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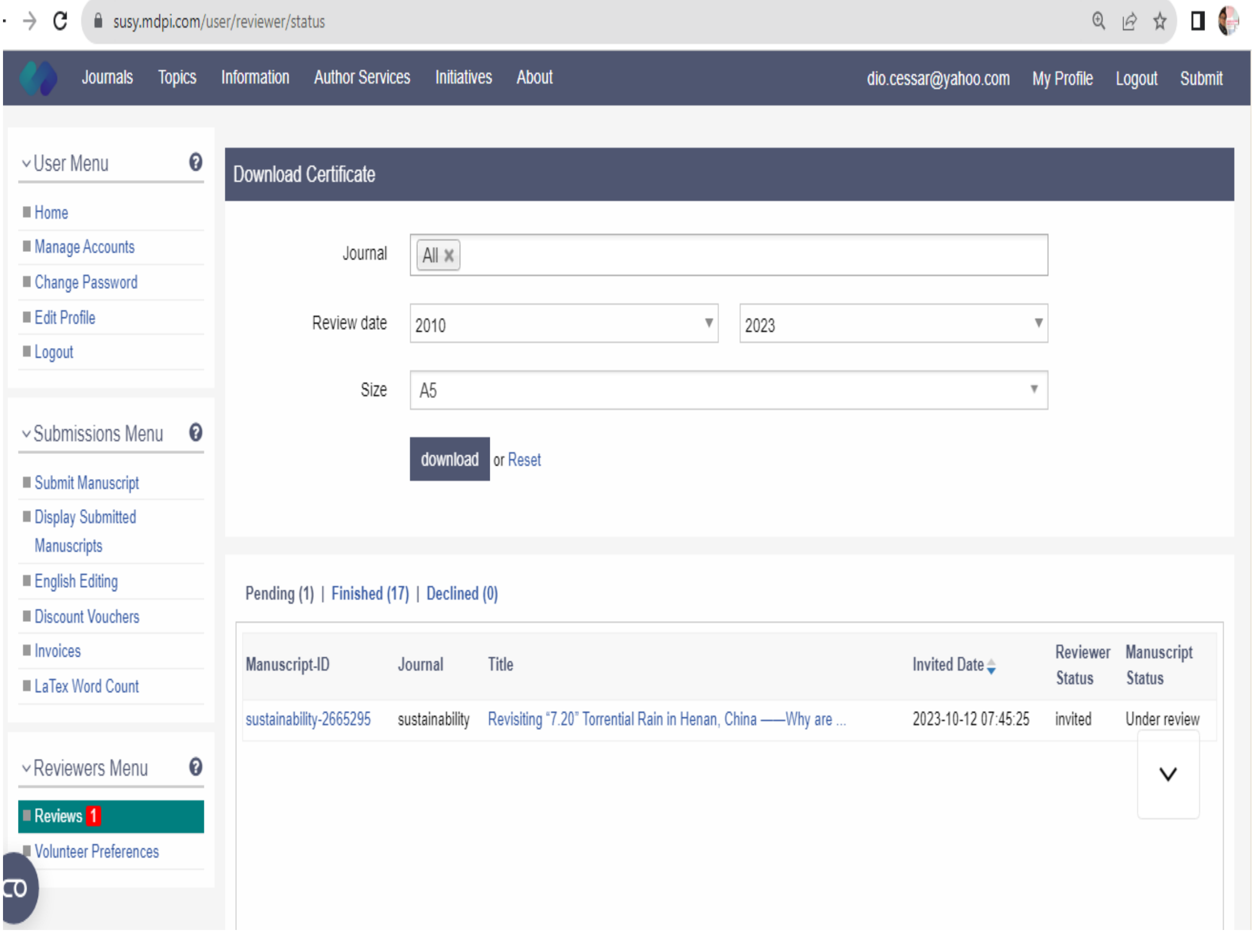

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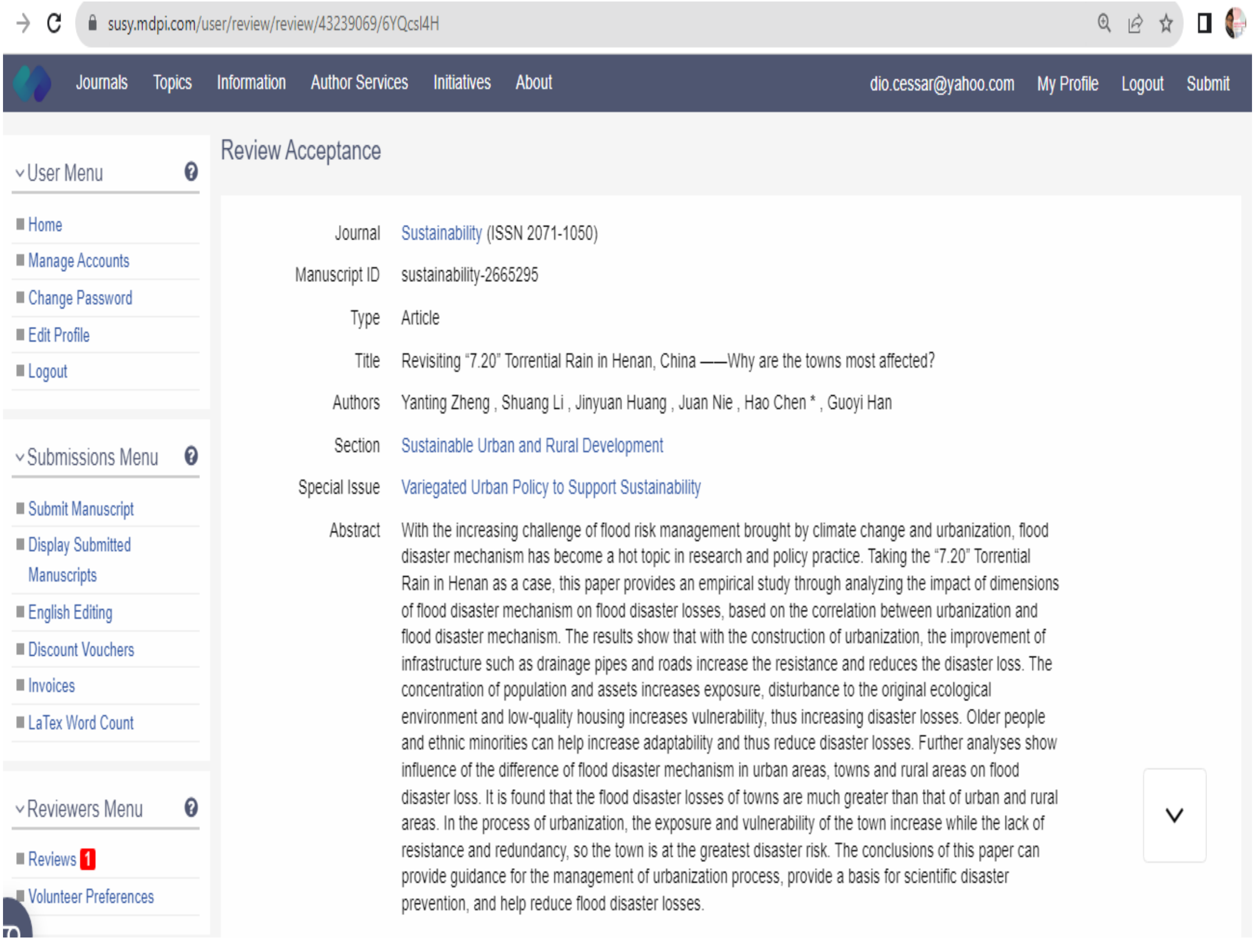


Review Acceptance

Journal: Sustainability (ISSN 2071-1050)

Manuscript ID: sustainability-2665295

Type: Article

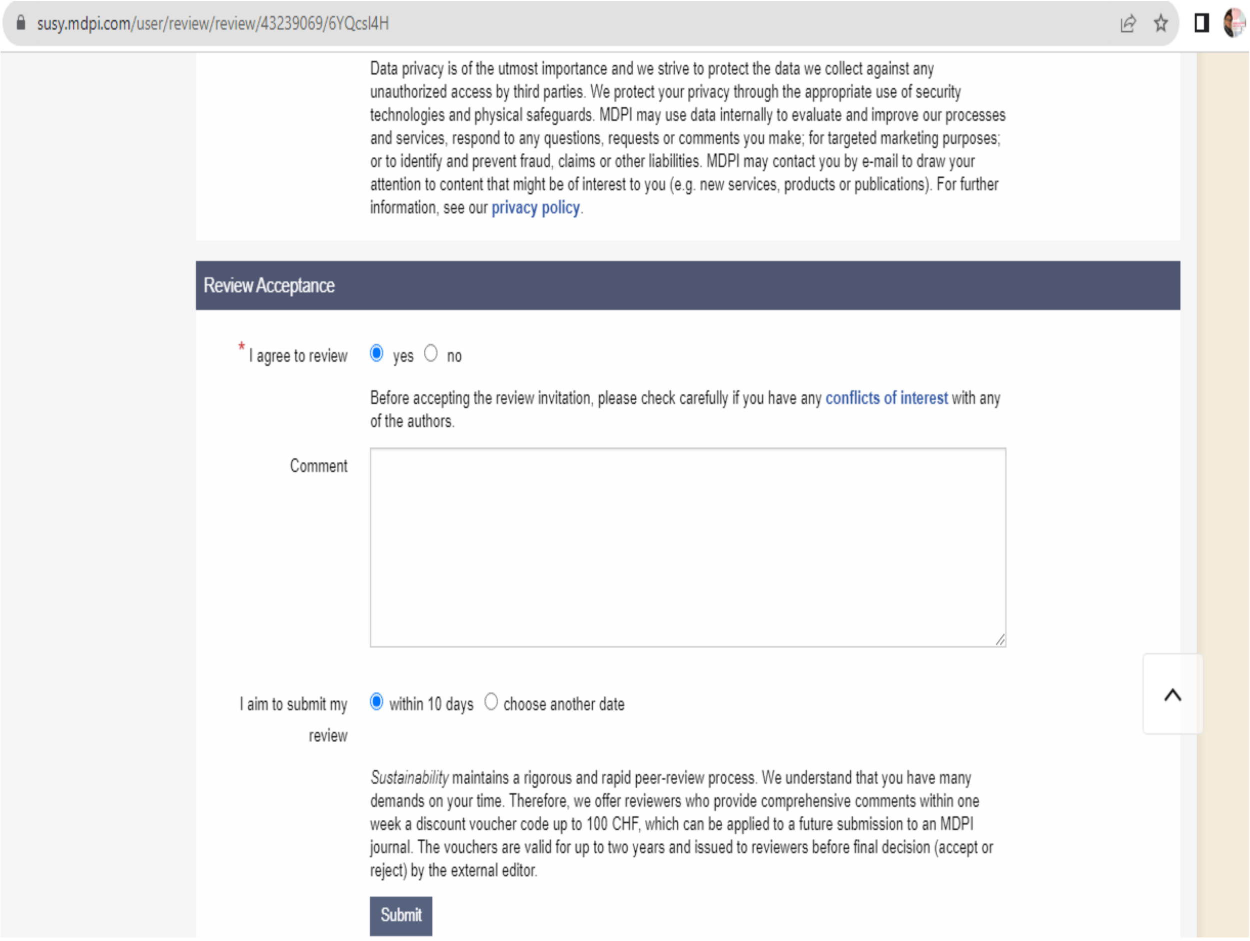
Title: Revisiting "7.20" Torrential Rain in Henan, China ——Why are the towns most affected?

Authors: Yanting Zheng , Shuang Li , Jinyuan Huang , Juan Nie , Hao Chen * , Guoyi Han

Section: Sustainable Urban and Rural Development

Special Issue: Variegated Urban Policy to Support Sustainability

Abstract: With the increasing challenge of flood risk management brought by climate change and urbanization, flood disaster mechanism has become a hot topic in research and policy practice. Taking the "7.20" Torrential Rain in Henan as a case, this paper provides an empirical study through analyzing the impact of dimensions of flood disaster mechanism on flood disaster losses, based on the correlation between urbanization and flood disaster mechanism. The results show that with the construction of urbanization, the improvement of infrastructure such as drainage pipes and roads increase the resistance and reduces the disaster loss. The concentration of population and assets increases exposure, disturbance to the original ecological environment and low-quality housing increases vulnerability, thus increasing disaster losses. Older people and ethnic minorities can help increase adaptability and thus reduce disaster losses. Further analyses show influence of the difference of flood disaster mechanism in urban areas, towns and rural areas on flood disaster loss. It is found that the flood disaster losses of towns are much greater than that of urban and rural areas. In the process of urbanization, the exposure and vulnerability of the town increase while the lack of resistance and redundancy, so the town is at the greatest disaster risk. The conclusions of this paper can provide guidance for the management of urbanization process, provide a basis for scientific disaster prevention, and help reduce flood disaster losses.



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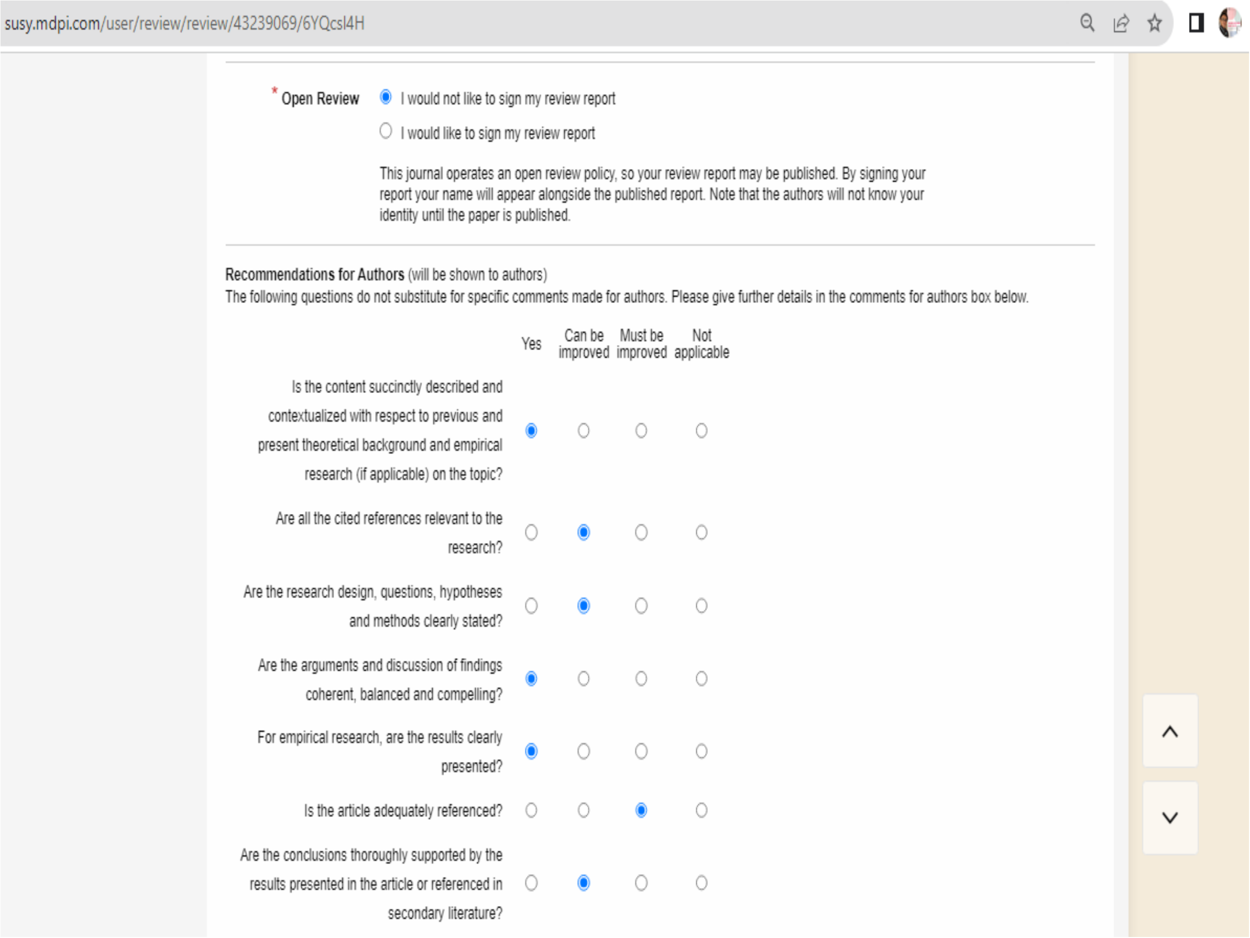

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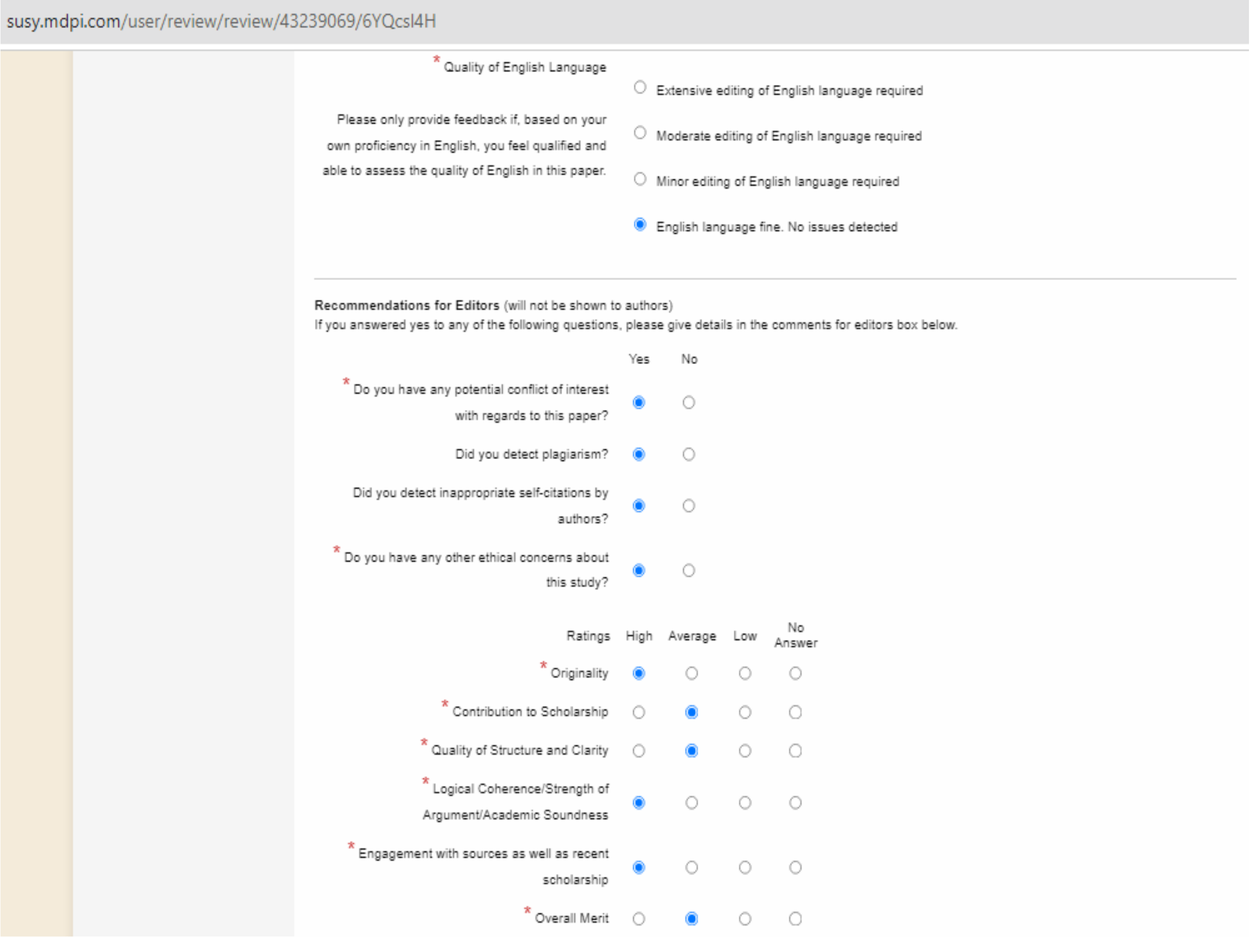

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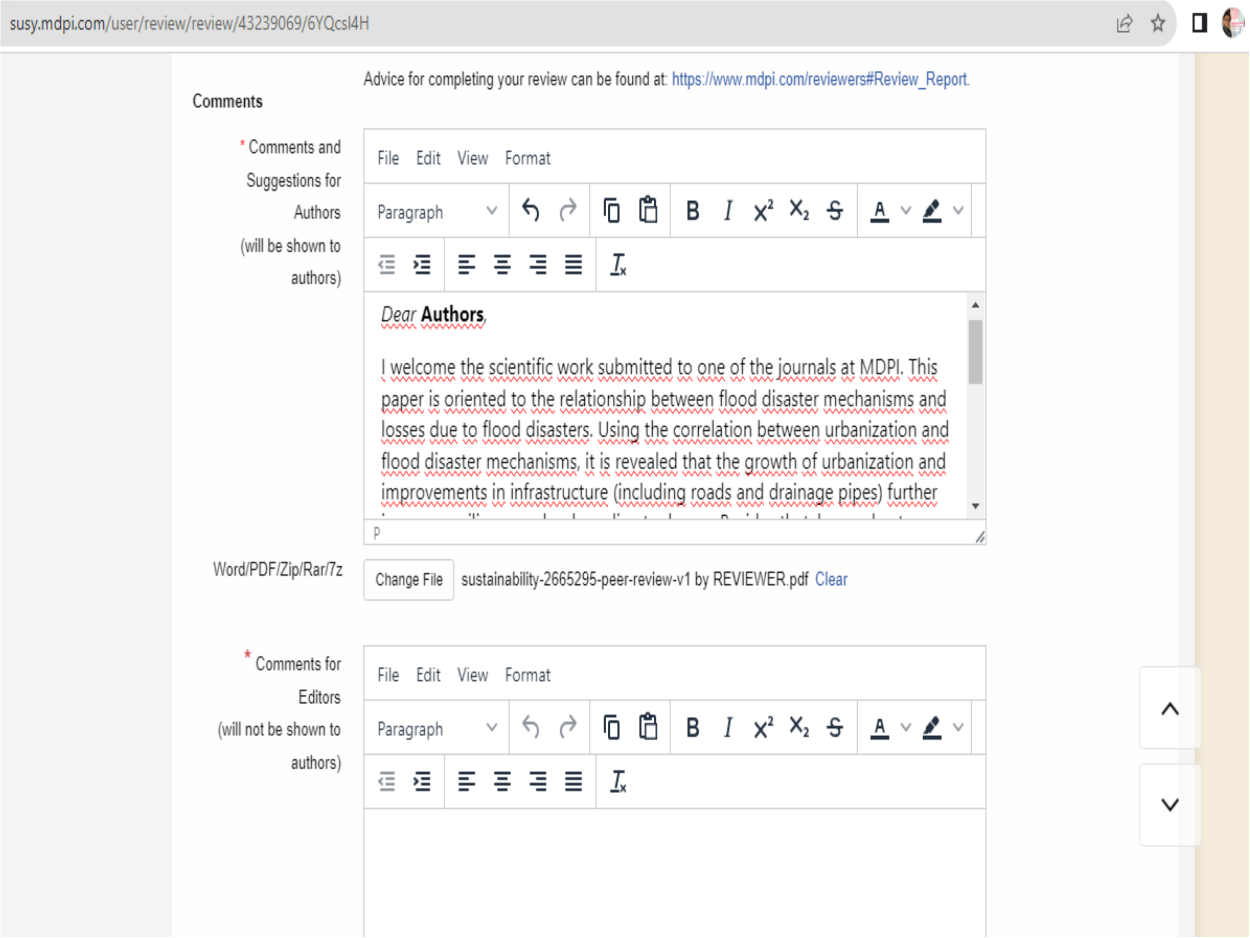

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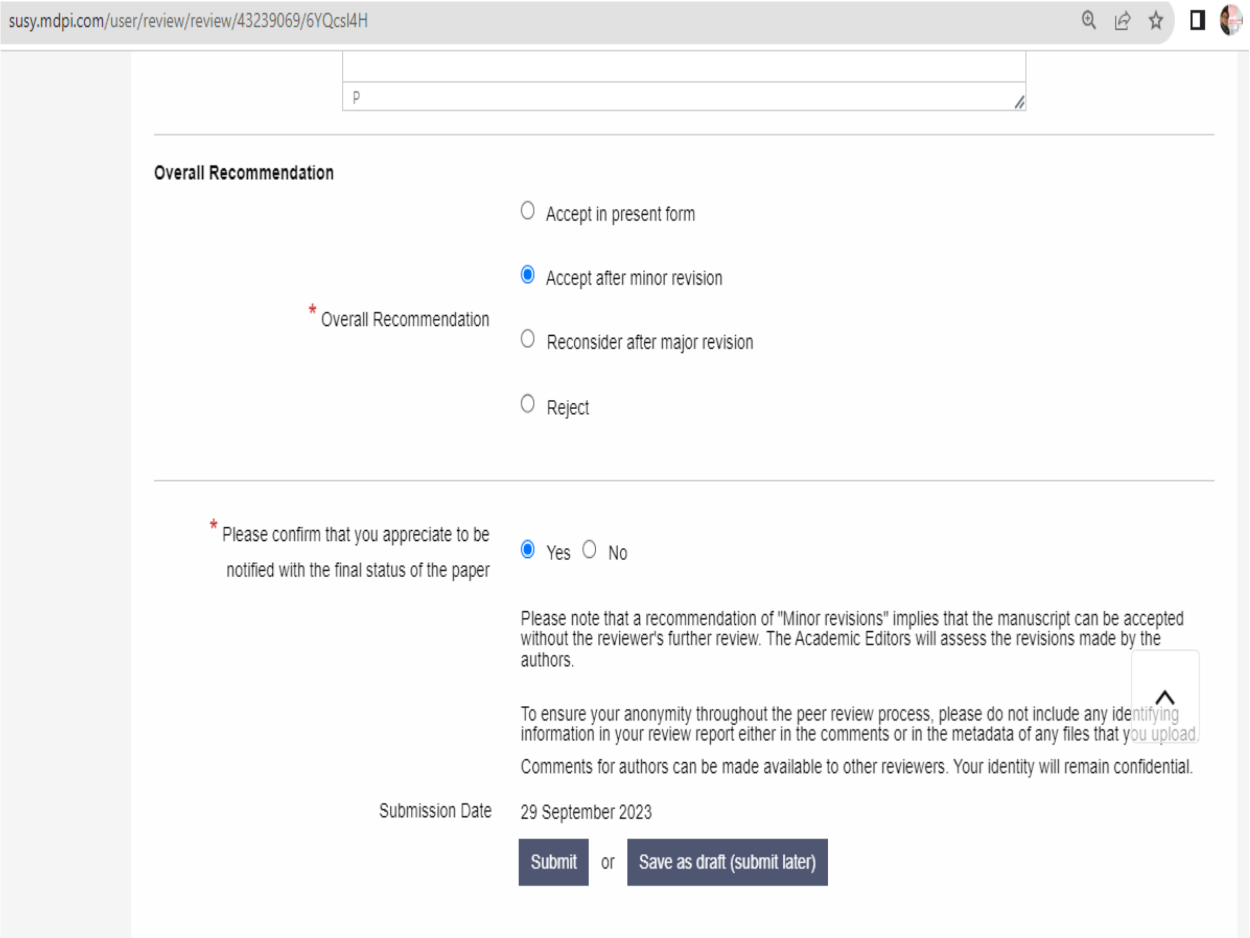

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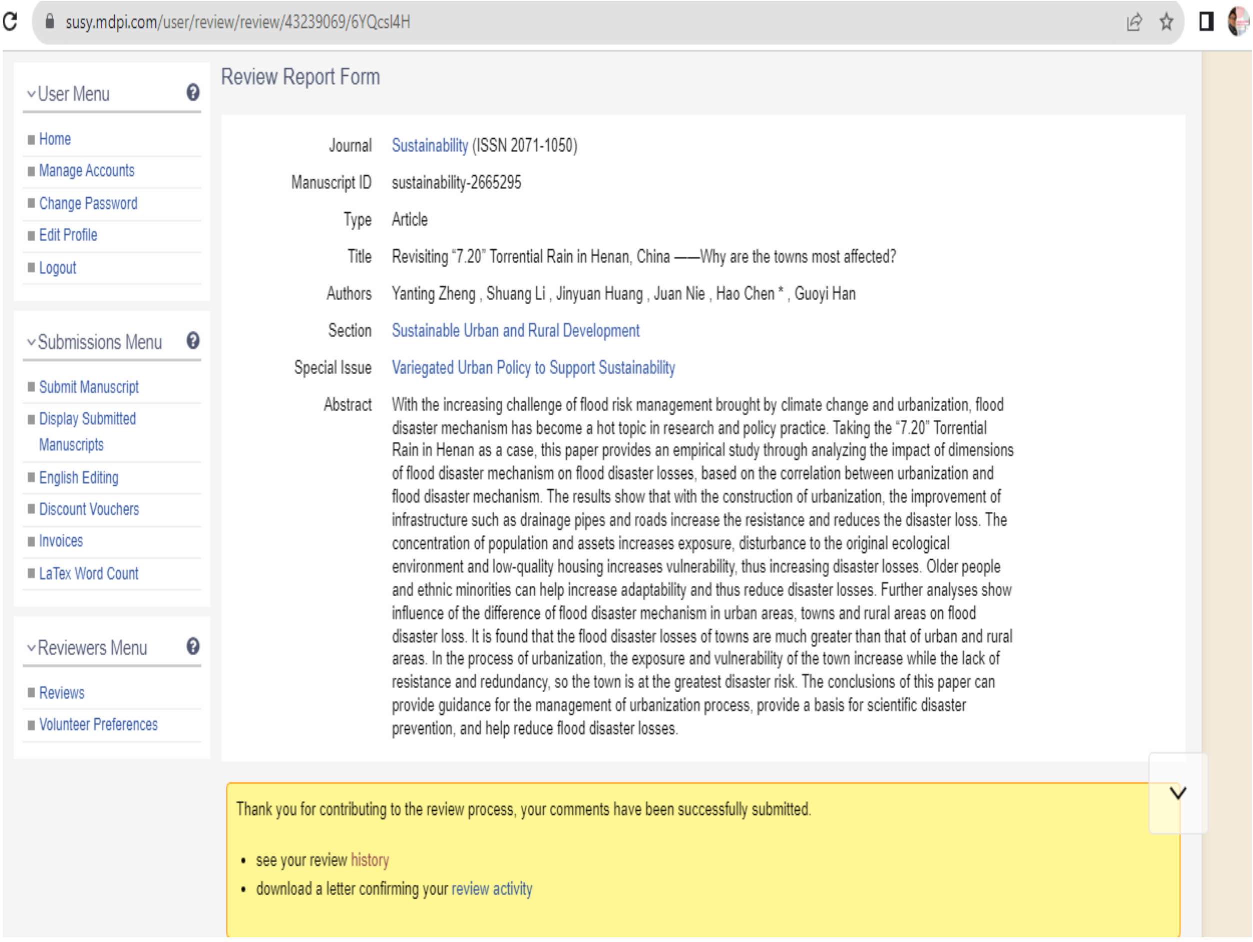

Review Report Form

Journal	Sustainability (ISSN 2071-1050)
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Type	Article
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Revisiting "7.20" Torrential Rain in Henan, China

——Why are the towns most affected？

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Keywords: flood disaster mechanism; urbanization; flood risk management

1. Introduction

With climate change and rapid urbanization, the frequency and magnitude of flood disasters have increased significantly worldwide (Keating *et al.* 2017; Khatri, 2022), increasingly threatening human life and economic stability (Jongman *et al.*, 2012; Arnell and Gosling, 2014; Aghakouchak, 2020). As one of the countries most affected by floods, China's flood-disaster losses accounted for almost 10% of the world's total in the period 1990–2017 (Kundzewicz *et al.*, 2019). China's urbanization rate will increase from 64.72% (in 2021) to 80% by mid-century (United Nations, 2019), which undoubtedly raises unprecedented challenges due to increased flood exposure of the population and property and an insufficient supply of essential infrastructure and services (Murillo, 2017). In the face of rapid social and economic transition, China must improve its flood risk management to reduce the losses caused by floods (White *et al.*, 2010; Tessler *et al.*, 2015).

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Under the impact of urbanization, the disaster-inducing mechanism of natural disasters has undergone major changes, including that the disaster inducing environment has been artificially improved or worsened, the disaster-inducing external forces have been artificially amplified or weakened, and the vulnerability of disaster carriers has become the main reason for the aggravation or alleviation of disaster. Traditional methods of flood management are no longer fit for purpose (Laeni *et al*. 2019; Wang *et al.*, 2021). Flood risk management is now shifting from primarily resistance and control (fighting with floods) to more integrated and adaptive approaches (living with floods) (Liao, 2012; Restemeyer *et al*. 2017; Laeni *et al*. 2019). Therefore, it is very important to understand how the socio-economic characteristics of the rapid urbanization process affect the disaster-inducing mechanism and thus the disaster loss, and to find out its law of spatial differentiation. Such research can provide reference for the preparation of emergency plans, and also help to deploy disaster prevention measures in advance and realize the transfer of disaster loss reduction to disaster risk reduction.

A large body of literature discusses the disaster-inducing mechanism of natural disasters, including the change of disaster-inducing factors (Tracy *et al.*, 2021; Veeravalli *et* *al*., 2022; Lyu *et al*., 2023), changes in the disaster-inducing environment (Ali *et al*., 2020; Kawyitri and Shekhar, 2020) and the change of resilience of urban carriers to flood disasters (Laeni *et al*., 2019; Laurien *et al*., 2020; Mehryar and Surminski, 2022). Some scholars point out that increasing complexities induced by urbanization should be taken into account when studying the mechanism of disaster (Asadzadeh *et al*., 2022). A series of changes brought about by urbanization are closely related to changes in disaster-inducing factors and environment. Rapid urbanization means the high concentration of a large number of population and economic activities in a certain region, the intensive construction of buildings and infrastructure, and the disorderly expansion of land, which not only bring great challenges to the original ecosystem, but also change the disaster-inducing environment and greatly increase the flood exposure of the region (Chen *et al*., 2015; Zhang *et al*., 2016; Cai *et al*., 2018).

On the other hand, urbanization can greatly promote regional economic development and capital accumulation, enabling the region to have sufficient manpower and funds to invest in the construction and operation of flood control infrastructure, thus forming a strong flood risk response ability and strengthening flood resilience (Huang *et al*., 2020; Zhou Qian and Liu Delin, 2020). However, few studies have analyzed the relationship between urbanization and disaster-inducing mechanism through practical cases. Some studies use comprehensive indicators, and it is difficult to capture the process of urbanization's effect on disaster-inducing mechanism. So, what changes brought about by urbanization are closely related to the disaster-causing mechanism, and thus affect the flood disaster loss? This question deserves further investigation.

In addition, current studies mainly examine the overall impact of urbanization on disaster-inducing mechanism, and few studies take into account the difference of flood inducing mechanism between urban areas and rural areas. In fact, the internal functional structure in a region is complex and the functions are closely connected, and the occurrence of disasters will have a subversive effect on the social structure and function in a region, resulting in extremely serious consequences in a large regional scope. The social and economic characteristics of different space within the region are different obviously. Urban and rural areas may face different flood disaster mechanism challenges than urban areas (Cox and Hamlen, 2015; Cutter et al., 2016). It is necessary to distinguish between urban area, town and rural area to empirically study the difference of flood disaster mechanism in different areas.

Taking the "7.20" Torrential Rain in Henan Province as a case, this paper investigates the relationship between urbanization and disaster-inducing mechanism, and the impact of various indicators on flood disaster loss. Firstly, this paper selects factors to characterize various dimensions of flood disaster-inducing mechanism, and confirms through empirical analysis which aspects of changes brought by urbanization process are closely related to disaster-inducing mechanism and flood disaster losses. This paper also attempts to explore the changes of disaster-inducing mechanism and the impact of urbanization on disaster loss in different spaces such as urban area, town and rural areas. The remainder of this paper is organized as follows. Section 2 describes the data and methods. Section 3 presents the results. Second 4 discusses the results and Section 5 is the conclusion.

2. Data and method

2.1. Study area

This paper focuses on the areas affected by the "7.20" Torrential Rain in Henan Province. From July 17 to 23, 2021, Henan Province suffered from a torrential rainfall rarely seen in history. The accumulated precipitation for the period was 589 mm in Hebi, 531 mm in Zhengzhou, and 512 mm in Xinxiang. The maximum hourly rainfall occurred in Zhengzhou from 16:00 to 17:00 on July 20, 2021, and was recorded by the Zhengzhou National Meteorological Station to be 201.9 mm, exceeding the highest value ever recorded by meteorological observation in mainland China. Heavy rainfall caused severe flooding in the north-central part of Henan Province. According to the assessment of the Ministry of Emergency Management, a total of 150 counties (county-level cities, districts) in Henan Province with a population of 14 786 000 people were affected, with direct economic losses reaching 120.06 billion yuan. A total of 398 people died or went missing due to the disaster.

The flood disaster loss data used in this paper includes 1709 sub-district offices and towns and townships in Henan. Our sample area consists of three categories: urban areas, towns, and rural areas. Urban areas refer to municipal sub-district offices; towns refer to established towns; rural areas refer to townships which have a lower level of urbanization than towns. Sub-district offices, towns, and townships belong to the same administrative level in China.

2.2. Models and variables

To measure the losses caused by flood disaster, we use three indicators: direct economic loss, affected population, and the number of collapsed or severely damaged buildings (C&D buildings). The data were obtained from the relevant disaster-management authorities.

Natural factors such as precipitation and topographic factors have a crucial influence on the flood-disaster risk of a region (Koks *et al*., 2015), so precipitation and slope were included as control variables in the model. The precipitation data were obtained from the National Meteorological Information Center and slope data derived from the SRTM DEM and SRTM DEM data was download from USGS.

Based on existing literatures, this paper measures factors affecting disaster-inducing mechanism from four dimensions, namely ecological environment factors, infrastructure factors, economic factors, and social environment factors (Cutter *et al*., 2016). In this paper, water area and green area are used to measure the possible effects of the ecological environment factors on flood-disaster losses (Moghadas *et al*., 2019). In terms of infrastructure factors, referring to Fedeski and Gwilliam (2007) and Jongman *et al*. (2012), this paper uses road density, drainage pipe length per capita, the ratio of brick-to-concrete houses, the ratio of houses built in 1980–1989 to the total number of houses, and the analogous ratios of bungalows and four- to six-story houses to measure how infrastructure facctors mitigates flood-disaster losses. In terms of economic factors, this paper focuses on GDP per capita and industrial structure, where the ratios of population in primary and secondary industries to the total industry population were considered (Zhou *et al*., 2014). In terms of social environment factors, we use the proportion of population aged 65 and over, the proportion of ethnic minority population, and the proportion of the population with a college degree or above, as Cutter *et al*. (2000, 2013). Additionally, the urbanization rate (i.e., the proportion of the population living in urban areas and towns to the total population) was controlled. Green space area and drainage pipe length per capita are at the city level, whereas the remaining data are at the district and county levels. Water area data are from the 2019 Third Land Survey, and data on green space area, drainage pipe length per capita, and GDP per capita are from 2020 Regional Statistical Yearbook. All other data are from the 2010 Sixth Population Census of China.

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The loss induced by flood disaster in Area i ($Loss_i$) is interpreted as a function of natural factors N_i, the ecological factors "$ecology_i$," infrastructural factors "$infra_i$," economic factors "$economy_i$," and social environment factors "$social_i$" with a random error term ε_i:

$$Loss_i = f\ (N_i, ecology_i, infra_i, economy_i, social_i, \varepsilon_i). \quad (1)$$

Based on Eq (1), the following linear regression model is used for least squares estimation to study how different dimensional factors affects economic loss and the affected population:

$$Loss_i = \beta_0 + \beta_1 N_i + \beta_2 econogy_i + \beta_3 infra_i + \beta_4 economy_i + \beta_4 economy_i + \varepsilon_i. \quad (2)$$

All data are standardized in the model. Additionally, we follow Kellenberg and Mobarak (2008) and use a negative binomial regression model to study the effects of resilience on C&D buildings, because the total number of C&D buildings is a non-negative integer and the variance in the data is significantly greater than the mean. Table A.1 shows the descriptive statistics of the variables used herein with each variable, and Table A.2 shows the correlation between the main variables.

3. Results

3.1. Geographic distribution of loss caused by "7.20" Torrential Rain in Henan

As shown in Figures 1, the areas with high direct economic loss and numerous C&D buildings are mainly in the north-central part of Henan, especially in the whole area of Hebi City, the western part of Zhengzhou, and the western part of Xinxiang. The top three sub-district offices or towns or townships in terms of direct economic loss and C&D buildings are all in Jun County, Hebi City. Xiaohe Town suffered the highest direct economic loss of 5.5 billion yuan, and Wangzhuang Town had the highest number of C&D buildings (24 320). In addition, the affected population is more dispersed, with Anyang, Hebi, Xinxiang, Zhengzhou, Kaifeng, and Zhoukou all with a significant portion of sub-district offices, towns, and townships with an affected population of over 30 000. Xinzhen Town in Jun County of Hebi City has the largest affected population of 93 000 people.

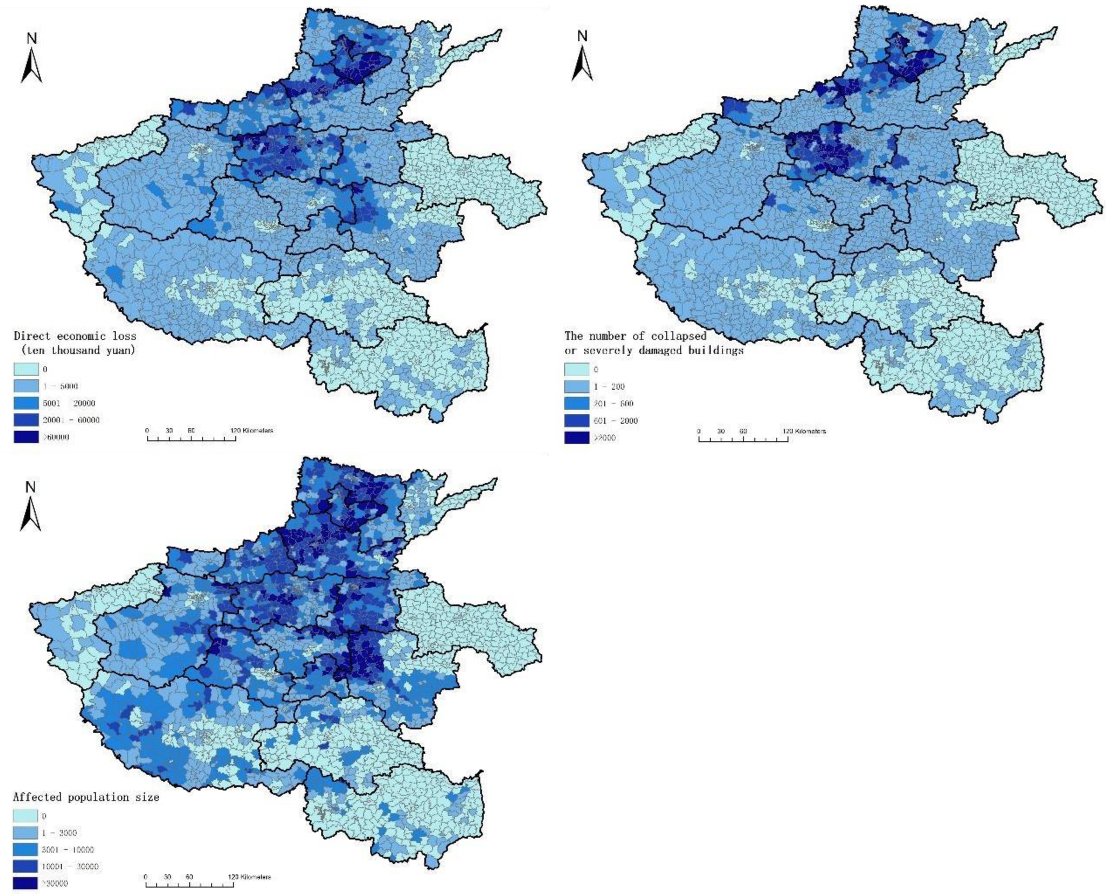

Fig. 1. Spatial distribution of disaster losses caused by "7.20" Torrential Rain in Henan.

3.2. Effect of flood resilience on flood-disaster losses

Table 1 shows how natural factors and the environment factors and infrastructure factors affect flood-disaster losses. In terms of natural factors, the coefficient of precipitation is significantly positive in all models, which indicates that more precipitation correlates with severer disasters. Economic loss and affected population decrease significantly with increasing slope. For ecological environment factors, an increase in water area significantly reduces flood-disaster losses. Additionally, an increase in green space increases regional economic loss and C&D buildings.

For infrastructure factors, the regression results show that the coefficients for road density are significantly negative in columns (1), (2), (5), and (6), indicating that areas with high road density have small direct economic loss and relatively few collapsed or severely damaged buildings. The results also show that more drainage pipe per capita reduces the population affected by flood disasters. An increase in the proportion of brick-concrete structures increases C&D buildings. The proportion of houses built between 1980 and 1989 correlates positively with all disaster losses indicators. An increase in the proportion of bungalows or a decrease in the proportion of four- to six-floor buildings reduces significantly the direct economic loss and C&D buildings.

Table 1 Effects of ecological environment and infrastructure factors on flood-disaster losses.

Ecological factors.

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	(6)
	OLS	**OLS**	**OLS**	**OLS**	**NB**	NB
	ecoloss	ecoloss	population	population	collapsed	collapsed
rain	0.229^{***}	0.213^{***}	0.412^{***}	0.402***	0.984^{***}	1.116^{***}
	(0.0441)	(0.0450)	(0.0317)	(0.0305)	(0.163)	(0.178)
slope	-0.0746^{***}	-0.0643^{**}	-0.197^{***}	−0.195***	0.155	0.162
	(0.0261)	(0.0252)	(0.0236)	(0.0246)	(0.156)	(0.130)
water_area		-0.0978^{***}		−0.0836***		-2.033^{***}
		(0.0144)		(0.0143)		(0.303)
green_area		0.0932^{***}		0.0552		0.449^{***}
		(0.0263)		(0.0684)		(0.0948)
_cons	1.01×10^{-9}	2.16×10^{-9}	-3.00×10^{-10}	-7.03×10^{-10}	5.039^{***}	4.182^{***}
	(0.0236)	(0.0234)	(0.0222)	(0.0220)	(0.162)	(0.187)
N	1709	1709	1709	1709	1709	1709
R^2	0.048	0.067	0.161	0.171		

Infrastructure factors

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	(6)
	OLS	**OLS**	**OLS**	**OLS**	**NB**	NB
	ecoloss	ecoloss	population	population	collapsed	collapsed
road_density	-0.0208^{***}	-0.0202^{***}	0.0195	0.0210	-0.172^{***}	-0.140^{***}
	(0.00487)	(0.00526)	(0.0157)	(0.0159)	(0.0352)	(0.0411)
drainage_per	0.0260	0.0276	-0.0442^{***}	-0.0419^{**}	0.0273	0.141
	(0.0246)	(0.0255)	(0.0161)	(0.0173)	(0.222)	(0.217)
structure	−0.0252	−0.00315	0.000114	−0.00348	0.290^{**}	0.580^{***}
	(0.0187)	(0.0162)	(0.0227)	(0.0208)	(0.124)	(0.117)
year	0.0772^{***}	0.0587^{***}	0.113^{***}	0.117^{***}	0.640^{***}	0.326^{***}
	(0.0222)	(0.0218)	(0.0242)	(0.0234)	(0.134)	(0.115)
floorA	-0.106^{***}		0.0267		-0.838^{***}	
	(0.0235)		(0.0249)		(0.153)	
floorB		0.0816^{***}		−0.0293		0.372^{**}
		(0.0274)		(0.0260)		(0.156)
_cons	1.38×10^{-9}	1.08×10^{-9}	-5.10×10^{-11}	5.11×10^{-11}	4.007^{***}	4.089^{***}
	(0.0234)	(0.0234)	(0.0219)	(0.0219)	(0.135)	(0.141)
natural factor	yes	yes	yes	yes	yes	yes
N	1709	1709	1709	1709	1709	1709
R^2	0.071	0.069	0.184	0.184		

Standard errors in parentheses * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$; the dependent variables are, in order: (1), (2), (7), (8) direct economic loss; (3), (4) , (9), (10) affected population; (5), (6) , (11), (12) C&D buildings. Natural factors are controlled.

Table 2 shows how the factors that measure economic factors and social environment factors affect loss caused by flood disasters. For economic factors, the results show that a larger GDP per capita correlates with a greater number of C&D buildings. And regions with a lower proportion of primary industries and a higher proportion of secondary industries suffered greater economic loss and had more C&D buildings.

For social environment factors, the results show that the coefficients for the proportion of people aged 65 and over are significantly negative in columns (1)-(6), indicating that a larger proportion of people aged 65 and over correlates with smaller disaster losses. Similarly, increasing the proportion of ethnic minority population in the region reduces flood-disaster losses. Additionally, the coefficients of the proportion of the population with the highest education at the college level and above are not significant, which indicates that the education level does not significantly affect flood-disaster losses in Henan.

Table 2. Effects of economic and social environment factors on flood-disaster losses

	Economic factors					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	NB	NB
	ecoloss	ecoloss	population	population	collapsed	collapsed
GDP_per	0.0243	0.0297	−0.0372	−0.0547**	0.547***	0.518***
	(0.0336)	(0.0297)	(0.0296)	(0.0258)	(0.133)	(0.116)
first	−0.0927***		0.0185		−0.522***	
	(0.0309)		(0.0288)		(0.181)	
second		0.104***		0.0211		0.706***
		(0.0296)		(0.0264)		(0.132)
_cons	1.30×10^{-9}	1.29×10^{-9}	-1.45×10^{-10}	-9.87×10^{-11}	4.055***	3.949***
	(0.0234)	(0.0233)	(0.0221)	(0.0221)	(0.152)	(0.134)
natural factor	yes	yes	yes	yes	yes	yes
N	1709	1709	1709	1709	1709	1709
R^2	0.069	0.071	0.171	0.171		

	Social environment factors					
	(1)	(2)	(3)	(4)	(5)	(6)
	OLS	OLS	OLS	OLS	NB	NB
	ecoloss	ecoloss	population	population	collapsed	collapsed
more65	−0.114***	−0.113***	−0.0977***	−0.104***	−0.712***	−0.747***
	(0.0272)	(0.0305)	(0.0220)	(0.0232)	(0.114)	(0.104)
minor	−0.0590***	−0.0597***	−0.0342**	−0.0311**	−0.333***	−0.295***
	(0.0135)	(0.0136)	(0.0155)	(0.0155)	(0.0918)	(0.101)
edupercent		0.00987		−0.0438		−0.249
		(0.0353)		(0.0311)		(0.172)

_cons	$1.64e\times10^{-9}$	1.63×10^{-9}	2.63×10^{-10}	2.72×10^{-10}	3.590^{***}	3.575^{***}
	(0.0232)	(0.0232)	(0.0218)	(0.0218)	(0.114)	(0.106)
natural factor	yes	yes	yes	yes	yes	yes
N	1709	1709	1709	1709	1709	1709
R^2	0.088	0.088	0.193	0.194		

Standard errors in parentheses * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$; the dependent variables are, in order: (1), (2), (7), (8) direct economic loss; (3), (4) , (9), (10) affected population; (5), (6) , (11), (12) C&D buildings. Natural factors are controlled.

3.3. Regional heterogeneous effects of flood resilience on flood-disaster losses

Figure 2 shows that the percentage of each disaster-loss indicator for towns is significantly greater than the corresponding indicator for urban and rural areas. The percentage of affected population and of C&D buildings in towns are both greater than the percentage of total population and of the total number of houses respectively. In contrast, the percentage of affected population and of C&D buildings in urban and rural areas are both smaller than the percentages of their total population and of the total number of houses respectively. The analysis shows that the disaster losses in towns is the most severe.

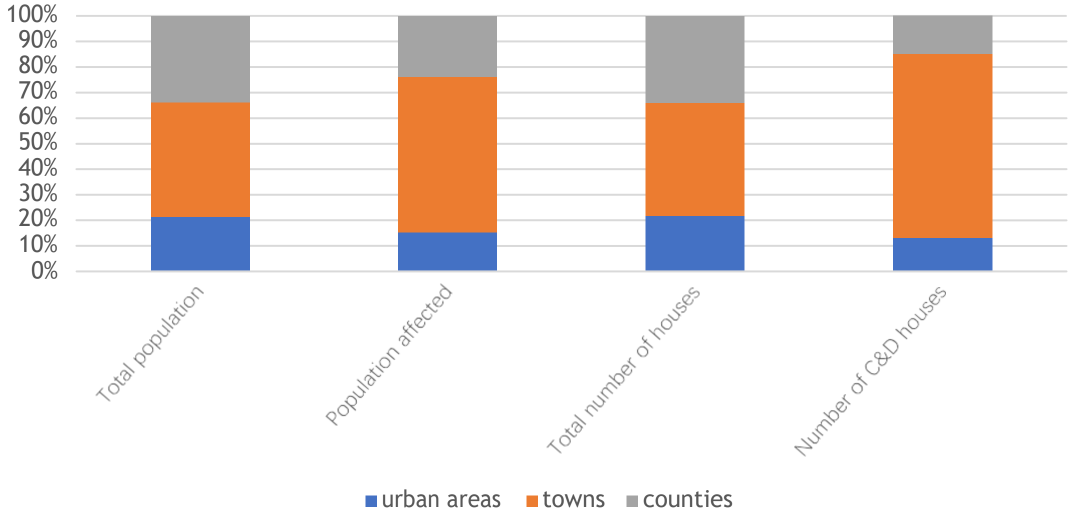

Fig. 2. Disaster losses in urban areas, towns, and rural areas.

Table 3 shows the regression results of the disaster-inducing factors for C&D buildings in urban areas, towns, and rural areas. How the factors affect C&D buildings in the three types of areas differ mainly in the coefficient of drainage pipe length per capita being significantly negative in columns (1) and (4), and the coefficient of GDP per capita being significantly positive in columns (1), (4), and (5). These results indicate that increasing the drainage pipe per capita in a city lowers C&D buildings in its urban areas. In addition, increasing the GDP per capita in a district or county increases C&D buildings in its urban areas and towns.

For industrial structure, the results show that a greater proportion of primary industry, lower proportion of secondary industry in a district or county correlate with fewer C&D buildings in its towns and rural areas. Additionally, a higher urbanization rate in a district or county corresponds with a greater number of C&D buildings in its rural areas.

Table 3. Effects of flood factors on C&D buildings: different areas

	(1)	(2)	(3)	(4)	(5)	(6)

	urban area	towns	rural area	urban area	towns	rural area
rain	1.415^{***}	1.439^{***}	1.234^{***}	1.462^{***}	1.450^{***}	1.292^{***}
	(0.374)	(0.155)	(0.206)	(0.367)	(0.171)	(0.200)
slope	0.493^{***}	-0.341^{***}	0.0821	0.400^{**}	−0.206	0.132
	(0.173)	(0.132)	(0.192)	(0.184)	(0.154)	(0.187)
water_area	-3.264^{***}	-1.219^{***}	-1.100^{***}	-3.112^{***}	-1.347^{***}	-1.162^{***}
	(0.456)	(0.275)	(0.271)	(0.394)	(0.351)	(0.282)
green_area	0.422^{***}	0.673^{***}	0.769^{**}	0.349^{***}	0.640^{***}	0.935^{***}
	(0.121)	(0.225)	(0.319)	(0.113)	(0.238)	(0.276)
drainage_per	-0.602^{***}	0.102	−0.392	-0.617^{***}	0.349	−0.360
	(0.130)	(0.342)	(0.349)	(0.127)	(0.390)	(0.312)
GDP_per	0.519^{***}	0.176	0.690	0.574^{***}	0.408^{**}	0.0984
	(0.124)	(0.162)	(0.457)	(0.134)	(0.188)	(0.505)
first	0.362	-0.933^{***}	-0.848^{***}			
	(0.245)	(0.203)	(0.313)			
urban				−0.285	0.259	1.188^{***}
				(0.238)	(0.288)	(0.433)
more65	−0.00448	-0.641^{***}	-0.728^{**}	0.0349	-0.612^{***}	−0.441
	(0.123)	(0.152)	(0.291)	(0.124)	(0.160)	(0.316)
minor	-0.394^{***}	-0.901^{***}	-1.295^{***}	-0.397^{***}	-0.986^{***}	-1.512^{***}
	(0.0824)	(0.179)	(0.310)	(0.0857)	(0.196)	(0.279)
_cons	3.908^{***}	3.790^{***}	3.761^{***}	3.932^{***}	3.710^{***}	3.688^{***}
	(0.289)	(0.162)	(0.259)	(0.283)	(0.184)	(0.228)
N	512	794	403	512	794	403

Standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The dependent variable is C&D buildings.

4. Discussion

4.1. Influencing flood-inducing factors in the urbanization process

An increase in GDP per capita and a shift in industrial structure from primary industry to secondary industry increases flood-disaster losses, which is consistent with the results of previous studies. As suggested by Kundzewicz *et al*. (2014) and Winsemius *et al*.

(2016), the concentration of population and assets created by urbanization increases exposure to flood disasters, thus increasing flood-disaster losses.

The increased road density and drainage pipe length per capita reduce the flood-disaster losses. The installation of drainage pipes reduces surface runoff and rainwater accumulation, and the increase in road density allows the areas to respond more quickly and effectively to flood disasters (Li *et al.*, 2021). So urbanization can reduce disaster losses through infrastructure construction.

The proportion of houses built in 1980–1989 correlates positively with disaster losses. This is possibly because there was an upsurge of rapid construction, especially in the suburbs in the early stage of Reforms and Opening up policy. At that time, construction technology is not mature enough, and numerous relatively low-quality brick and concrete houses were built in the suburbs (Fang, 2009). This leads to an increase of risks and the vulnerability to flood disasters.

Direct economic losses and C&D buildings were less in areas with a large proportion of bungalows and greater in areas with a large proportion of four- to six-story houses. The original data reveal that the high proportion of bungalows is mostly in remote counties that are not densely populated, such as Linzhou, Neihuang, and Hua counties in Anyang City, where urbanization level is lower and flood resilience is less affected. The flood-disaster damage to these areas is thus relatively small. Areas with many 4–6 floor houses and few bungalows are mostly suburban districts or counties around the main urban area, such as Yindu District, Longan District, Anyang County, and Tangyin County in Anyang City. These areas are often undergoing rapid urbanization and have a relatively dense population, with mostly brick and concrete buildings and poor public facilities. The vulnerability to flood disaster thus increases, resulting in significant flood-disaster losses in these areas.

Larger water areas reduce flood-disaster losses because rivers, lakes, and reservoirs play a positive role in buffering and regulating flood waters. Larger areas of green space correlate with greater economic loss and more C&D buildings. There are often more green spaces in urban areas and construction land there has taken over the original natural river, pond, rice field, or other wetlands, thereby reducing rainwater storage (Li *et al.*, 2013). The constructed green space does not replace the role of the original ecosystem in flood control and drainage, so an increase in green space increases the disaster vulnerability of the area, resulting in increased flood-disaster losses.

A higher ratio of population aged 65 and over correlates with a reduced flood-disaster losses. Older people have more time to volunteer to help others in the community (Wiles and Jayasinha, 2012) and have greater experience in hardships that can serve well for resilience (VanDen *et al.*, 2014). The presence of older people allows people to take more effective measures to cope with disaster, enhancing their adaptability in the face of disaster.

Higher proportion of ethnic minority population in a region reduces flood-disaster losses. There are 957 000 people of Hui nationality in Henan, accounting for 84.8% of its total minority population (2010). The unique architecture of houses of Hui nationality is strong and thus they better resist flood disasters. Additionally, Hui is generally Islamic, and their religious beliefs can be a source of psychological strength, which may help enhance community cohesion (Aten *et al.*, 2010) and increase the adaptability of people in the face of disaster, thus reducing flood-disaster losses.

In contrast with the conclusion by Zhou *et al.* (2014), the level of education is not a key factor in determining flood-disaster losses in this study. This may be because Henan has many droughts and few floods (Zhao, 2021), so the people generally lack experience in coping with flood disasters. A higher level of education does not necessarily give people the requisite experience in coping with flood disasters. This contrasts with the coastal areas of China where people regularly experience typhoon-induced flood disasters, so well-educated people there can find more effective measures to reduce the disaster losses (Shen *et al.*, 2020).

It can be seen that urbanization affects the disaster-inducing mechanism in various dimensions and ways. While enhancing resilience through infrastructure construction, it will also increase disaster losses by increasing economic exposure and vulnerability in the process of urbanization. Of course, increased adaptability in social life can also help mitigate disaster losses.

4.2. Regional differences in the impact of disaster-inducing mechanism on flood disaster losses

With a high degree of urbanization and a high concentration of population and economic assets, urban areas have the highest exposure to disaster, thereby increasing the risk of disaster (Huang *et al*., 2020b). Urban areas also have more resources to support the construction of infrastructure and the provision of basic public services, which significantly increase the resilience of urban areas to flood disasters. The redundancy of key infrastructure is very important in flood-risk management: once a system is damaged, a backup infrastructure system is often available to meet the emergency needs when disaster strikes. Therefore, although the exposure of urban areas is the greatest, well-developed infrastructure and public service systems often have sufficient capacity to accommodate the population (both initial and migrant) and withstand the flood impact in urban areas, thereby reducing the severity of flood disasters. These results seem consistent to the existing literatures.

The disaster losses of towns are severer than that of urban and rural areas; the higher level of non-agriculturalization in a district or county, the more disaster losses in its towns. The infrastructure and public service systems of towns are often unable to adapt to the rapid urbanization process. In the process of rapid urbanization, towns have more concentrated population and assets than rural areas while the infrastructure and public service systems of towns are significantly weaker than those of urban areas, and the redundancy of key infrastructure is also significantly less than in urban areas.

In addition, the level of planning and management of towns does not match their urbanization process. In many regions, traditional planning efforts focus on the spatial use of land in urban areas, and the overall planning “emphasizes urban areas, but not towns and townships,” so the land management and building regulations in towns are relatively confusing and less stable (Jiang & Qiu, 2012). This is often responsible for forcing the migrant population of towns to live in substandard housing, which, when combined with a lack of effective management when floods occur, increases the vulnerability to flood disasters. Thus the infrastructure, public service systems, and the level of planning and management of towns are not able to adapt to the concentration of population and assets caused by the non-agricultural transformation of population and industry, and the exposure of towns to flood is greater than that of rural areas, and its resistance to flood is weaker than that of urban areas. Therefore, when faced with flood disasters, the flood-disaster losses in towns are maximized.

In the “7.20” flood disaster, rural areas in Henan were relatively less affected compared with towns. As reported by Cutter *et al* (2016), rural areas are the most connected to natural systems and have a lower concentration of population and resources, which makes the natural resilience of rural areas much stronger. Meanwhile, compared with urban areas, the clan culture in rural areas in China generates a strong network of social relations in rural areas. Residents are more prepared for hazards, and their participation in community and neighborhoods enhances cohesion between people, so their adaptability to disasters is heightened (Kerstholt *et al*., 2017).

Notably, in counties with higher urbanization rates, the rural areas are more severely affected. This may be because the non-agricultural transformation of population and industry caused by urbanization has removed numerous young and strong laborers from the rural areas (a phenomenon called “rural population hollowing”) (Chen & Chen, 2017). This prevents rural areas from taking timely preventive measures against disaster, such as the improvement of aging houses, thus the vulnerability of the houses increases when disaster comes, thereby increasing the flood-disaster losses.

5. Conclusions

this paper analyzes the relationship between changes brought by urbanization process and flood disaster-inducing mechanism through practical cases, as well as its impact on flood disaster loss, providing support for theories of urbanization and flood disaster-inducing mechanism. The urbanization process is closely related to ecological, infrastructural, economic and social dimensions, thus affecting regional flood losses. Through detailed analysis of various dimensions of flood disaster factors, we found that in addition to natural factors, social and economic factors under the influence of urbanization played a very important role in the disaster-inducing mechanism.

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The disaster-inducing mechanism in urban areas, towns, and rural areas varies significantly, suggesting that efforts to improve flood risk management must be customized to the local context (e.g., considering the unique differences between different administrative units). The infrastructure and public service systems of towns are much less developed than those of urban areas, and the level of planning and management in towns is poor in comparison with urban areas, leaving towns with high exposure to flood disasters and a low resistance against flood disasters, giving towns the highest disaster risk in the event of a flood disaster. In the current urban planning process in China, towns are often the most neglected units (except for the towns where the county administrative center is located), and there is an urgent need for targeted regional planning and flood risk management.

This paper examines only one case of flood disaster caused by a historically rare extreme heavy rainfall in Henan Province, China, which may lead to some limitations in the results of this paper. The relationship between urbanization and disaster-inducing mechanism may be different in different geographical regions and in the face of different magnitudes of floods. In the future, more flood case studies may be needed to verify the results of this paper.

Appendix A.1

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Generally, appendix tables (outside the manuscript) are placed after the reference section.

Table A.1. Descriptive Statistics

Variable		Mean	Std. Dev.	Max	Min
	Dependent variables				
ecoloss	direct economic loss (Ten thousand yuan)	7025.161	22835.501	553013.1	0
population	affected population size	8314.163	12220.966	93000	0
collapsed	The number of collapsed or severely damaged buildings (C&D buildings)	278.511	1362.357	24320	0
	Natural controls				
rain	precipitation (mm)	320.846	201.458	765.903	14.521
slope	slope	0.949	1.234	4.928	0.011
ecological environment factors					
water_area	water area (km^2)	54.780	73.738	538.096	0.388
green_area	reclaimed green space (km^2)	101.475	90.365	333.62	24.29
infrastructure factors					
road_density	road density (km per km^2)	0.222	0.413	6.053	0.072
drainage_per	drainage pipe length per capita (m)	4.000	4.127	43.119	0.421

structure	Proportion of brick-concrete structure buildings	0.547	0.171	0.884	0.115
year	Proportion of houses built from 1980 to 1989	0.204	0.046	0.351	0.101
floorA	Proportion of bungalow	0.599	0.240	0.946	0.020
floorB	Proportion of four to six storey houses	0.129	0.161	0.631	0.006
economic factors					
GDP_per	GDP per capita (Ten thousand yuan)	6.036	3.539	26.815	1.203
first	Proportion of primary industry population in industry population	0.609	0.249	0.904	0.010
second	Proportion of secondary industry population in industry population	0.175	0.108	0.490	0.032
social environment factors					
more65	Proportion of population aged 65 and over	0.082	0.012	0.116	0.052
minor	Minority population ratio	0.012	0.014	0.134	0.001
edupercent	Proportion of population with a college degree or above	0.068	0.076	0.399	0.014

Appendix A.2

Table A.2. Pairwise correlations

	rain	slope	water_area	green_area	road_density	drainage_per	structure
rain	1						
slope	0.295	1					
water_area	−0.0326	0.113	1				
green_area	0.110	0.0597	−0.0654	1			
road_density	−0.0930	−0.107	−0.142	0.0409	1		
drainage_per	0.0142	0.136	−0.204	0.418	0.134	1	
structure	0.158	0.198	−0.106	0.354	0.0128	0.201	1
year	0.205	0.182	−0.127	−0.160	−0.0282	0.183	−0.0767
floorA	0.175	0.148	0.180	−0.381	−0.236	−0.300	−0.410
GDP per	−0.0145	−0.00580	−0.210	0.528	0.127	0.475	0.312
first	0.154	0.0485	0.349	−0.380	−0.267	−0.418	−0.355
more65	−0.140	−0.134	0.167	−0.274	0.101	−0.101	0.00530
minor	−0.154	−0.0295	−0.0694	0.144	0.214	0.183	0.105
edupercent	−0.190	−0.131	−0.223	0.471	0.293	0.281	0.241

	year	floorA	GDP per	first	more65	minor	edupercent
year	1						
floorA	0.266	1					
GDP per	−0.0723	−0.558	1				

first	0.0108	0.802	−0.556	1			
more65	0.0968	0.202	−0.266	0.223	1		
minor	−0.0686	−0.326	0.130	−0.287	0.138	1	
edupercent	−0.189	−0.769	0.564	−0.779	−0.312	0.282	1

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The list of references cited is good. However, it is necessary to expand and include other publications that are related to the discussion. I suggest adding several other scientific works related to this study.

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