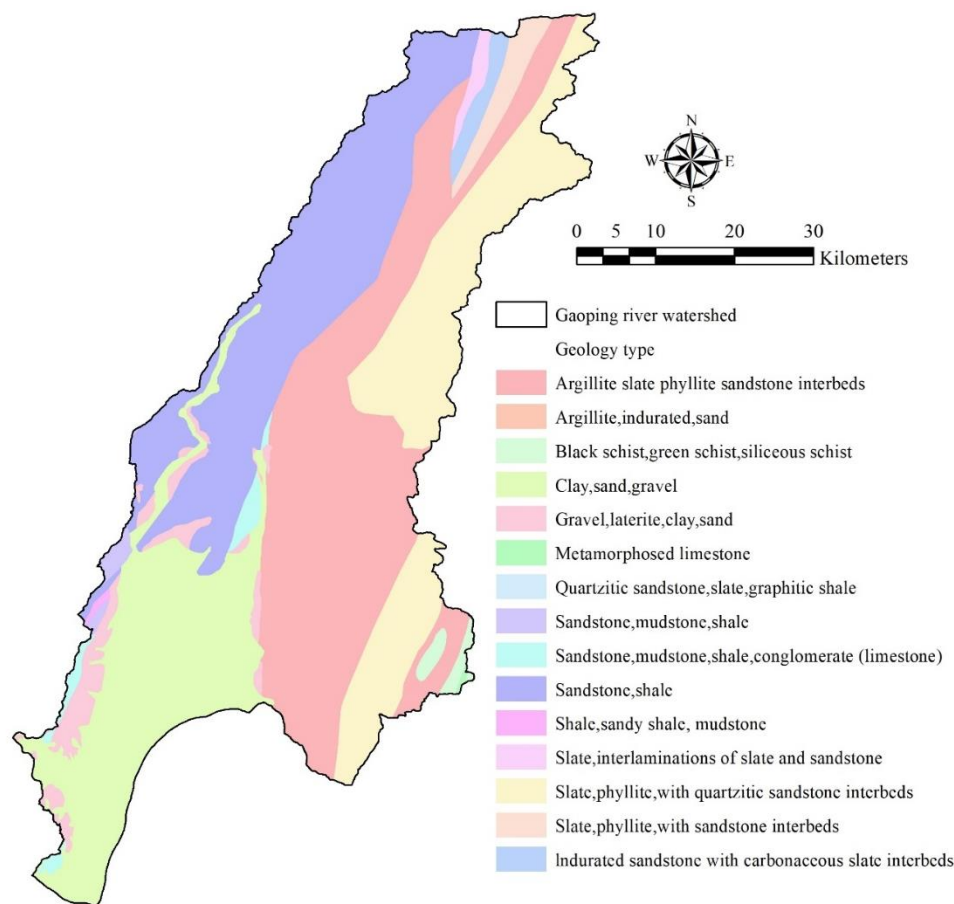


Figure 2. Geological map of Gaoping watershed [24].

2.2. Long Term Climate and Hydrological Changes

According to Taiwan's hydrological data from the past 55 years, there has been a gradual increase in precipitation and typhoon intensity. Both the frequencies of occurrence and the severity of flooding are showing an increasing trend. Figures 3 and 4 show the long-term climate and hydrological data from 1962 to 2016 recorded by the Kaohsiung weather station in the study area. From Figure 3, the annual average temperature in the study area exhibited an increasing trend. Beginning in 1997, the annual average temperature was higher than the average temperature in the past 55 years (24.8 °C) and after 2000, the increase of annual average temperature was more significant. Precipitation after 1996 was more significant and most of the annual precipitation was higher than the long-term annual average precipitation of 1770 mm. The deviation between high and low precipitation became larger and the duration of high and low precipitation became shorter (Figure 4).

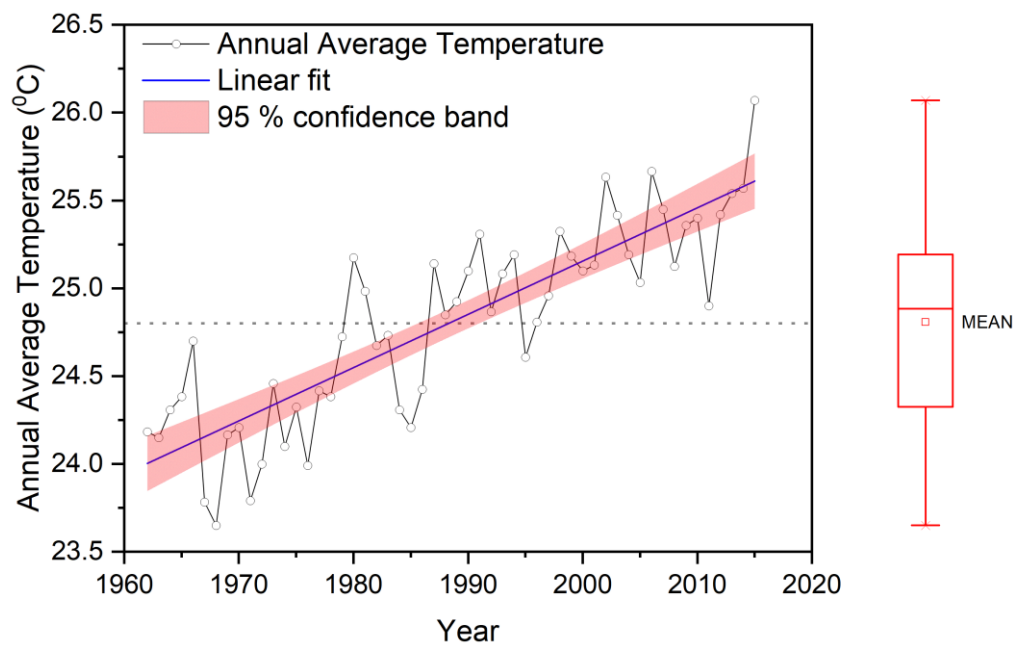


Figure 3. Changes in annual average temperature recorded by the Kaohsiung weather station, 1960–2016.

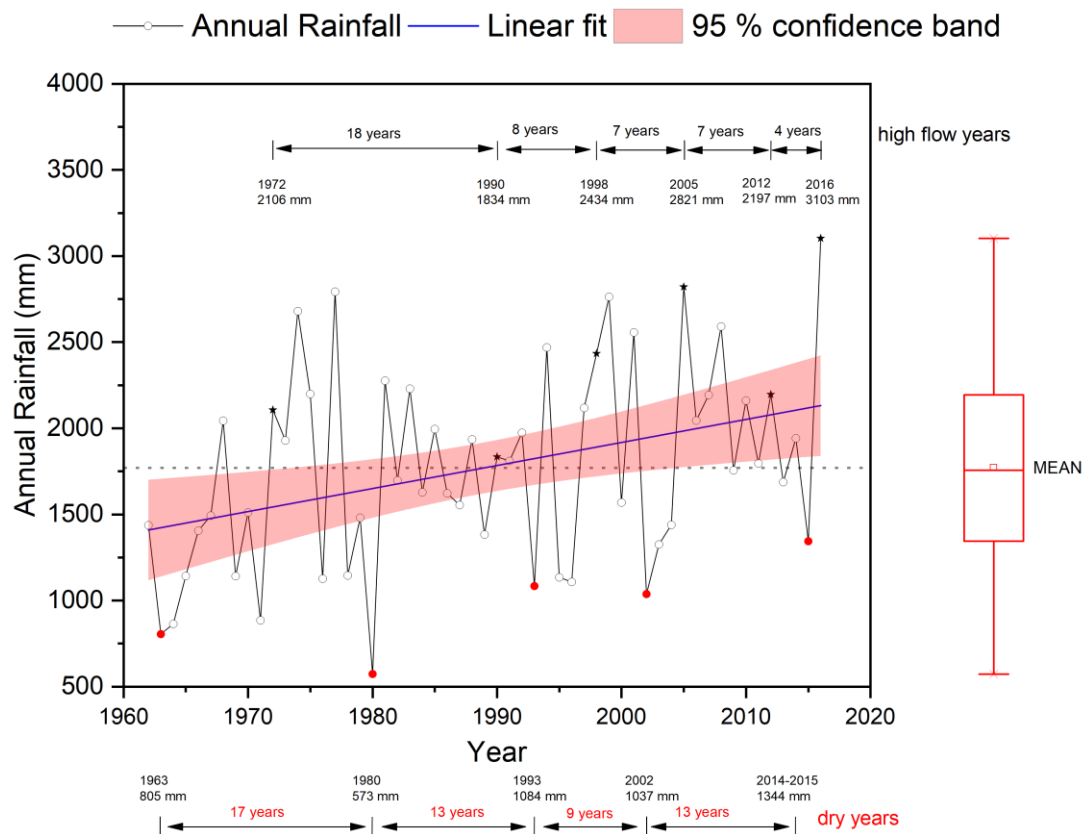


Figure 4. Changes in annual precipitation recorded by the Kaohsiung Weather Station, 1960–2016.

2.3. The Physiographic Soil Erosion-Deposition Model (PSED Model)

The PSED Model [4,25] is a physical mechanism-based model that was developed by integrating the Geographic Information System (GIS) with a Physiographic Precipitation-Runoff model. It incorporates the effects of slope and river channel erosion, entrainment and deposition on river bed erosion-deposition for a watershed. Based on topography, landform, river system, land use and soil characteristics of

the watershed, the PSED Model utilizes GIS to partition the watershed area into non-structural computational cells. The computed cells are then classified into slope cells, river cells and special cells. Esri ArcMap 10.7 was utilized to obtain hydrological and physiographical data within each cell. In addition, the extension modules of ArcMap (spatial analysis, hydrologic model, 3D Analyst and Network Analyst) and their object-oriented programming language were used.

The model consists mainly of two parts; a water flow simulation and a soil erosion-deposition simulation. Water flow simulation calculates the transport of precipitation runoff in the watershed area. The continuity equation of water flow is as follows:

$$A_i \frac{\partial h_i}{\partial t} = \sum_k Q_{i,k}(h_i, h_k) + P_{ei}(t) \quad (1)$$

where: t is time; A_i is area of the i cell; h_i and h_k represent the water stage of the i and k cell, respectively; $Q_{i,k}$ denotes the flow rate (discharge) from the k cell into its neighboring i cell; and P_{ei} expresses the effective rainfall volume per second in the i cell, which is equal to the effective rainfall per second in the i cell multiplied by its area. Depending on the topography and landform information, the watershed area can be divided into several computed cells and the water level change of each cell should then satisfy the continuity equation of water flow and flow rate simulation, as expressed in Equation (1).

In the soil erosion-deposition simulation for the watershed, simulations for slope cells and river cells were calculated separately. The sediment transport rate and river bed erosion profile of each cell were simulated by using the suspended load equation (Equation (2)), the river bed variation continuity equations (Equation (3)) [26], and the river bed load transport equation.

$$\frac{\partial V_{si}}{\partial t} = \sum_k Q_{SC_{i,k}} + Q_{sei} - Q_{sdi} + R_{DTi} \quad (2)$$

$$(1 - \lambda) \frac{\partial V_{di}}{\partial t} = \sum_k Q_{SB_{i,k}} - Q_{sei} + Q_{sdi} - R_{DTi} \quad (3)$$

where: V_{si} is the soil volume of water body in i cell ($= A_i \times D_i \times C_i$); D is the cell water depth; C is the suspended load volume concentration; λ is the porosity; V_{di} is the alluvium volume of cell i ; $Q_{SC_{i,k}}$ and $Q_{SB_{i,k}}$ denote the suspended and the river bed load flow rates, respectively, from the k cell into its neighboring i cell; Q_{sei} represents the entrainment rate of ground surface soil or river bed sediment of the i -th cell; Q_{sdi} expresses the deposition rate of river bed sediment for i cell; and R_{DTi} is the precipitation separation rate of the i cell.

2.4. Computational Cells

Figures 5–7 show the Digital Elevation Model (DEM), soil map and land use maps of Gaoping River Basin, respectively. The basin ranges from 0 m to more than 3000 m above sea level and is dominated mostly by forest land at elevations higher than 500 m. Based on the DEM, land use, soil maps, road system maps, and slope maps (Figure 8) the basin was divided by Esri ArcMap 10.7 into 17,635 computational cells for further analysis.

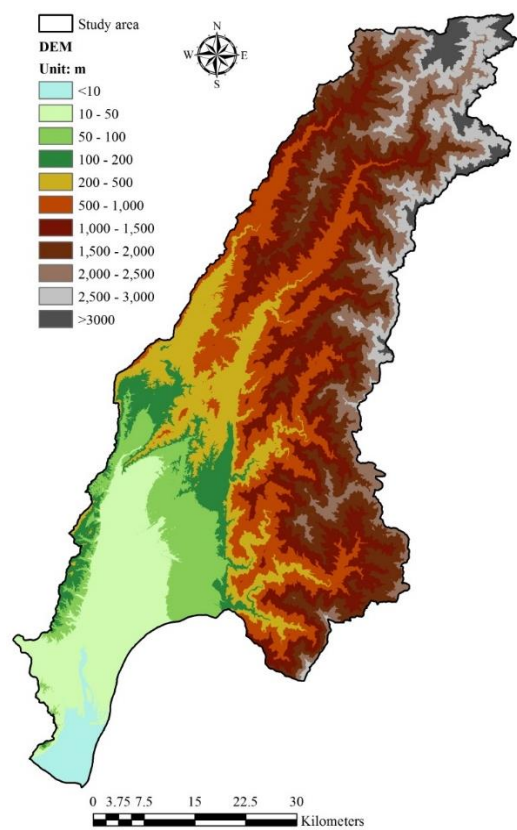


Figure 5. Digital elevation model (DEM) of the Gaoping River watershed.

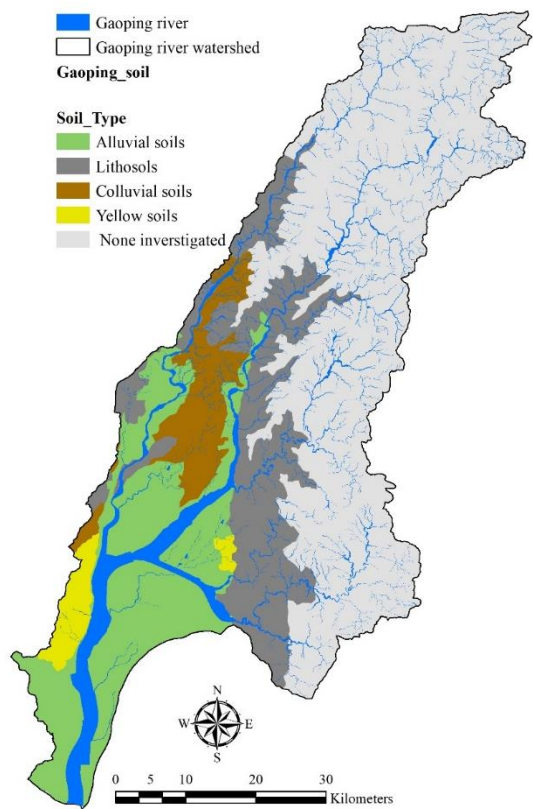


Figure 6. Soil map of the Gaoping River watershed [27].

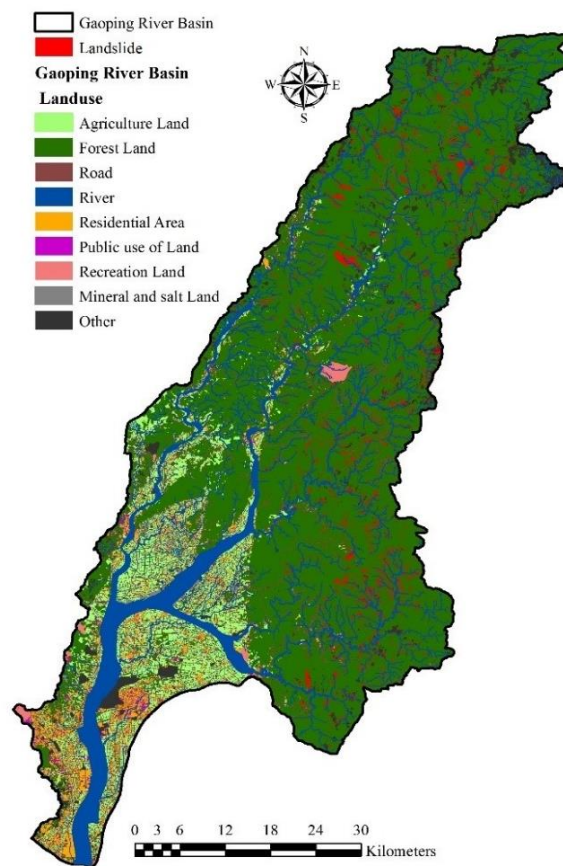


Figure 7. Digital land use map of the Gaoping River watershed [28].

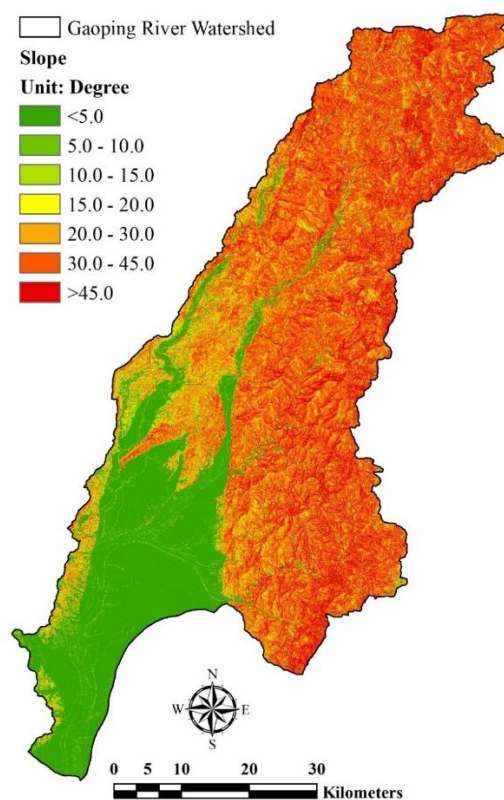


Figure 8. Slope map of Gaoping River watershed.

2.5. Input Data and Model Setup

In the basin, there are 28 precipitation monitoring stations established by the Central Weather Bureau; however, they are not evenly distributed. In order to minimize computational errors, we applied the Thiessen polygons method to determine the controlling area of each precipitation monitoring station. The reader should note that the Thiessen polygons were not used to derive the weighted precipitation. Instead, precipitation data for each station were used as the precipitation volume of computed cells in the control area for the same precipitation monitoring station (Figure 9).

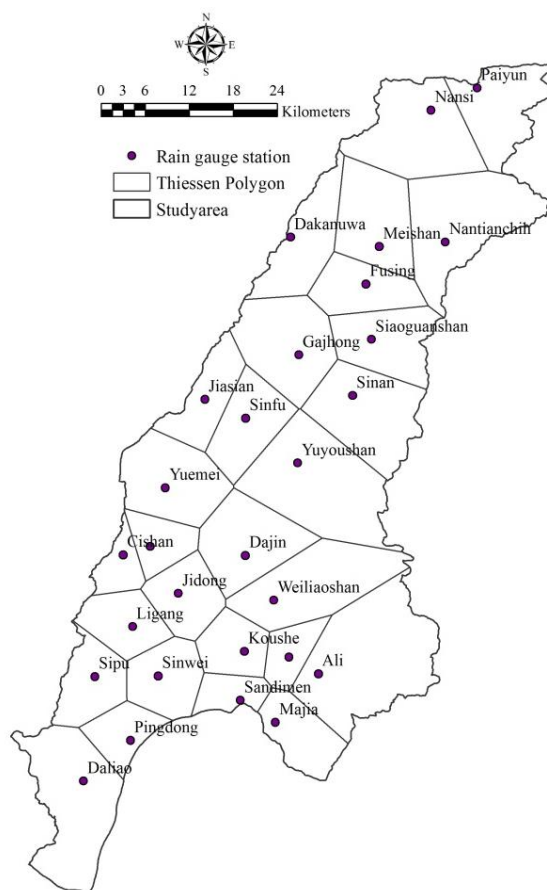


Figure 9. Effective area for precipitation gauging stations in the Gaoping River watershed.

PSED simulated sediment transport was validated by comparing the flow rate and sediment transport data collected by sediment monitoring stations of the 7th River Management Office of Water Resources Agency, MOEA, which are located at the downstream of the Gaoping River and its tributaries. They include the Shanlin Bridge of Qishan River, Tachin Bridge of Laonong River, Sandimen Bridge of Ailiao River, and Lilin Bridge of Gaoping River (Figure 10).

The future scenario in this study was set from 2020 to 2039 and the corresponding baseline was set from 1980 to 1999. The Taiwan Climate Change Projection and Information Platform Project (TCCIP) provided downscaled precipitation data at 5 km² resolution. To process the data, TCCIP relies on 24 GCMs as described in the Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report (AR4) [29]. Additionally, IPCC identifies A2, A1B and B1 as the most probable scenarios; hence, this study adopted the A1B-S for analysis, which is regarded as a worse scenario and is similar to the A1B scenario. The worst-case scenario is primarily obtained through subtracting or adding one standard deviation between the estimated values of GCMs from the multi-model ensemble of all GCMs [30]. Monthly precipitation scenario information was further combined with a weather generator to evaluate the impact of climate change on daily precipitation volume.

The baseline was defined by precipitation data from 1980 to 1999. Historical daily precipitation data from the monitoring stations were used as input files for the climate derived models. These were then applied to generate the daily precipitation data representing the future climate change scenario. In addition, the daily precipitation data of the baseline scenario were combined with the precipitation distribution in the watershed area to translate into precipitation profiles to be used by the PSED model.

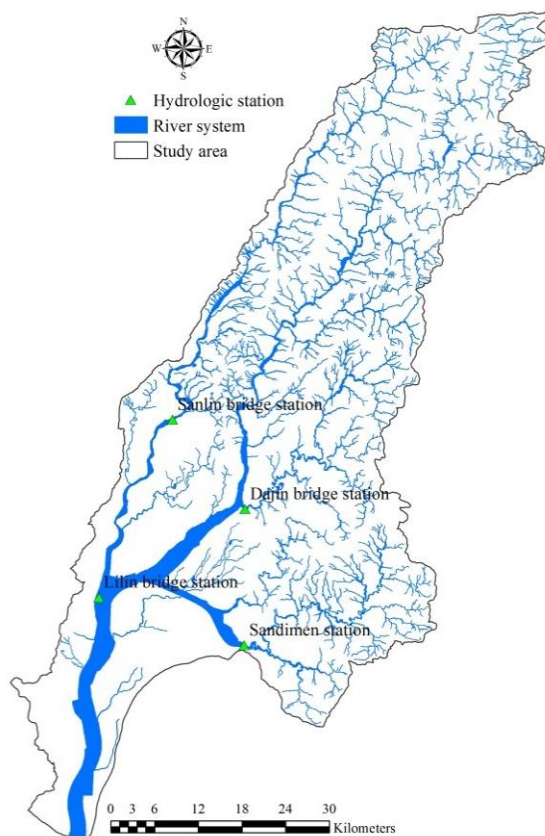


Figure 10. Sediment monitoring stations on the Gaoping River and its tributaries.

2.6. Model Verification

Typhoon Morakot (2009), the most disastrous storm to have hit Taiwan in the last century, was used to validate runoff and suspended load hydrographs from the PSED model. We further compared actual discharge and sediment transport from each hydrological station to simulated data. Simulated and observed flow hydrograph from Lilin Bridge is shown in Figure 11. The peak of the simulated hydrograph coincided with that from the observed data, and the hydrograph shapes are similar. This suggests that the model can be successfully applied.

Since the hydrological monitoring stations along the Gaoping River system do not have suspended load concentration data hydrographs, the historical discharge and suspended load data from sediment monitoring stations downstream of the main branch of the Gaoping River were used to establish the correlation between discharge and sediment transport volume of each hydrological monitoring station. These served as the basis for validating the suspended load concentration hydrograph obtained from the numerical model. The simulated discharge and suspended load transport rate under Typhoon Morakot in 2009 were plotted onto the correlation diagram between the observed discharge and sediment transport rate for the Sanlin, Dajin, Sandimen and Lilin bridge Stations (Figures 12–15). In these figures, points are actual historical measured data. The solid line represents the regression relation between discharge and sediment transport rate for each hydrological monitoring station. It is noted from the figures that the simulated correlation between discharge and sediment transport rate was consistent with the correlation between discharge and sediment transport rate of the actually

observed data for all monitoring stations except Lilin Bridge station, particularly under high discharge. The model slightly overestimated data at this station (Figure 15). Nonetheless, the model also indicated reasonable estimates on suspended load and suspended load transport.

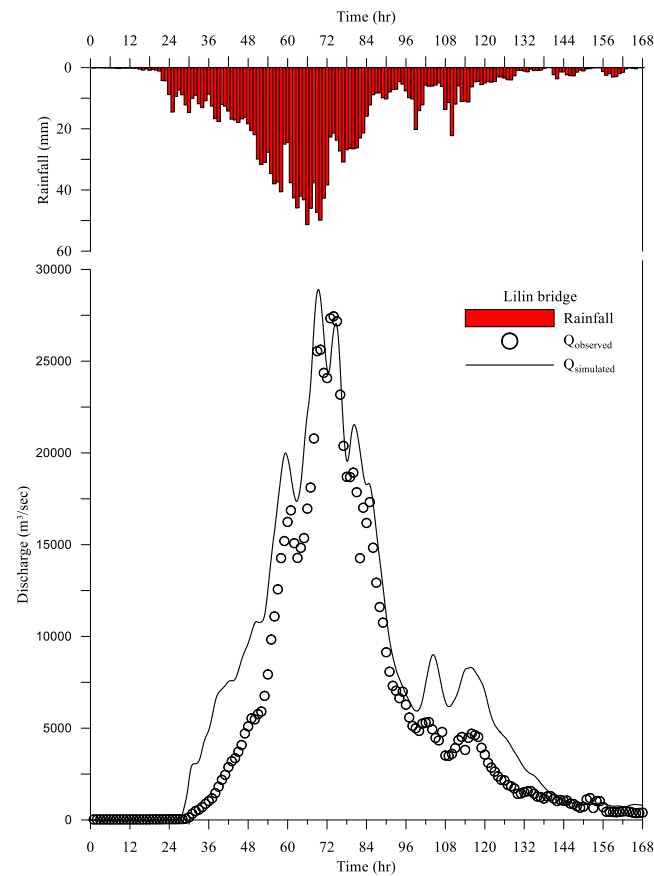


Figure 11. Simulated and observed discharge during Typhoon Morakot in 2009 at Lilin Bridge station.

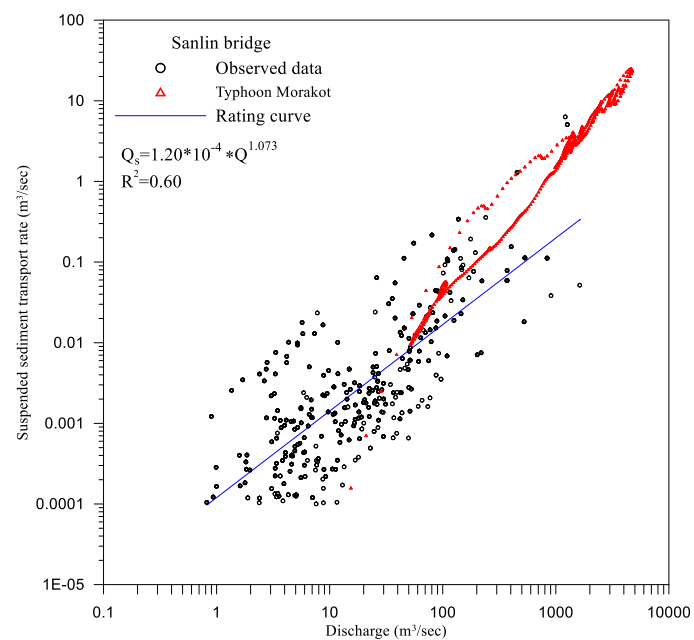


Figure 12. Simulated and observed correlation between flow discharge and sediment transport rate at Sanlin Bridge station.

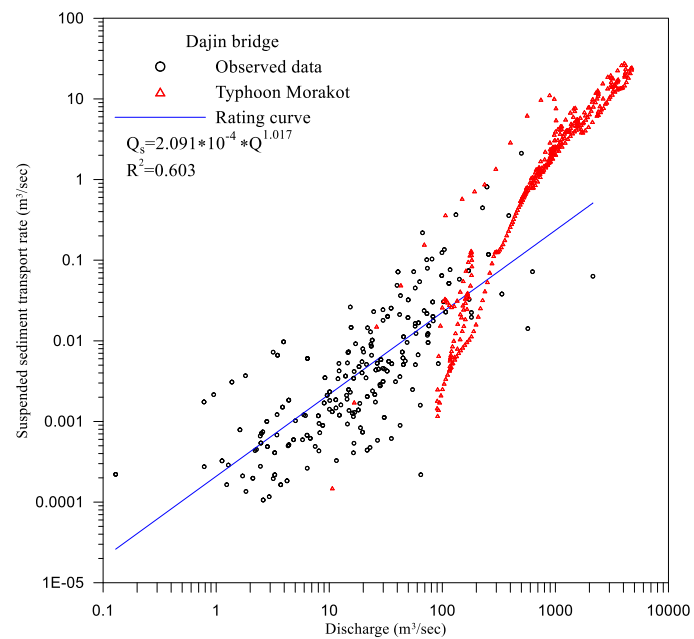


Figure 13. Simulated and observed correlation between flow discharge and sediment transport rate at Dajin Bridge station.

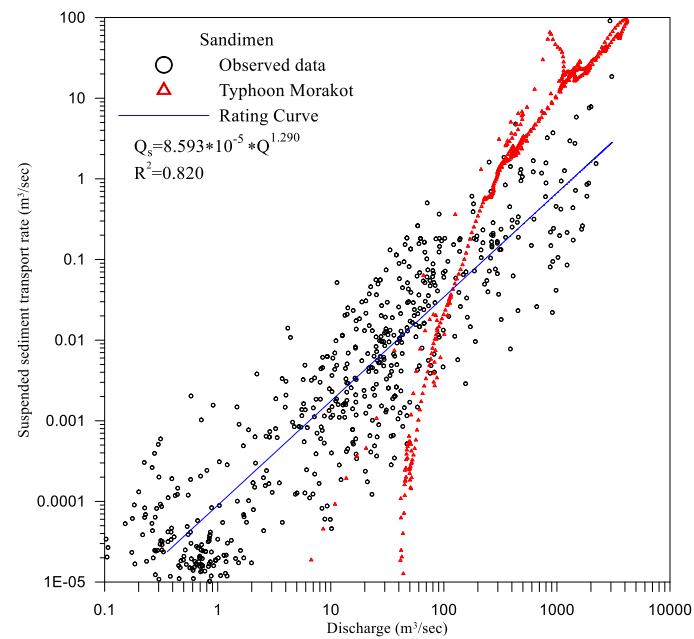


Figure 14. Simulated and observed relationship between flow discharge and sediment transport rate at Sandimen Bridge station.

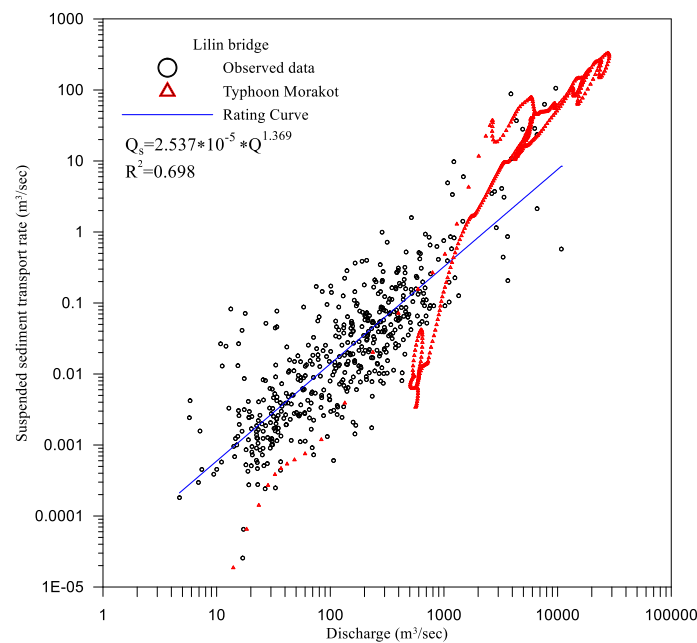


Figure 15. Simulated and observed relationship between flow discharge and sediment transport rate at Lilin Bridge station.

3. Results

3.1. Impacts of Climate Change on Erosion Volume and Sediment Yield

Different precipitation types, rainfall distribution, rainfall intensities and precipitation volume will result in different runoff processes, leading to different erosion volumes and sediment yields in a watershed. The precipitation volumes collected by each precipitation monitoring station in the watershed area for each return period (2, 5, 10, 25, 50, 100 and 200 year return period) under the baseline and A1B-S scenarios were used to calculate the average maximum rainfall intensity and average rainfall for each return period via the controlled area weighted method. The above return periods were selected as they are the standards used for most engineering designs in Taiwan. The precipitation results for the baseline were then compared with the results of the A1B-S scenario. Table 1 shows the comparison of average maximum rainfall intensity and average rainfall between the baseline and selected scenarios of each return period. Average maximum rainfall intensity increased more than average rainfall, suggesting that under the influence of climate change, not only did the precipitation volume increase but also the precipitation intensity.

Table 1. Average maximum rainfall intensity and average rainfall increase rates under baseline and A1B-S scenarios for various return periods.

Return Period	Average Maximum Rainfall Intensity (mm/hr)			Average Annual Rainfall (mm)		
	Baseline (1980–1999)	A1B-S (2020–2039)	Increase Rate (%)	Baseline (1980–1999)	A1B-S (2020–2039)	Increase Rate (%)
2	27.52	29.14	5.89	411.18	434.90	5.77
5	39.00	41.90	7.43	584.82	627.39	7.28
10	46.53	51.63	10.97	701.12	776.94	10.81
25	55.10	65.92	19.65	843.42	1004.26	19.07
50	61.12	78.24	27.99	957.97	1212.17	26.53
100	66.96	91.98	37.36	1094.72	1466.32	33.95
200	72.75	107.35	47.56	1280.60	1794.54	40.13

Simulated erosion volume and sediment yield under the baseline and A1B-S scenarios for various return periods are shown in Table 2. Total erosion volume and sediment yield under the A1B-S scenario for various return periods are greater than under the baseline. The increase in the total sediment yield rate was higher than that of the total erosion volume. The total erosion volume and total sediment yield increases by 4–25% and 8–65%, respectively, when compared to the baseline. This implies that climate change contributed to 15% and 36% increases in soil erosion volume and sediment yield, respectively, when compared to the baseline average.

Table 2. Soil erosion and sediment yield increase rates under baseline and A1B-S scenarios for various return periods.

Return Period	Total Erosion (m ³)			Total Sediment Yield (m ³)		
	Baseline (1980–1999)	A1B-S (2020–2039)	Increase Rate (%)	Baseline (1980–1999)	A1B-S (2020–2039)	Increase Rate (%)
2	25,025,101	26,158,002	4.53	3,610,538	3,919,368	8.55
5	33,683,874	35,566,538	5.59	6,312,775	7,083,252	12.21
10	38,589,952	41,576,563	7.74	8,280,890	9,711,170	17.27
25	43,557,305	49,077,034	12.67	10,631,451	13,811,304	29.91
50	46,687,318	54,601,150	16.95	12,325,453	17,496,549	41.95
100	49,482,826	59,940,637	21.13	14,010,777	21,564,822	53.92
200	52,023,499	65,223,943	25.37	15,708,576	25,927,062	65.05

3.2. Climate Change Effect on Erosion and Erosion Distribution

Soil erosion simulation results for the studied area were compiled and summarized in Table 3. The least return period indicated a 0.54% increase in area, while for under 200 year return period there was a 2.3% increase. The impacts of climate change on erosion were found to be lower when compared to other areas within the Asian region. Pal and Chakraborty [31] simulated the impacts of climate change on soil erosion in a sub-tropical monsoon dominated watershed based on a RUSLE model, and found erosion to increase by 33% under a 15 year return period.

Table 3. Comparison of the increase rate of soil erosion area increase under the baseline and A1B-S scenarios for various return periods.

Return Period	Area Increase (m ²)	Increase Rate (%)
2	11,888,256	0.54
5	16,749,128	0.7
10	29,890,573	1.22
25	42,155,931	1.67
50	47,859,021	1.92
100	50,239,407	1.97
200	58,921,624	2.3

Climate change was also shown to cause larger erosion depths (Figure 16). Except in a few selected areas, a greater percentage indicates an increasing trend, and erosion depth increased with increasing return period. This is in line with observations made by Giang et al. [32], who predicted that Asian countries would be among the hardest hit regions globally.

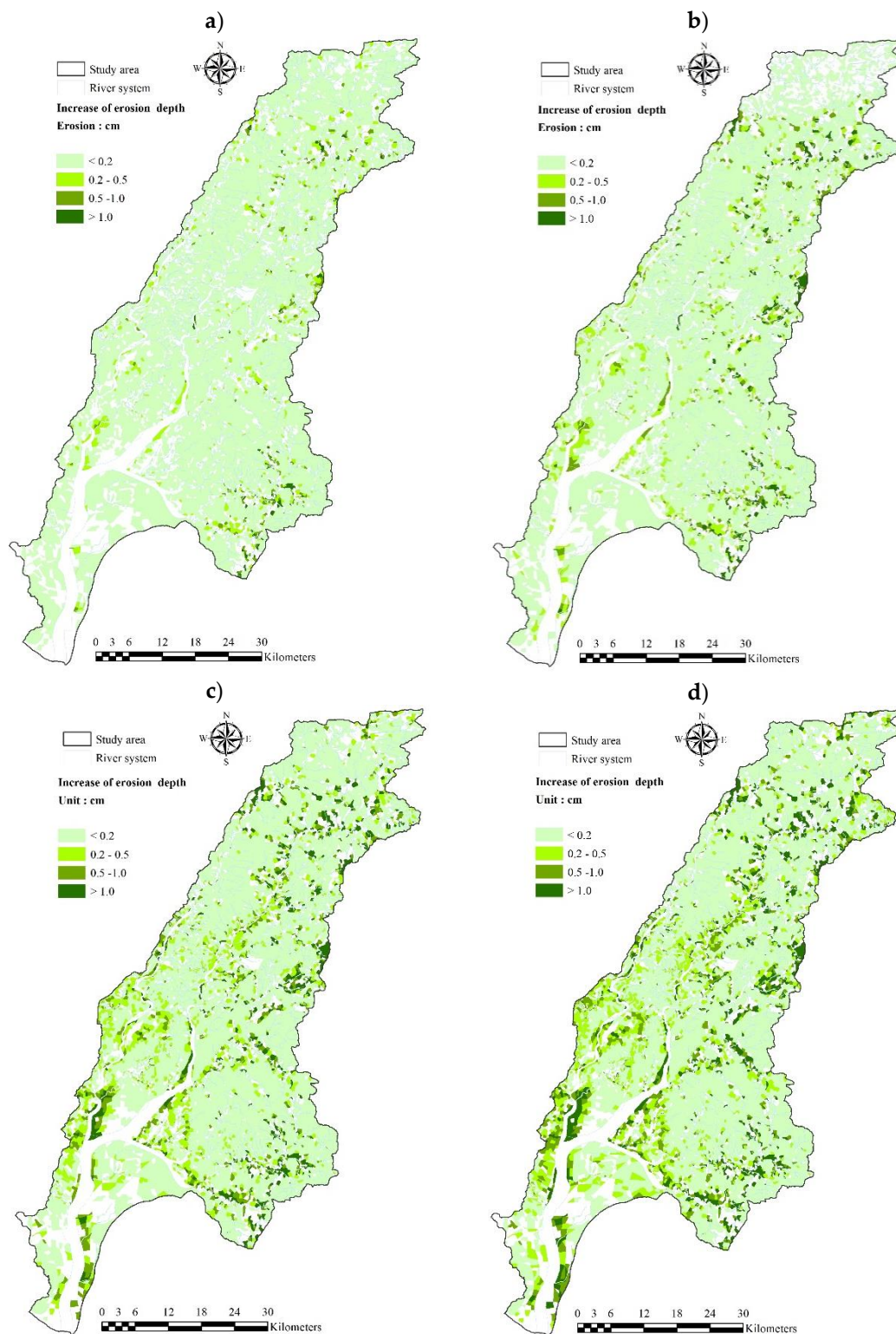


Figure 16. Spatial distribution of erosion depth increase under the influence of climate change under (a) 10 year, (b) 25 year, (c) 100 year and (d) 200 year return periods.

3.3. Climate Change Effects on Deposition Volume and the Deposition Distribution

Deposition distributions under baseline and climate change scenarios for 10 and 100 year return periods are shown in Figures 17 and 18, respectively. High deposition was observed mainly at the confluences; between Gaoping and Qishan River (zone A), Gaoping River and Laonong River

(zone B), Ailiao River Gaoshu Bridge and Ailiao weir (zone C) and in the middle and downstream of Gaoping River (zone D). Zone areas are shown in Figure 19. Large deposition at these areas is attributed to widening of the cross sections, low river bed slopes and low flow rates. Deposition in each computational cell was calculated by multiplying the deposition height of a cell by its area, and the total deposition of all cells was simply the summation of the volumes in each cell. A summary of the deposition under the different return periods is shown in Table 4.

Figure 20 shows the spatial distribution of deposition depth increase under the baseline and climate change scenarios. Similar increase patterns were observed between the simulated cases, with a larger deposition depth increase located in the middle and downstream of river channels. Deposition depth increase was highest in the main channel as expected, and increased with increasing return periods indicated by dark green areas in Figure 20.

Table 4. Increase in volume of estimated sediment deposition under baseline (1980–1999) and A1B-S (2020–2039) scenarios for various return periods.

Return Period	Baseline (m ³) (1980–1999)	A1B-S (m ³) (2020–2039)	Deposition Volume Increase for Baseline and A1B-S Scenarios (m ³)	Increase Rate (%)
2	9,499,196	9,720,588	221,392	2.33
5	11,984,107	12,425,532	441,425	3.68
10	13,292,933	14,141,714	848,781	6.39
25	14,618,375	16,252,862	1,634,487	11.18
50	15,424,874	17,836,223	2,411,349	15.63
100	16,180,722	19,313,894	3,133,172	19.36
200	16,855,567	20,857,945	4,002,378	23.75

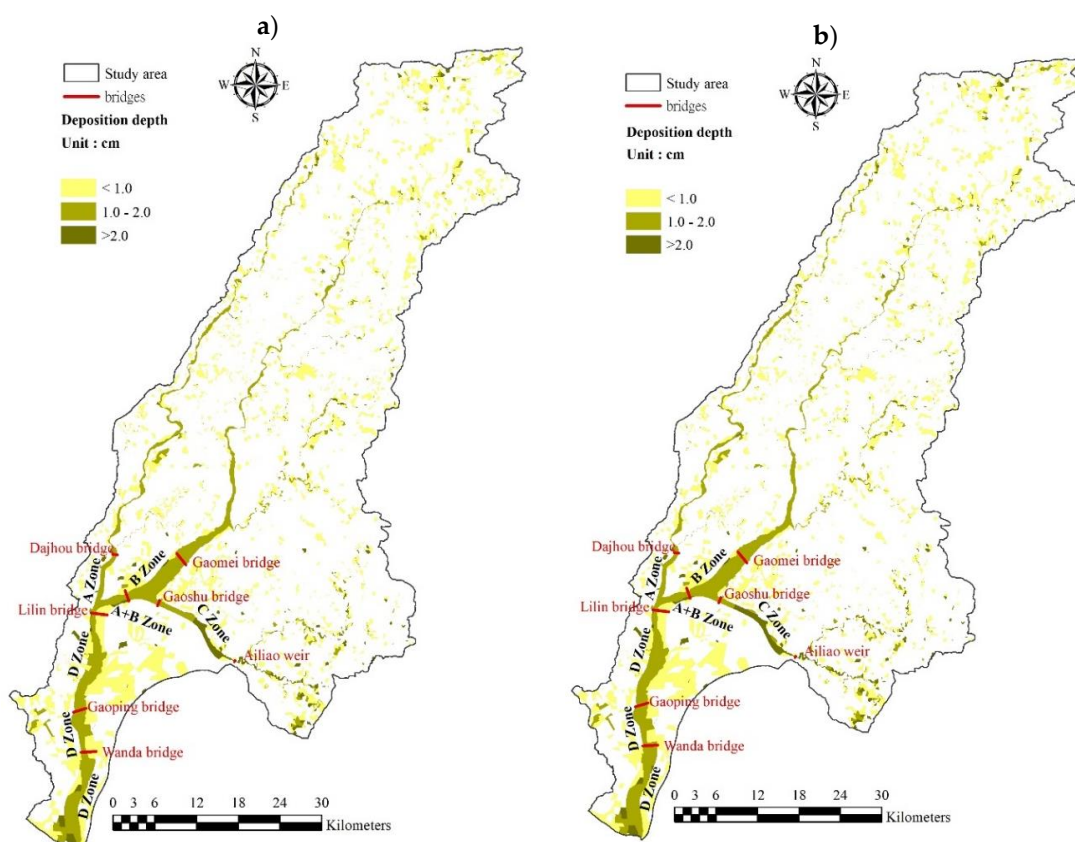


Figure 17. Deposition depth distribution under 10 year return period for (a) baseline and (b) climate change scenarios.

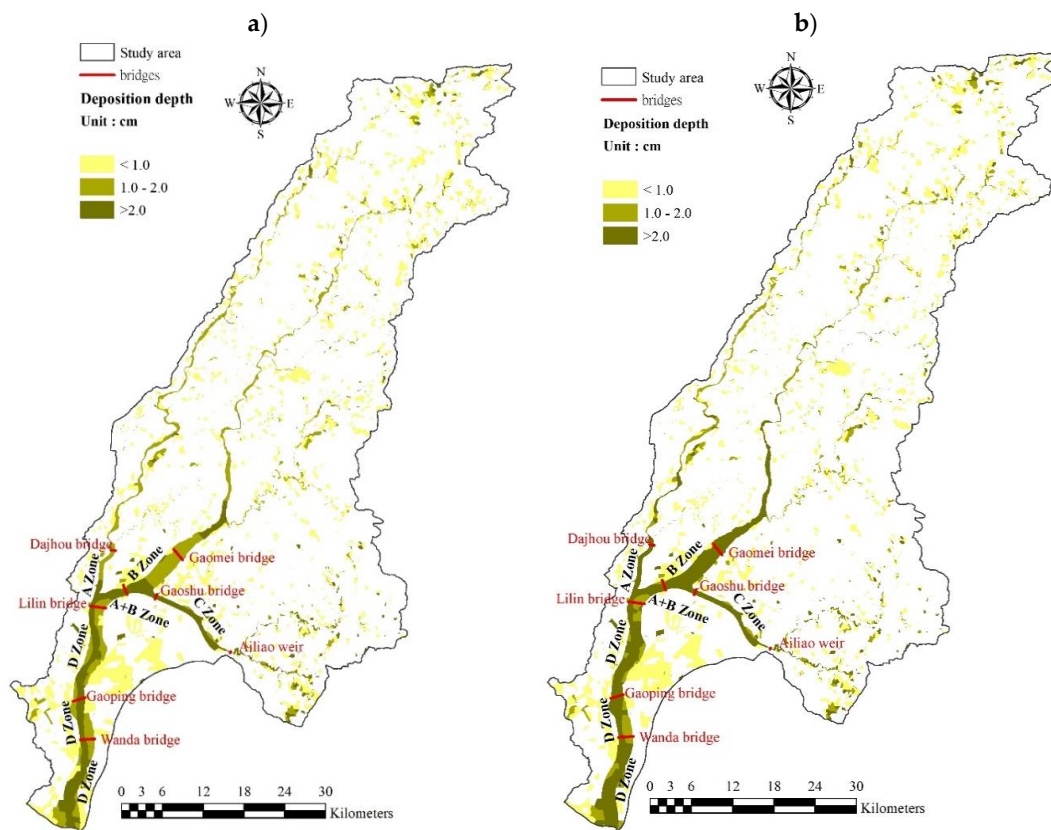


Figure 18. Deposition depth distribution under 100 year return period for (a) baseline and (b) climate change scenarios.

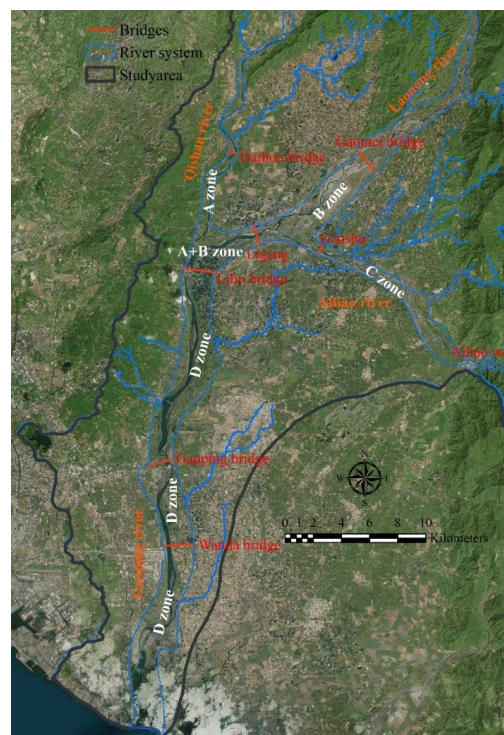


Figure 19. Location of various river sections in the Gaoping River basin that are vulnerable to soil deposition.

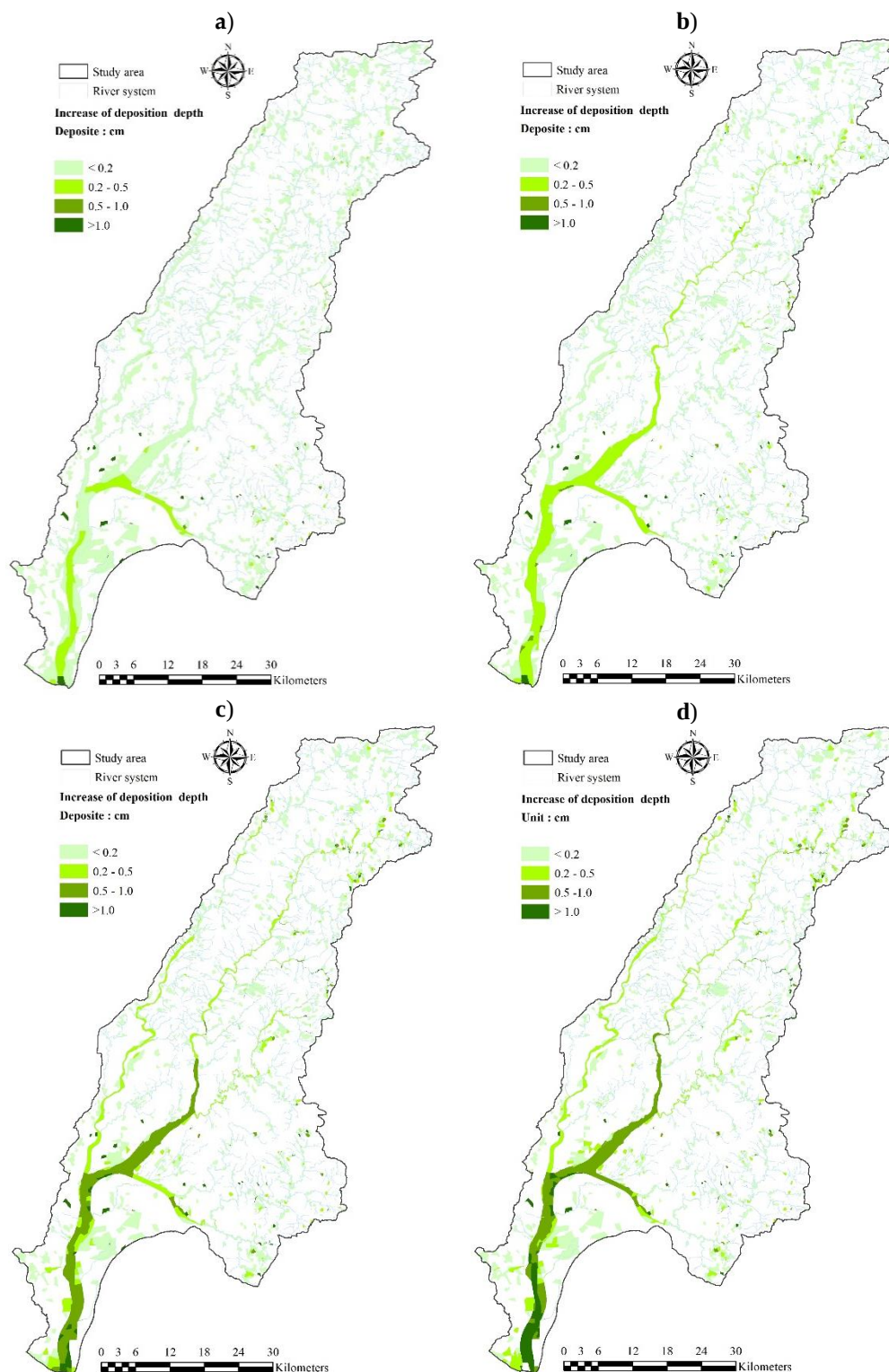
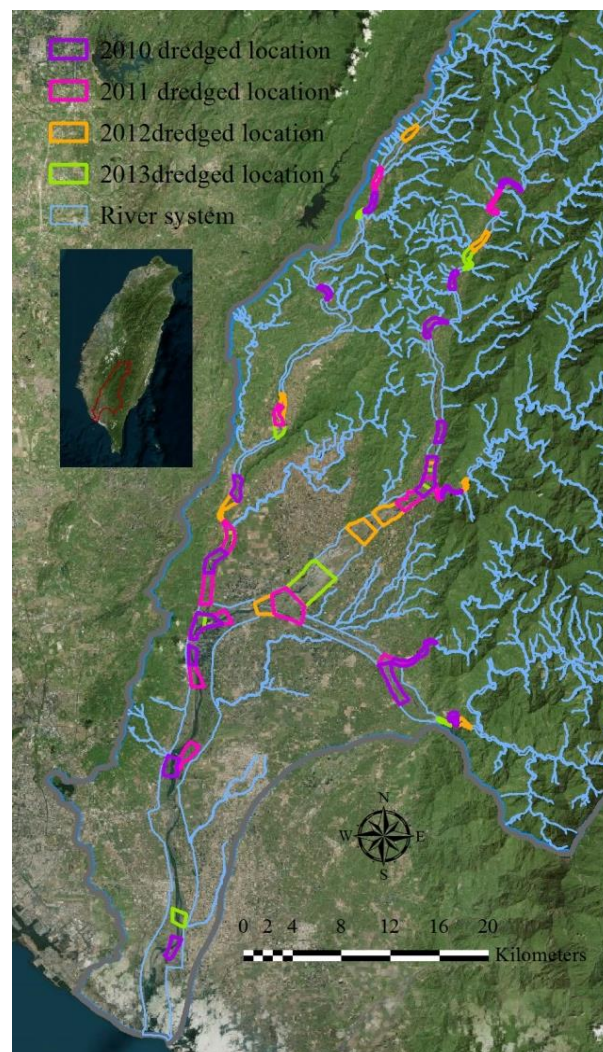


Figure 20. Spatial distribution of deposition depth increase under the influence of climate change for (a) 10 year, (b) 25 year, (c) 100 year and (d) 200 year return periods.

Gaoping River basin exhibited high erosion volume and sediment yield. According to statistical data reported by the Water Resources Agency [22], 76,870,000 m³ have been dredged between 2010 and 2013. Table 5 shows the dredged volume of each year, while Figure 21 indicates the location of the dredged site. Dredged locations coincide with high deposition areas computed by the PSED model, as illustrated by Figure 21.

Table 5. The actual dredged sediment deposition amounts from 2010 to 2013 in each river [22].

River	Actual Dredged Amount (10^4 m^3)			
	2010	2011	2012	2013
Laonong	947.26	1516.37	855.74	623.36
Zhuokou	27.68	75.00	6.49	44.60
Qishan	423.07	241.70	187.77	244.46
Ailiao	555.21	689.79	184.91	139.99
Gaoping	534.61	203.68	104.33	81.54
Total	2487.83	2726.54	1339.24	1133.95

**Figure 21.** Dredged locations in Gaoping River basin from 2010 to 2013.

In each year, a huge amount of money is needed to carry out the dredging works at Gaoping River. With climate change increasing the deposition rates, not only will there be more pressure on financial resources, but flooding risk is also expected to increase. Hence, appropriate structures and policies should be put in place in order to redress climate change impacts. Proposed strategies include identifying and mapping areas more prone to soil erosion and implementing river management and stability measures. Planning the overall river basin operations and management strategies can effectively control the sediment yield in a watershed, hence reducing sediment deposition in river channels due to soil erosion and eliminating flooding disasters due to limited water passage.

4. Conclusions

This study applied a numerical model to investigate the impacts of climate change on erosion volume, sediment yield and erosion deposition in a watershed. The results showed that precipitation under the A1B-S climate change scenario would significantly increase soil erosion volume, sediment yield and sediment transport rate. Total erosion volume and total sediment yield in the watershed under the A1B-S scenario for various return periods increased by 4–25% and 8–65%, respectively, from 2 year to 200 year return periods. Climate change further increased deposition volume by 2–23% relative to the baseline and by 13% relative to the baseline average. Deposition was found to mostly occur at the river confluences, river middle and at the downstream end of Gaoping River. The study clearly revealed the adverse impacts climate change is likely to bring to this basin; hence, appropriate conservation measures are suggested.

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