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The Economic Impact of Water Vulnerability on Corporate Sustainability: A Perspective of Corporate Capital Cost

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Abstract: Studies have argued that water risk affects corporate sustainability, but few of them have fully explored whether or not and how water resources have a direct impact on corporate finance and strategy. This study takes the listed companies in the Chinese A-share market from 2019 to 2023 as a sample to understand the threat of water vulnerability to corporate sustainability from the perspective of capital cost. This study argues that water vulnerability positively relates to corporate capital cost by increasing corporate financing constraints. Meanwhile, this study also examines the role of water regulation and water investment in the relationship between water vulnerability and corporate capital cost. Water regulation brings legitimate pressure to corporations and increases the transformation risks faced by them, so it has a positive moderating effect. Water investment can alleviate the vulnerability of local water resources and reduce the physical water risk faced by corporations, so it has a negative moderating effect. The study finds that the two measures mainly play a significant moderating effect on the cost of debt. In addition, the study finds that the positive relationship between water vulnerability and capital cost has industrial and firm-level heterogeneity, while the moderating effect of government water governance has only industrial heterogeneity.

Keywords: water vulnerability; water governance; capital cost; water regulation; water investment; water risk; cost of debts; cost of equity; SOEs; water-intensive industry

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1. Introduction

Water sustainability is central to several of the United Nations' sustainable development objectives. The World Meteorological Organization's report reveals that, currently, 3.6 billion individuals experience insufficient water supply for a minimum of one month per year. This number is projected to exceed 5 billion by 2050, primarily due to the combined effects of climate change and population growth (World Meteorological Organization, 2022) [1]. The water crisis has risen to become the third-greatest worldwide concern, making it one of the top risks that businesses must address (World Economic Forum, 2017) [2].

Research has demonstrated that businesses are confronted with multiple water-related risks, including physical, reputational, and regulatory risks, simultaneously (Jones et al., 2015; Tello, 2013) [3,4]. These risks have substantial consequences for business growth when companies acknowledge and address them (Zhu et al., 2024; Afrin et al., 2022; Liu et al., 2024) [5–7]. However, many academics primarily concentrate on transformational water risks. They examine the influence of social factors using institutional theory or stakeholder theory. Unfortunately, they overlook the straightforward consequences of water conditions on corporate sustainability, which are highlighted in studies by Dias et al. (2022), George et al. (2015), Tashman (2021), and Tashman & Rivera (2016) [8–11]. Water vulnerability refers to the condition of a water resource system that is susceptible to disturbances caused by both human activities and natural changes and indicates the level of difficulty in restoring the system to its original state after a disturbance occurs (Xia J. et al., 2012) [12]. This concept is also employed as a measure of physical water risk

(Zheng et al., 2022; Gui et al., 2021) [13,14]. Therefore, what is the precise influence of water vulnerability on businesses? What is the cause-and-effect relationship of this impact? How can businesses respond to these risks? These concerns are now being examined at the theoretical level, but there is limited empirical study being conducted at the practical level (Burritt et al., 2016; Ortas et al., 2019; Sojamo & Rudebeck, 2024) [15–17].

Government-led water governance is considered essential for addressing water-related challenges and preventing the Tragedy of the Commons. However, the bulk of research conducted so far has focused on regulatory tools, neglecting the diverse impacts of other governance mechanisms (Li & Yuan, 2021; Ban & Liu, 2021; Ma & Hou, 2020) [18–20]. Excessive emphasis on environmental regulation in research leads governments to impose more stringent regulations and fails to take into account the full range of environmental governance tools used by governments. Although stringent environmental rules are helpful in attaining regulatory goals, they have the potential to generate unanticipated negative consequences on the production and operation of enterprises if the burden becomes severe. Because of this, businesses may have a more difficult time successfully adapting to the external institutional environment in terms of sustainable growth. Consequently, there may be a dearth of effective methods at the micro-level to guarantee the long-term sustainability of water resources. (Cui & Jiang, 2019) [21].

By investigating the relationship between water vulnerability and corporate capital costs and testing the roles of the two kinds of water governance tools in the relationships, this study attempt to find evidence that water conditions and related government-led water governance are of vital importance to corporate sustainability because they could bring harmful influence on corporate financing activities. Based on the research above, it is possible to divide the contributions made by this research into two factors. The first thing to note is that water condition is proven to be one of the most important factors influencing corporate sustainability, which not only compensates for the neglect of natural environmental variability in current corporate management research but also expands the study of micro consequences of water vulnerability. Secondly, this study provides evidence that the various approaches used by the government for the purpose of environmental governance have distinct effects, therefore adding to the existing knowledge of environmental governance, concentrating only on regulatory measures.

2. Literature Review

2.1. The Socio-Economic Impact of Water Vulnerability

Current research on water vulnerability mainly focuses on the evaluation and the causes of water vulnerability, but some studies have expanded to areas such as adaptive management of water resources, water resource policy evaluation, and the socio-economic impact of water vulnerability (Yuan & Zheng, 2022) [22].

In the study of the socio-economic impact of water vulnerability, Jenkins et al. (2021) calculated that water vulnerability could bring a GBP 1.4 billion direct economic loss to the United Kingdom [23]. This economic loss comes not only from the direct impact of insufficient input of water resources as a production factor but also from the ripple effect generated by the linkage between water resources and other fields. Kim and Kaluarachchi (2016) found that, as the main representations of water vulnerability, water scarcity and salinization can result in smaller variable profits for land and thus reduce water productivity [24]. Wang et al. suggest that water resource issues in a region may inhibit the development of a low-carbon economy, as there is a strong correlation between water resource availability and low-carbon economic growth [25]. Furthermore, research has shown that trade is also an important pathway for water scarcity to spread from local to global levels. Yi et al. verified through data that local water scarcity can not only lead to economic losses in local or neighboring areas but also have remote effects on geographically distant regions through national supply chains [26]. Zhao et al. also found that, through trade, the chemical industry in Zhejiang, Jiangsu, and Shandong; the communication equipment, computer, and other electronic equipment industry in Jiangsu and Guangdong; and the food processing and tobacco industry in Shandong are easily affected by water scarcity in other provinces [27]. Other related economic loss calculated by researchers includes the loss of human life and medical costs caused by water pollution. Ugochukwu et al. (2022) reported that water pollution in Enyimagalagu and Mkpuma Akpatakpa communities in Ebonyi State, Nigeria, caused economic losses ranging from USD 20.7 million to USD 543.3 million in estimated lifespan, and medical expenses ranging from USD 1.41 million to USD 3.72 million [28]. Temkin et al. (2019) also calculated that nitrite pollution in water causes an economic cost equivalent to USD 250 million to USD 1.5 billion annually in cancer healthcare burden in the United States, as well as a potential impact of USD 1.3 to USD 6.5 billion due to productivity losses [29]. Furthermore, Gleick (2014) discovered that water vulnerability affected economic development and then brought social instability in Syria [30]. Schilling et al. (2020) also confirmed that social conflicts arose with the deterioration of water conditions because public's water needs cannot be met under water vulnerability [31].

Economic development and social stability are an important basis for corporate sustainability, and the harmful impacts of water vulnerability on economic growth and social stability mean that it is also a major hidden danger for corporate development. Some scholars have thus further presented that water vulnerability becomes a physical risk that affects business sustainability (e.g., Bonnafous et al., 2017; Muthulingam et al., 2022; Northey et al., 2019) [32–34]. Zheng. et al. (2022) proved that water vulnerability has a significantly direct negative influence on the ROA of enterprises [13]. Liu et al. (2024) opined that water risk affects operational and financial uncertainty and corporate legitimacy [7].

2.2. Environmental Factors Affecting Corporate Capital Costs

The factors affecting corporate capital costs can be categorized into technological factors, organizational factors, and environmental factors. Technological factors refer to the methods and assumptions used to estimate corporate capital costs (Jagannathan et al., 2017) [35] and to the new technologies used to alleviate corporate financial constrains, such as fintech (Lyu et al., 2023) [36]. Organizational factors refer to accounting factors such as profitability and capital structure (Jagannathan et al., 2017) [35], as well as factors such as corporate governance and strategy (Benlemlih, 2017) [37]. Environmental factors contain market-related, institutional-related and biophysical-related factors (e.g., Sassi et al., 2019; Li et al., 2024; Daouk et al., 2006) [38–40]. Among these three types of factor, although organizational factors are the ones most concerned by scholars, environmental factors have also received relatively high attention.

In the studies of environmental factors, Sassi et al. (2019) found that intensified product market competition results in lower equity financing costs [38], and Amairi et al. (2022) investigated the relationship between market competition and equity financing and found it to be a U-shape [41]. Apart from market competition, Hillier & Loncan (2019) and Li et al. (2024) respectively verified that stock market integration and stock market liberalization could reduce financing costs [39,42], and Vega-Gutierrez et al. (2021) found that labor market conditions are also another important factor [43]. Among institutional-related factors, economic policy uncertainty (Xie & Lin, 2023) [44]; government macroeconomic management tools such as monetary policy, tax, and security laws (Sheng et al., 2017; Lendvai et al., 2013; Daouk et al., 2006) [40,45,46]; and customer satisfaction (Truong et al., 2021) [47] have also been found to be influencing factors.

With the increasing attention from accounting and management academia on the deterioration of the natural environment, the relationship between biophysical environment and corporate capital costs also begins to grow, but it is still at the initial stage. At present, scholars mainly explore the impact of climate change on capital costs. Kling et al. (2021), Huang et al. (2018), and Yildiz & Temiz (2024) verified that climate change does harm corporate financing [48–50], while the study from Du et al. (2023) denied there was a significant relationship between climate change and the cost of equity [51]. Other biophysical environments receive scattered attention. Liu (2016) and Tan et al. (2022) found that the cost of debts increases with the increase of air pollution [52,53]. As far as we know, only Nguyen et al. (2022) found that drought has negative effects on both leverage and the speed of leverage adjustment to enterprises [54], offering undirected evidence regarding the relationships between water conditions and the cost of capital.

2.3. Government Water Governance

In Section 2.1, we briefly review the negative socio-economic impacts of water vulnerability. To mitigate these negative impacts, researchers have proposed adaptive water resource management strategies, although some public management studies do not encourage top-down authoritative water regulation as they believe that mandatory and centralized water management policies may lead to conflicts between private actors (Heikkila, 2017; Harley et al., 2014) [55,56]. However, many countries, such as China and Israel, still believe that the government is the most important governing body in addressing water resource issues.

The government usually adopts various policy tools for water resource adaptive management. Firstly, the government adopts commend-and-control measures to strongly constrain the behavior of various subjects to improve water conditions. For example, the government directly allocates the amount of available water resources through administrative means, such as water intake permits (Li, et al., 2019) [57], and implements the Water Pollution Prevention and Control Action Plan to directly constrain industrial pollution discharge (Lu et al., 2022) [58]. In addition, the government also adopts market-incentive mechanisms such as water rights and discharge right, water pricing and water tax, ecological compensation, and so on, which can induce the economic interests of water users to achieve the goals of alleviating water scarcity and restoring the water ecological environment from a micro perspective. These regulation tools have been widely proven to alleviate water resource scarcity and degradation, promote industrial structure adjustment and economic development, and enhance the green transformation of enterprises (Li et al., 2019; Lin, X.C., et al., 2022; Luckmann et al., 2016; Zhou et al., 2021) [57,59–61].

Apart from regulation, the government will adopt various infrastructure investments to alleviate the scarcity problem of the uneven spatial and temporal distribution of water resources, repair damaged water ecological environments, and increase the region's ability to respond to water and drought disasters (Li, et al., 2020; Adeniran et al., 2021) [62,63]. For example, the Chinese government's investment in the construction of the South to North Water Diversion Project has alleviated the water resource problems in the Beijing Tianjin Hebei region (Long, et al., 2020) [64]. Meehan (2014) also showed that the advantages of these investments in water infrastructure will not only restore water conditions but could also help in maintaining social stability and consolidate political power in return [65].

2.4. Review

The literature review above shows that extensive research on water vulnerability, corporate capital costs, and government water governance has produced valuable results. However, research gaps and opportunities remain. Firstly, although the socio-economic impact of water vulnerability has received some attention, it focuses mainly on the macro impacts and lacks micro verifications such as the impact on organizations (Baudoin & Arenas, 2020; Zhu et al., 2024) [5,66], especially the impact on the cost of capital. For the study of the cost of capital, the biophysical impact is one of the cutting-edge topics in the current combined research of financial management and natural science. Kling et al. (2021) and Huang et al. (2018) have made relevant explorations [48,49], but there is still an urgent need for more empirical research to further clarify the specific relationship between the two, especially under different natural environments including water issues. Secondly, government water governance is regarded as the main means of water resources adaptive management, and both social scientists and natural scientists have studied it. Among them, natural scientists start from the perspective of water infrastructure investment and construction to verify its macro impact to ecology, society, and economic growth (Yang et al., 2024) [67] and overlook the impact of such measures on micro-entities such as enterprises (Li & Yuan, 2021; Ban & Liu, 2021; Ma & Hou, 2020) [18–20]. Social scientists typically focus on the direct constraints of institutions on social actors, seldom paying attention to how their interaction with the natural environment will affect social actors such as businesses (Tashman, 2016) [11]. Thus, the impact of water vulnerability and its interaction with government water governance measures on corporate capital costs requires further study.

3. Hypothesis

3.1. The Impact of Water Vulnerability on Corporate Capital Cost

Water vulnerability could be caused by water scarcity, water pollution, and variations across time and place because of climate change-related changes in precipitation patterns under extreme weather events (Xia et al., 2012; Gui et al., 2021; Sun & Kato, 2021) [12,14,68]. For water scarcity, it means the interruptions in the daily operations of enterprises located at the area of water scarcity or enterprises that heavily rely on goods from the area of water scarcity (Appiah & Abass, 2014; Hazelton, 2013; Vos & Hinojosa, 2016) [69–71]. For water pollution, it means the restrictions in the ability for enterprises to obtain investment and attract skilled individuals because water vulnerability would squeeze out populations and hinder economic development (Wang et al., 2023) [72]. Both water scarcity and water pollution bring rising operational costs. On one hand, enterprises encounter escalated water expenses as a result of higher water prices, water rights fees, water taxes, and other related charges in water diminishing areas (Martinez, 2015; Fogel & Elizabeth, 2014) [73,74]. On the another hand, the worsening water quality leads to increased expenses for businesses to maintain their legitimacy because the decline in water quality increases the likelihood of the local government and community questioning the legitimacy of firms (Northey et al., 2019; Christ, 2014) [34,75]. Additionally, droughts, floods, and other natural disasters rising from the variability of water resources are instances of the capricious physical risks that might jeopardize company operations (Bonnafous et al., 2017; Jiao et al., 2022) [32,76]. For enterprises, droughts can exacerbate water shortages, while floods can disrupt operations and result in equipment loss (Song et al., 2019) [77].

In summary, water vulnerability destabilizes the supply and production of businesses and raises operational expenses, this presenting a risk to corporate sustainability. Zheng et al. (2022) also confirm that a company's financial performance is adversely affected by its vulnerability to water scarcity [13]. The risk compensation hypothesis posits that the cost of capital for a company represents the additional return that investors demand to compensate for assuming a certain level of uncertainty. The overall cost of capital for a corporate can be divided into two components: the cost of debt and the cost of equity. The cost of debt is calculated by adding the nominal risk-free rate to the risk premium. On the other hand, the cost of equity capital is determined by the level of risk according to the asset pricing model. Water vulnerability directly amplifies the business risk of a company as explained above, thereby exposing investors to elevated credit risk. The basis of this paper relies on the following hypothesis:

Hypothesis 1a: *The higher the water vulnerability, the higher the cost of debt.*

Hypothesis 1b: *The higher the water vulnerability, the higher the cost of equity.*

3.2. The Moderating Effect of Government Water Governance

Adaptive water resource management solutions are essential for dealing with the effects of climate change and human activities on water vulnerability (Xia, Qiu & Li 2012) [12], among which government intervention, as a way to adaptive water resource management, is widely recognized as being useful to prevent the Tragedy of the Commons and is necessary to ensure the efficient allocation of public goods for the benefit of society (Qin, Harrieon & Chen, 2019) [78]. Regulatory tools, such as law and enforcement, as well as investments in ecological engineering and environmental restoration, are the primary techniques that governments use to deal with environment challenges (Li, 2017) [79].

Environmental regulations exert pressure on businesses by requiring licenses to operate and by imposing substantial fines and fees. As the demand for stronger environmental regulations becomes more prominent, companies are facing greater pressure to maintain their environmental credibility. Meanwhile, environmental regulations reallocate resources from the production sector to the pollution sector, resulting in an increase in enterprises' marginal costs (Greenstone et al., 2012) [80], and the performance of businesses will see a decline in the near term (Zheng et al., 2022, Long & Wan, 2017) [13,81]. Research on corporate environmental responsibility has shown that enterprises that practice responsible water management could offset the harmful impact from water vulnerability and its related regulation pressures (e.g., Jones et al., 2015; Egan, 2015; Lambooy, 2011) [3,82,83]. However, the path of transformation is also one full of risks because green technologies entail a certain level of unpredictability and risk, and technological progress does not necessarily guarantee immediate safety for enterprises (Yan et al., 2021) [84]. Therefore, water regulation increases the uncertainty faced by businesses, resulting in investor demand for a higher risk premium. We predict the following:

Hypothesis 2a: *Water regulation positively moderates the relationship between water vulnerability and the cost of debts.*

Hypothesis 2b: *Water regulation positively moderates the relationship between water vulnerability and the cost of equity.*

Water infrastructure improvements and ecosystem restoration initiatives are the ways the government intends to alter water vulnerability (Petts & Gurnell, 2022) [85]. Investment in infrastructure projects could increase the availability of water and the resistance of an area to floods and droughts. In addition, improvements to the water quality caused by investment in restoration projects may result in a reduction in the costs of labor and bring about an increase in the total productivity of the corporation (Li et al., 2020; Zhu et al., 2023) [86,87]. Even businesses may experience greater expenses for water because these investments would be recovered through market mechanisms; it is believed that the operating burden from these water expenses could be in a reasonable and acceptable range, owing to the fact that water prices generally remain low under the acknowledgment of water resources as a human right (Egan, 2015; Martinez, 2015) [73,82]. Therefore, water investment mitigates the negative impact of water vulnerability on enterprises, leading investors to potentially request a reduced risk premium. We predict the following:

Hypothesis 3a: *Water investment negatively moderates the relationship between water vulnerability and the cost of debt.*

Hypothesis 3b: *Water investment negatively moderates the relationship between water vulnerability and the cost of equity.*

Based on the hypothesis above, the conceptual model of the study is shown as Figure 1.

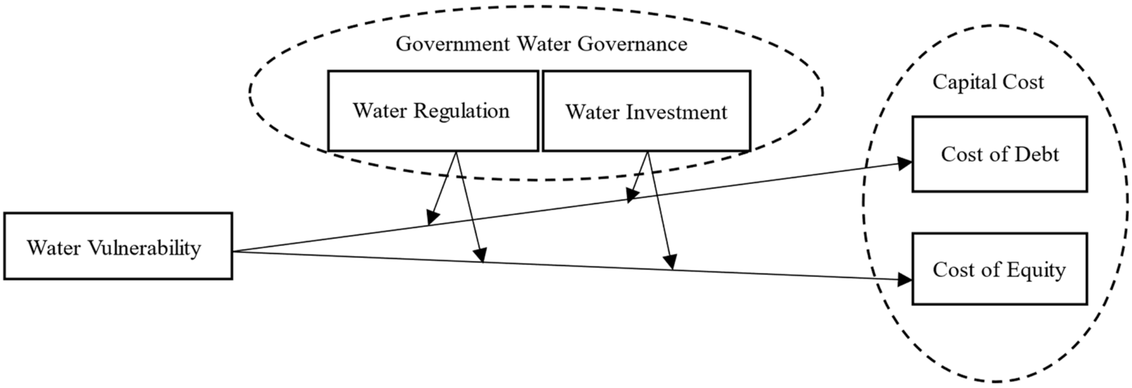

Figure 1. Conceptual model of the impact of water vulnerability on corporate capital costs considering government water governance moderating effects.

4. Study Design and Data Description

4.1. Sampling

This study utilizes data from 30 Chinese provinces and municipalities, excluding Tibet, Hong Kong, Macao, and Taiwan, for a period of five years (2019–2023). The rationale for excluding Hong Kong, Macao, and Taiwan is their significant level of autonomy, which clearly distinguishes their political systems from that of mainland China. The omission of Tibet is due to the absence of data.

This analysis also excludes companies in the financial sector due to their significantly different investment and financing patterns compared to the rest of the economy. Due to the distinct risk characteristics of organizations on delisting alert compared to non-delisting alert firms, the cost of capital for the former is also not considered in the sample. After excluding individuals with incomplete data, the article has a total of 12,361 samples.

Following is a list of the data sources that were employed in this paper: The databases maintained by CSMAR are the source of the financial information. Both the statistics on water vulnerability and the data on government water investment are gathered from a variety of sources, such as the China Statistical Yearbook, the China Water Resources Statistical Yearbook, the China Water Resources Bulletin, and the China Urban and Rural Construction Statistical Yearbook. The data represent water regulations acquired from work reports produced by the provincial government. Stata 17.0 was used to carry out the data processing duties.

4.2. Construction of Variables

4.2.1. Water Vulnerability

Water vulnerability refers to the state of a water resource system that is vulnerable to disturbances produced by human activities and natural fluctuations, as well as the degree to which it is difficult to restore the system to its original form when such disturbances have occurred (Xia J. et al., 2012) [12]. Gui, Chen, and He (2021) propose that water vulnerability can be categorized into four dimensions: sensitivity, exposure, hazard, and adaptivity [14]. Sensitivity indicates the extent of fluctuation in water resources. The concept of exposure highlights the extent to which economic and social progress relies on the availability and sustainability of water resources. Hazard denotes the magnitude of the economic and social consequences resulting from the temporal and spatial fluctuations of water resources. Adaptability refers to the degree to which water resources have been effectively managed in relation to social and economic growth. The relevant aspects were assessed using indicators from studies conducted by Gui, Chen & He (2021), Liu & Chen (2016), and Su et al. (2018) [14,88,89]. A complete assessment was conducted using the entropy approach. The precise indicators are displayed in Table 1.

Table 1. The assessment of water vulnerability.

Dimensions	Items	Data Sources
Sensitivity	Absolute value of annual precipitation variation	China Water Resources Statistical Yearbook
	Absolute value of annual total water resources variation	China Water Resources Statistical Yearbook
Exposure	GDP per capita	China Statistical Yearbook
	Share of GDP in primary production	China Statistical Yearbook
	Water resources per capita	China Statistical Yearbook
	Total water resources/total area of the region	China Water Resources Statistical Yearbook, China Urban and Rural Construction Statistical Yearbook
	Total water resources/total annual rainfall	China Water Resources Statistical Yearbook
	Proportion of high-quality surface water	China Water Resources Statistical Yearbook, China Environmental Statistical Yearbook
	Ratio of water resources supply to demand	China Urban and Rural Construction Statistical Yearbook
	Proportion of groundwater supply	China Water Resources Statistical Yearbook
	Water consumption of CNY 10,000 of GDP	China Water Resources Bulletin
	Water consumption of CNY 10,000 of industrial value added	China Water Resources Bulletin
	Water consumption by urban residents for domestic use	China Water Resources Bulletin
	Water consumption for agricultural irrigation	China Water Resources Bulletin
Hazard	Regional population affected/National population affected in the year	Bulletin of flood and drought disasters in China
	Regional direct economic losses/National losses in the year	Bulletin of flood and drought disasters in China
	Area of crops affected in the region/National damage in the year	Bulletin of flood and drought disasters in China
	Population with drinking water difficulties in the region/National population affected in the year	Bulletin of flood and drought disasters in China
Adaptivity	Wastewater treatment rate	China Urban and Rural Construction Statistical Yearbook
	Water reuse rate	China Urban and Rural Construction Statistical Yearbook
	Ratio of protected arable land	China Water Resources Statistical Yearbook
	Protection of population ratio	China Water Resources Statistical Yearbook
	Effective utilization rate of irrigation water	China Water Resources Bulletin

4.2.2. Capital Cost

The capital cost is primarily categorized into the debt cost and the equity cost. Currently, there are two primary methods for measuring the cost of debt. The first method involves using the interest rate on bank borrowings as a proxy variable. The second method involves using the current year's interest as a proportion of the firm's current year liabilities as a proxy variable. This study contends that bank borrowing is merely one avenue for obtaining debt financing. Bank funds offer a lesser interest rate compared to other funds, although banks establish a higher barrier for borrowers. This article asserts that bank borrowing rates inadequately capture the complete cost of debt. Referring to Zou et al. (2003) [90], the formula for calculating the cost of debt is as follows: divide the sum of interest expense and capitalized interest by the average amount of interest-bearing debt for the year.

There are multiple methods to determine the cost of equity, mostly categorized into ex-ante and ex-post models. The ex-ante approach, such as the PEG model, is regarded as more advantageous than the ex-post model, such as the CAMP model (Mao et al., 2012) [91]. However, because intermediate services like analyst forecasting in China started late, there is only a limited amount of analyst forecasting data available for a small number of enterprises. And the CAMP model's ability to determine the cost of equity for enterprises is restricted in developing countries (Kling et al., 2021) [48]. Thus, this work adopts the approach of Lin, Zheng & Bo (2015), Zhou et al. (2018a; 2018b) [92–94], etc., by utilizing the reciprocal of the P/E ratio as an indicator of the cost of equity.

4.2.3. Water Governance

This study aims to distinguish between the regulatory and investment aspects of government water governance. Currently, there are two methods to measure water regulation. The first method involves analyzing industrial emissions that are connected to water resources as a substitute variable. The second method involves analyzing the occurrence and significance of terms related to water resources in government work reports, which indicates the level of regulatory pressure exerted by the government (Chen & Chen, 2018; Chen et al., 2018) [95,96]. This article asserts that the government's work report is a strategic document that functions as a blueprint for the execution and enforcement of the authority's decisions and resolutions in compliance with the law. Because of this, the frequency and percentage of water-related phrases in the government work report serve as a more complete measure of water regulation.

The particular techniques that were followed in order to produce the indicators that represent water regulation are outlined in this research as follows: The first stage consisted of manually collecting work reports written by the government from thirty different provinces during the course of the years 2019 to 2023. As a further step, the terminology that represents water regulation was established. We followed the research done by Zheng et al. (2022) to choose the following terms: water environment, water resources, water pollution, water safety, water ecology, river and lake, river (lake) chiefs, water price, water use, and water quality [13]. The final step was to compute the frequency of these terms and the percentage of them to the total number of words that were found in the government work reports.

The China Water Statistics Yearbook states that government investment in water resources mostly focuses on flood control, irrigation, drainage, water supply, hydropower, soil conservation, ecological restoration, institutional capacity building, early-stage projects, and other related areas. The preliminary measurement of water investment is determined by calculating the sum of investments made during the current year after omitting the investments in hydropower and institutional capacity development. This approach is adopted since investments in hydropower primarily serve the purpose of addressing energy issues, while strengthening institutions is aimed at keeping the operation of the government. In the meantime, this study makes use of the ratio of total water investment to local GDP as the indicator of water investment to reduce the influence of regional economic inequalities on water investment and to improve the capability of comparing water investment across provinces.

4.2.4. Control Variables

A number of factors at the firm level, including financial performance (ROA), market-to-net ratio (BM), firm size (SIZE), asset-liability ratio (LEV), stock liquidity ratio (Turnover), and equity concentration (SHR), have been selected to be the control variables. This decision was made after taking into consideration previous research (for example, Kling et al., 2021; Huang et al., 2018; Zhou et al., 2018a,b) [48,49,87,88]. The total regional gross domestic product (GDP) and the growth rate of regional GDP (GGROWTH) are the representative variables at the regional level that are under consideration to be controlled.

4.3. Model and Estimate Method

In accordance with recent research results (Zheng et al., 2022; Kling et al., 2021) [13,48], we used the following equation to study and test the hypotheses:

$$Capital = \beta_0 + \beta_1\, Water_{Vul} + \sum_i \beta_i Controls_i + \sum_j \beta_j Industrialfixed_j + \sum_l \beta_l Yearfixed_l + \varepsilon_{it} \quad (1)$$

To further test the moderating effect of water governance, the interaction term between water governance and water vulnerability is introduced in Equation (1). The equation is as follows:

$$Capital = \beta_0 + \beta_1\, Water_{Vul} + \beta_2\, Water_{Gov} + \beta_3\, Water_{Vul} * Water_{Gov} + \sum_i \beta_i Controls_i + \sum_j \beta_j Industrialfixed_j + \sum_l \beta_l Yearfixed_l + \varepsilon_{it} \quad (2)$$

In the above equations, *Capital* respectively represents the cost of debt (r_debt) and the cost of equity(r_equity), $Water_{Vul}$ represents water vulnerability, $Water_{Gov}$ respectively represents water investment (Water_Inv) and water regulation (Water_Ins). In addition, the Hausman test indicates that the fixed effects model should be adopted in this paper.

5. Empirical Analysis

5.1. Descriptive Analysis

This report provides a comprehensive examination of water vulnerability in China, examining it at both a regional and a provincial level. The regional vulnerability of water resources is displayed in Table 2, whereas the provincial vulnerability is depicted in Figure 2. The descriptive statistics of water vulnerability are consistent with the geographical distribution of water resources in China, demonstrating that the assessment of water vulnerability in this study has reliability and could be used to investigate the true relationship with capital costs. According to our assessment, there are significant differences in the degree to which various areas in China are vulnerable to water crises. The vulnerable state of water resources is much more severe in the northern area compared to the southern region. Water vulnerability is most pronounced in north China. This is primarily due to the limited availability of water resources in the region, as well as the high demand for water by society. Meanwhile, there are problems with water resources and the water environment, such as the excessive extraction of groundwater and a decline in water quality (Sun & Kato, 2021) [68]. The area of southwest China has the lowest degree of water vulnerability and functions as the principal source of water for the rest of China. This may be ascribed to the abundant water resources located there as well as the comparatively low human density.

Table 2. Descriptive statistics of the yearly average of water vulnerability in seven regions of China.

Region	2019	2020	2021	2022	2023	Mean
North China	0.343	0.338	0.293	0.331	0.278	0.317
Northeast China	0.319	0.320	0.312	0.275	0.273	0.300
Northwest China	0.332	0.312	0.310	0.295	0.274	0.305
Eastern China	0.232	0.195	0.189	0.186	0.179	0.196
South-Central-China	0.192	0.183	0.177	0.162	0.159	0.175
Southwest China	0.143	0.140	0.131	0.130	0.119	0.133

Note: All values are calculated by entropy weight method based on the water vulnerability assessment system shown in Table 1.

When compared to the other provinces, Ningxia is the most susceptible to water vulnerability. Ningxia is the province that has the greatest degree of vulnerability among all of the provinces. According to Han et al. (2020) [97], the high concentration of human activity in the area, along with drought and frequent natural disasters, has led to severe water shortages in Ningxia. These elements have had a role in the present difficulties faced by the province. After Ningxia, Heilongjiang Province is the second-most vulnerable due to its high water sensitivity. The reasons for this include the considerable seasonal fluctuations in water resources, the limited capacity for generating water, and the abrupt growth in water demand brought on by socioeconomic development (Qiu et al., 2008) [98]. In addition to a water supply-and-demand mismatch, the three provinces of Beijing, Tianjin, and Shanghai are also battling water contamination issues (Cao et al., 2019) [99]. Consequently, these provinces have a greater susceptibility to water-related issues. Due to their exceptional water environment quality and abundance of water resources, provinces like Guangdong, Guangxi, Zhejiang, and Jiangxi are less susceptible to water scarcity than other provinces in China.

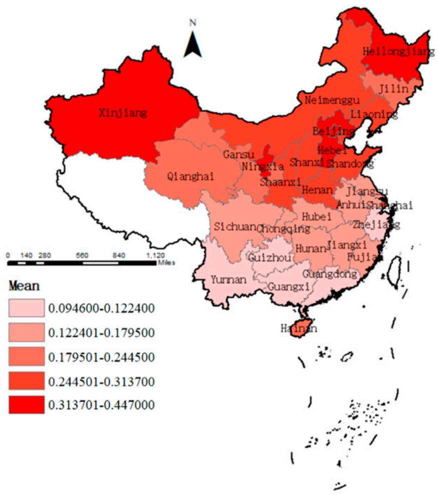

Figure 2. Diagram of the total average of water vulnerability in each province in China. Note: All values are calculated by entropy weight method based on the water vulnerability assessment system shown in Table 1.

The major factors are studied in a descriptive fashion, as shown in Table 3, in order to provide a more thorough assessment of the influence that water vulnerability has on the cost of capital. This is done in order to provide a more comprehensive study. When it comes to the cost of capital, the average cost is not very high; nonetheless, there is a substantial gap between the highest and lowest values within the value range. The fact that this is the case suggests that some groups continue to struggle with acquiring finance, which leads to significant expenditures associated with financing. The likelihood of development over the long run is negatively impacted by this circumstance. Water vulnerability in China varies geographically, with a mean value of 0.193, ranging from a low value of 0.047 to a high value of 0.392. Based on this, it can be concluded that China's overall water vulnerability is rather low; however, there are significant variations throughout the country's many areas. Despite the fact that the Chinese government has been able to accomplish exceptional achievement in water control, this finding also suggests that businesses may be unaware of the dangers associated with water or may underestimate the potential effect of water vulnerability. A number of additional control variables are also taken into consideration in this work. The values of these control factors are quite similar to those discovered in prior research.

Both the Pearson correlation test (highlighted in the bottom triangle) and the Spearman correlation test (highlighted in the top triangle) were employed in order to identify instances of multicollinearity within the model. In Table 4, the correlation coefficients are presented. The results of the study suggest that there is a significant connection between the cost of debt and the vulnerable state to water. Consequently, this provides a partial validity for hypothesis H1a, which shows that businesses are susceptible to the dangers associated with physical water risk. It is necessary to do more research since the current negligible negative association between water vulnerability and the cost of equity suggests the existence of a more complex connection between the two variables. Such a connection would need further examination. Some evidence in support of Hypotheses 2 and 3 may be found in the link between the instruments used by the government for water governance, the cost of capital, and water vulnerability. The correlation coefficients among all of the variables are substantially lower than 0.6, which indicates that there is not a serious collinear concern.

Table 3. Descriptive statistical results of each variable.

Variables	Mean	S.D.	Min	Max
r_debt	0.009	0.025	−0.097	0.063
r_equity	0.038	0.035	0.001	0.207
Water_Vul	0.193	0.091	0.065	0.392
Water_Ins	0.002	0.001	0.000	0.005
Water_Inv	0.006	0.004	0.001	0.026
ROA	0.056	0.045	0.002	0.228
BM	0.629	0.247	0.122	1.189
SIZE	22.343	1.246	20.114	26.140
LEV	0.401	0.183	0.064	0.837
TOVER	5.666	0.738	3.674	7.196
SHR	0.155	0.107	0.017	0.521
LGDP	10.718	0.679	8.499	11.615
GGROWTH	5.986	2.017	0.500	9.300

Table 4. Correlations of each variable.

	Water_Vul	r_equity	r_debt	Water_Ins	Water_Inv	ROA	BM	SIZE	LEV	TOVER	SHR	LGDP	GGROWTH
Water_Vul		0.045	0.043 ***	−0.164 **	−0.1034 ***	−0.124 ***	0.055 ***	0.099 ***	0.049 ***	−0.032 ***	0.027 ***	−0.472 ***	−0.079 ***
r_equity	0.013		0.020 **	−0.022 **	0.0083	0.561 ***	0.437 ***	0.425 ***	0.113 ***	−0.308 ***	0.157 ***	0.028 ***	−0.069 ***
r_debt	0.038 ***	0.049 ***		−0.004	0.0048	−0.054 ***	0.062 ***	0.082 ***	0.050 ***	−0.032 ***	−0.014	−0.039 ***	0.001
Water_Ins	−0.205 ***	−0.024 **	−0.003		0.1284 ***	0.024 **	−0.047 ***	−0.055 ***	−0.021 **	0.075 ***	−0.021 **	0.228 ***	0.060 ***
Water_Inv	0.055 ***	0.001	0.018 *	0.171 ***		0.000	−0.004	0.036 ***	0.012	0.039 ***	0.013	−0.468 ***	0.129 ***
ROA	−0.108 ***	0.368 ***	−0.044 ***	0.016	−0.028 ***		−0.338 ***	−0.091 ***	−0.382 ***	−0.105 ***	0.130 ***	0.123 ***	0.015
BM	0.078 ***	0.434 ***	0.072 ***	−0.052 ***	0.017 ***	−0.372 ***		0.518 ***	0.396 ***	−0.273 ***	0.087 ***	−0.067 ***	−0.079 ***
SIZE	0.133 ***	0.455 ***	0.083 ***	−0.052 ***	0.040 ***	−0.077 ***	0.532 ***		0.525 ***	−0.352 ***	0.124 ***	−0.132 ***	−0.037 ***
LEV	0.057 ***	0.167 **	0.046 ***	−0.015	0.035 ***	−0.366 ***	0.394 ***	0.532 ***		−0.051 ***	0.026 ***	−0.070 ***	−0.027 ***
TOVER	−0.046 ***	−0.254 ***	−0.043 ***	0.073 ***	0.041 ***	−0.010 ***	−0.281 ***	−0.386 ***	−0.060 ***		−0.310 ***	0.076 ***	−0.151 ***
SHR	0.048 ***	0.164 ***	−0.005	−0.028 ***	0.010	0.105 ***	0.115 ***	0.207 ***	0.052 ***	−0.357 ***		−0.032 ***	0.004
LGDP	−0.450 ***	0.005 ***	−0.033 ***	0.130 ***	−0.544 ***	0.108 ***	−0.073 ***	−0.128 ***	−0.077 ***	0.053 ***	−0.040 ***		−0.109 ***
GGROWTH	−0.042 ***	−0.037 ***	−0.008	0.089 ***	0.081 ***	0.009	−0.032 ***	−0.052 ***	−0.024 **	−0.180 ***	0.005	−0.017 *	

Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively.

5.2. Results of Main Regression

The results of evaluating the correlation between water vulnerability and corporate capital cost are presented in Table 5. In the full-sample regression, we observe a statistically significant positive relationship between water vulnerability and company capital costs. An increase in water vulnerability of 1% could result in a 1.8% increase in the cost of debt and a 1.5% increase in the cost of equity. This discovery validates our prior hypothesis that water vulnerability has emerged as a significant risk for businesses, and financial markets have started to acknowledge the presence of this risk. H1a and H1b have been proven.

Table 5. Regression results of water vulnerability to corporate capital costs (2019–2023).

	Cost of Debt	Cost of Equity
Water_Vul	0.018 ***	0.015 ***
	(3.12)	(2.92)
ROA	−0.017 **	0.459 ***
	(−1.88)	(3.56)
BM	0.003 *	0.065 ***
	(1.74)	(3.07)
SIZE	0.001 ***	0.005 ***
	(4.41)	(2.83)
LEV	−0.002	0.011 **
	(−0.35)	(2.49)
TOVER	−0.001 *	0.002 ***
	(−1.98)	(3.42)
SHR	−0.007 ***	−0.006 **
	(−2.97)	(−2.12)
LGDP	0.001	0.001 ***
	(1.03)	(2.79)
GGROWTH	0.001	0.001 **
	(0.01)	(2.23)
Constant	−0.013	−0.185 ***
	(−0.35)	(−3.04)
Fixed Effects	Yes	Yes
Obs	12,363	12,363

Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively; the values in parentheses represent the t-value after robust standard error adjustment.

5.3. Robustness

We performed two rigorous tests to assess the reliability and stability of our main regression findings. Initially, we modified a different time period of the sample in order to evaluate the resilience of the main regression. We utilized data from 30 Chinese provinces and municipalities, specifically excluding Tibet, Hong Kong, Macao, and Taiwan, for the time frame spanning 2014 to 2018. The data presented in Table 6 indicate a positive correlation between water vulnerability and both the cost of debt and the cost of equity.

Table 6. Robustness results of water vulnerability to corporate capital Costs.

	Sample Change		PSM	
	Cost of Debt	Cost of Equity	Cost of Debt	Cost of Equity
Water_Vul	0.021 ***	0.011 **	0.032 **	0.021 *
	(2.56)	(2.49)	(2.48)	(1.78)
Controls	Yes	Yes	Yes	Yes
Fixed Effects	Yes	Yes	Yes	Yes
Constant	2.413 *	1.460 **	0.090 ***	0.011
	(1.75)	(2.41)	(2.81)	(1.34)
Obs	8736	8736	11,476	11,476

Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively; the values in parentheses represent the t-value after robust standard error adjustment.

Furthermore, propensity score matching (PSM) is employed to conduct a more in-depth analysis of the reliability of the main regression findings. The principle of propensity matching involves comparing organizations that share similar traits but exhibit inconsistent behaviors in order to form a matching group. Given that firms have the freedom to choose their geographical location, we have chosen enterprises situated in regions with above-average water vulnerability as the treatment group, and enterprises located in regions with below-average water vulnerability as the control group. This article utilizes return on assets (ROA), price to book ratio (BM), total asset (SIZE), financial leverage (LEV), turnover of stocks (TOVER), and share concentration (SHR) as matching variables. The samples are paired one-on-one. The regression coefficients for water vulnerability are positively and significantly associated, confirming the reliability of the findings, as presented in Table 6.

5.4. Endogeneity Tests

As a result of our initial premise that water vulnerability comprises specific characteristics that are impacted by social and economic development, we conducted an analysis of the endogeneity of water vulnerability and capital costs. It is possible that the variable of water vulnerability does not fulfill the criterion of exogeneity owing to the existence of unaccounted variables or measurement mistakes. This is despite the fact that we have control over some factors that reflect the economic growth of the area. Thus, we follow the approach proposed by Wooldridge (2010) to test whether or not water vulnerability meets strict exogeneity requirements [100]. The result of endogeneity tests is shown in Table 7.

$$\text{Capital}_{it} = \alpha_1 + \beta_1\text{Water\_Vul}_{jt} + \sum\text{Controls}_{it} + \mu_i + \varepsilon_{it} \quad (3)$$

$$\text{Water\_Vul}_{jt} = \alpha_2 + \delta_1\text{SUN}_{jt} + \beta\delta_2\sum\text{Controls}_{it} + \omega_{it} \quad (4)$$

Table 7. Endogeneity results of water vulnerability to corporate capital costs using two-stage regression method.

	Water_Vul	**r_equity**	**r_debt**
Water_Vul		0.010 ** (2.68)	0.013 ** (1.88)
VUL_hat		−0.006 (−0.37)	−0.012 (−0.17)
SUN	0.213 *** (4.59)		
Controls	Yes	Yes	Yes
Constant	−1.175 *** (−3.46)	−0.179 *** (−5.68)	−0.016 * (−1.73)
Obs	12,361	12,361	12,361

Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively; the values in parentheses represent the t-value after robust standard error adjustment.

First, we start with a random-effects model, as Equation (3). The next step is to incorporate the variable of the yearly hour of sunlight (SUN) in order to determine whether or not the condition of endogeneity is satisfied by water vulnerability. In this study, it is considered that the amount of economic development in an area may have an effect on water vulnerability; nevertheless, the average annual hour of sunlight is less impacted by the level of social and economic development than water vulnerability is. We calculated the residuals by using Equation (4), and then we included those residuals into the initial Equation (3). The cost of equity, also known as r_equity, has a coefficient of the residual, which is written by the symbol VUL_hat, which is −0.006, and its *t*-value is −0.37. The cost of debt, also known as r_debt, has a coefficient of the residual, which is indicated by the symbol VUL_hat, which is −0.012, and its t-value is −0.17.

VUL_hat is the difference between the real Water_Vul and the Water_Vul fitted by Equation (4), representing the endogenous impact of the independent variable on the biased estimation of the dependent variable. If the regression coefficient of vul_hat in Equation (3) has no significance, it means that the endogenous influence of the real water_vul will not cause the regression result to produce a significantly biased estimation. In this study, the regression coefficients of VUL_hat for r_debt and r_equity are both not significant. That is to say, water_vul meets the assumption that the independent variable is exogenous to obtain a consistent estimator. Therefore, the multiple regression, applied by this study to test the relationship between water vulnerability and corporate capital costs, will not produce significant biased estimates due to the possible endogeneity of water_vul, indicating the robustness of the main regression results.

5.5. Channel Analysis

Hypothetically, we suggest that water vulnerability exposes investors to higher credit risks that increase corporate capital costs. Credit risk would result in financing constraints, so we apply financial constraints to measure credit risk. For the measurement of financing constraint, we draw on the research of Kaplan and Zingales (1997) [101]. The higher the value of the KZ, the greater the degree of financing constraints. The data of KZ are from CSMAR. We also draw on the method of Wen and Ye (2014) to construct models (5)–(7) to examine whether or not the mediating effect of financing constraint (KZ) exists [102]. Equation (5) is the main test model, and the coefficient α_1 measures the total effect of the independent variable on the dependent variable. Equation (6) is used to examine the impact of water vulnerability on financing constraints, and the coefficient β_1 is the focus. Equation (7) mainly examines the impact of water vulnerability and financing constraints on the corporate capital costs, and the coefficients γ_1 and γ_2 are the focus. If γ_1 is insignificant but γ_2 is significant, it indicates that financial constraints play a complete mediating effect. If γ_1 and γ_2 are both significant, it indicates that financial constraints play a partial mediating effect.

$$\text{Capital}_{it} = \alpha_0 + \alpha_1 \text{Water\_Vul}_{jt} + \sum \text{Controls}_{it} + \sum_j \alpha_j \text{Industrialfixed}_j + \sum_l \alpha_l \text{Yearfixed}_l + \varepsilon_{it} \quad (5)$$

$$\text{KZ}_{it} = \beta_0 + \beta_1 \text{Water\_Vul}_{jt} + \sum \text{Controls}_{it} + \sum_j \beta_j \text{Industrialfixed}_j + \sum_l \beta_l \text{Yearfixed}_l + \varepsilon_{it} \quad (6)$$

$$\text{Capital}_{it} = \gamma_0 + \gamma_1 \text{Water\_Vul}_{jt} + \gamma_2 \text{KZ}_{it} + \sum \text{Controls}_{it} + \sum_j \gamma_j \text{Industrialfixed}_j + \sum_l \gamma_l \text{Yearfixed}_l + \varepsilon_{it} \quad (7)$$

Table 8 displays the results of the channel analysis. The first step of the mediation effect test is presented in R1 and R4, which is also the outcome of the main regression in Equation (1). The regression coefficient for water vulnerability on corporate capital costs is positively and significantly related with the significance of α_1. The results of step 2 are shown in R2 and R5. The regression coefficient of water vulnerability on financing constraints is positive and significant at the $p < 5\%$ level, indicating that water vulnerability significantly promotes financing constraints. R3 and R6 present the outcomes of the third step, with the coefficients for water vulnerability and financing constraints both below significance at the $p < 5\%$ levels. This suggests that the increase in financing constraints, spurred by water vulnerability, contributes to the higher corporate capital costs, with financing constraints serving as a partial mediator.

Table 8. Channel analysis of water vulnerability to corporate capital costs.

	r_debt			r_equity		
	R1	**R2**	**R3**	**R4**	**R5**	**R6**
	r_debt	**KZ**	**r_debt**	**r_equity**	**KZ**	**r_equity**
Water_Vul	0.018 *** (3.12)	0.035 ** (2.17)	0.018 *** (3.35)	0.015 *** (2.92)	0.001 ** (2.03)	0.011 *** (3.06)
KZ			0.030 ** (2.84)			0.332 *** (2.98)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes

Table 8. *Cont.*

	r_debt			r_equity		
	R1	**R2**	**R3**	**R4**	**R5**	**R6**
	r_debt	**KZ**	**r_debt**	**r_equity**	**KZ**	**r_equity**
Constant	−0.013 (−0.35)	−0.043 (−0.68)	−0.012 (−0.93)	−0.185 *** (−3.04)	−0.614 (−0.54)	−0.172 ** (−2.16)
Obs	12,361	12,361	12,361	12,361	12,361	12,361

Note: ***, ** indicate significant at the 1%, 5% levels, respectively; the values in parentheses represent the t-value after robust standard error adjustment.

5.6. Moderating Effect

The findings displayed in Table 9 indicate that government water regulation generally has a positive influence on the connection between water vulnerability and the cost of debt. However, it has an insignificantly negative impact on the link between the cost of equity and the vulnerability of water. H2a has been proven, but H2b has not. The results on the cost of debt lend credence to the notion that government water regulation exacerbates the impact of water vulnerability on the financial performance of firms (Zheng et al., 2022) [13], hence encouraging creditors to demand higher premiums for water risks. The results of the equity cost analysis may indicate that government regulation of water resources has the potential to facilitate the transition of businesses towards environmentally friendly practices. This, in turn, would mitigate the risks associated with water scarcity and contribute to the long-term sustainability of enterprises.

Table 9. Moderating effects of water institutions and water investment on the relationship between water vulnerability to corporate capital costs.

	r_debt	**r_equity**
Water_Vul	0.019 *** (2.61)	0.065 *** (3.88)
Water_Ins	0.097 (1.03)	0.179 (1.24)
Water_Vul × Water_Ins	3.268 * (1.68)	−1.854 (−0.98)
Water_Vul	0.018 *** (2.75)	0.015 *** (2.94)
Water_Inv	0.232 * (1.71)	0.087 (1.08)
Water_Vul × Water_Inv	−1.397 * (−1.67)	−0.166 (−0.83)
Controls	Yes	Yes
Fix Effects	Yes	Yes
Obs	12,363	12,363

Note: ***, * indicate significant at the 1%, and 10% levels, respectively; the values in parentheses represent the t-value after robust standard error adjustment.

The findings displayed in Table 9 indicate that government water investment has a minor adverse moderating influence on the relationship between water vulnerability and the cost of debt. However, it does not have any meaningful moderating effects on mitigating the impact of water vulnerability on the cost of equity. H3a has been validated; however, H3b does not pass the hypothesis testing. The results on the cost of debt support the idea that government investment in water infrastructure mitigates the negative effects of water vulnerability on business financial performance (Zheng et al., 2022) [13], hence reducing the demand for higher water risk premiums from creditors. The findings of the cost of equity analysis may suggest that government investment in water infrastructure has the potential to enhance local water conditions and mitigate the disadvantageous effects of water vulnerability, albeit to a limited extent.

5.7. Heterogeneity

This paper further investigates the two heterogeneities in the relationship between water vulnerability and corporate capital costs. This is due to the fact that there are significant differences in water risk perception between water-intensive industries and non-water intensive industries, as well as between state-owned and non-state-owned corporations (Zheng et al., 2022) [13].

5.7.1. Industrial Heterogeneity

Currently, there is a lack of cohesion in the allocation of water-intensive businesses. The National Bureau of Statistics of China regulates the water consumption data of ten industries that are considered to be water-intensive. These industries include coal mining and washing, ferrous metal smelting and rolling processing, non-metallic mining and selection, electric power and heat production and supply, textiles, paper products industry, nonferrous metal smelting and rolling processing, chemical raw materials and chemical products manufacturing, non-metallic mineral products industry, petroleum processing and coking, and nuclear fuel processing.

Table 10 exhibits the industrial heterogeneity in main regression. The coefficient of water vulnerability, as seen in R1 and R5, suggests that it does not have a substantial impact on the capital cost of water-intensive enterprises. This outcome appears anomalous and contradicts conventional wisdom. Nevertheless, we contend that the impact of water vulnerability on the capital cost of water-intensive enterprises is minimal due to their implementation of adaptive water resource management strategies. These enterprises have taken measures to protect themselves from water vulnerability, as evidenced by studies conducted by Bulcke et al. (2020), Burritt et al. (2016), and Northey et al. (2019) [15,34,103]. This is primarily due to the greater institutional pressure faced by water-intensive enterprises compared to non-water intensive counterparts. Callaghan et al. (2020) discovered that companies that consume large amounts of water have improved their ability to cope with water vulnerability by using technology innovation and embracing environmentally friendly practices [104].

Table 10. Heterogeneity in regression results of water vulnerability to corporate capital costs.

	r_debt				r_equity			
	Industrial Heterogeneity		Firm Heterogeneity		Industrial Heterogeneity		Firm Heterogeneity	
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**
Water_Vul	0.004 (0.36)	0.022 *** (2.67)	0.020 ** (2.45)	0.016 ** (2.02)	0.010 (1.10)	0.013 ** (1.88)	0.002 (0.19)	0.024 *** (2.86)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fix Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3246	9015	4001	8360	3246	9015	4001	8360
Chow Test	3.01 **		2.75 *		3.72 **		4.72 ***	

Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively; the values in parentheses represent the *t*-value after robust standard error adjustment.

Table 11 exhibits the industrial heterogeneity regarding moderating effects. Panel A illustrates the diversity in the moderating impact of water regulation. R1 and R2 demonstrate that the positive moderating effect is significant in industries that are not highly dependent on water, but not in the water-intensive sector. Water-intensive firms have implemented adaptive management practices and have been subject to government monitoring and regulation for a significant period of time (Bulcke et al., 2020; Burritt et al., 2016; Northey et al., 2019) [15,34,103]. As a result, the risk associated with water-related regulations is minimal and decreasing. Thus, water regulation has a negligible effect on water-intensive firms but a slightly noticeable effect on non-water-intensive industries.

Table 11. Heterogeneity in moderating effects of water institutions and water investment on the relationship between water vulnerability and corporate capital costs.

Panel A—Water Regulation								
	r_debt				r_equity			
	Industrial Heterogeneity		Firm Heterogeneity		Industrial Heterogeneity		Firm Heterogeneity	
	R1	R2	R3	R4	R5	R6	R7	R8
Water_Vul	0.004	0.023 ***	0.024 **	0.017 **	0.014	0.013 **	0.002	0.026 ***
	(0.34)	(3.57)	(1.98)	(2.21)	(0.17)	(2.11)	(1.09)	(2.67)
Water_Ins	0.174	0.076	0.341	0.036	0.321	0.055	−0.041	0.220
	(0.39)	(0.73)	(0.12)	(0.24)	(0.81)	(0.52)	(0.18)	(1.25)
Water_Vul ×	1.752	4.018 *	3.675	3.481 *	−2.404	−2.410	−4.966	3.147
Water_Ins	(1.08)	(1.82)	(1.59)	(1.92)	(−1.69)	(−1.42)	(−1.59)	(1.44)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fix Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3246	9015	4001	8360	3246	9015	4001	8360
Chow Test	4.44 **		4.15 **		3.96 **		4.88 ***	
Panel B—Water Investment								
	r_debt				r_equity			
	Industrial Heterogeneity		Firm Heterogeneity		Industrial Heterogeneity		Firm Heterogeneity	
	R1	R2	R3	R4	R5	R6	R7	R8
Water_Vul	0.004	0.022 ***	0.0210**	0.016 **	0.112	0.012 **	0.001	0.024 ***
	(0.34)	(3.56)	(1.88)	(2.08)	(0.16)	(2.09)	(1.03)	(2.64)
Water_Inv	0.090	0.276 *	0.111	0.302 *	0.346	−0.069	−0.1131	0.220*
	(0.22)	(1.85)	(0.37)	(1.94)	(0.84)	(−1.06)	(−0.17)	(1.77)
Water_Vul ×	−0.184 *	1.733 *	−0.404	−2.652 **	−2.868 **	1.780 **	0.256	0.160
Water_Inv	(−1.69)	(1.79)	(−1.15)	(−2.24)	(−2.53)	(1.98)	(0.86)	(0.44)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fix Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Obs	3246	9015	4001	8360	3246	9015	4001	8360
Chow Test	4.72 **		3.98 **		4.01 **		4.90 ***	

Note: ***, **, * indicate significant at the 1%, 5%, and 10% levels, respectively; the values in parentheses represent the *t*-value after robust standard error adjustment.

Panel B demonstrates the heterogeneity in the moderating effect of water investment. The analysis reveals that government water investment has a notable negative impact on water-intensive enterprises, but it has a considerable beneficial impact on non-water-intensive firms, as indicated by the results in R1 and R2 and R5 and R6, respectively. As previously stated, government investment in water can enhance local hydrological conditions, and water-intensive companies already employ adaptive management strategies. Consequently, companies that use significant amounts of water experience substantially reduced water-related risks, which suggests a decrease in the additional return on investment required by investors. Government expenditures in water infrastructure would be paid off through marketing incentive tools such as water prices. However, enterprises that do not heavily rely on water resources may have limited understanding of the importance of implementing adaptive water management practices. Therefore, it is possible that non-water intensive companies would see more pressure on their profitability, indicating that investors are still taking into account the possibility of a water risk premium.

5.7.2. Firm Heterogeneity

We further categorize the sample into two groups: state-owned and non-state-owned firms. This division allows us to determine whether enterprise ownership mitigates or exacerbates the impact of water risk. Certain researchers hold the belief that state-owned firms have the potential to enhance their profitability by utilizing natural resources rent (Lim & Morris, 2022) [105]. Contrarily, other researchers argue that state-owned firms serve as a means to implement government policies, although they may not achieve satisfactory financial results in order to fulfill non-commercial objectives (Huang et al., 2020) [106]. The issue of water is closely intertwined with human rights (Hazelton, 2013) [70], and it is imperative for state-owned corporations to assume more duties in safeguarding civil rights. As an illustration, Huang et al. (2020) discovered that state-owned firms incur higher costs in terms of pollutant discharge fees [106].

Table 10 demonstrates that the effect of water vulnerability varies between the cost of debts and the cost of equity. Regarding state-owned enterprises (SOEs), it appears that creditors are more inclined to request a water risk premium (R3), whilst equity investors show less concern about water risk to SOEs (R7). The water risk premium of debt of SOEs is attributed to their financial underperformance, as corporate solvency and corporate financial risk are significant determinants of the cost of debt. SOEs are more susceptible to experiencing greater financial losses and typically exhibit larger levels of debt ratios, as highlighted by Ferrarini and Hinojales (2019) [107]. The lack of concern from equity investors towards water risk can be understood as SOEs demonstrating a greater commitment to social responsibility in order to uphold their social and environmental credibility. Extensive research has consistently shown that companies with better corporate social responsibility performance tend to have lower costs of equity. Additionally, a company's previous responsible performance can provide significant insurance effects to protect their equity (Afrin et al., 2021) [6].

Furthermore, SOEs possess inherent political benefits when it comes to obtaining natural resources (Chen et al., 2011; Zhou et al., 2018a, b) [87,88,108]. SOEs, when compared to non-SOEs, are more favorable for engaging in rent-seeking activities and less inclined to suffer the associated costs (Zhou et al., 2018a, b) [87,88]. Consequently, investors are less inclined to want greater compensation for the uncertainty associated with the cost of equity of SOEs due to water risks. This implies that non-SOEs will face increased demands for compensation from equity investors for their water-related risks. The findings indicate that if water risk were to increase by 1%, equity investors would increase the cost of equity for non-SOEs by 2.4% (R8).

Table 11 demonstrates that firm heterogeneity mostly influences the moderating impact on debt costs. Panel A illustrates the diversity in the moderating impact of water regulation. R3 indicates that government water regulation does not appear to have a substantial influence on SOEs. As previously understood, SOEs may have a greater obligation to pursue non-commercial objectives, making them more inclined to comply with government directives for adaptive water management. The market would provide greater value to SOEs due to their governmental characteristics (Xiao & Yang, 2021) [109], which might counterbalance the adverse effects of underperformance. Meanwhile, SOEs are able to engage in power rent-seeking more effortlessly in order to mitigate the negative consequences of policies, without incurring the expenses associated with rent-seeking activities (Chen et al., 2011; Zhou et al., 2018a, b) [87,88,108]. Panel B illustrates the diversity in the moderating impact of water investment. R3 illustrates that government investment in water infrastructure does not replace the ongoing social responsibility of SOEs in addressing water-related matters.

6. Discussion and Conclusions

Examples of academics emphasizing the importance of recognizing and valuing natural resources and the significant impacts on the sustainability of businesses are limited. Our findings illustrate that the negative impact of deteriorating nature on corporate sustainability also rise from access to financial resources. Companies located in areas with high susceptibility to water vulnerability experience more financial expenses. Aligning with works done by Zheng et al. (2022) and Huang et al. (2018), who have confirmed that ecological issues themselves do negatively impact corporate financial sustainability [13,49], our findings with the research conducted by Kling et al. (2021) demonstrate that the detrimental consequences of ecological degradation rise from the availability of financial resources [48]. Along with the research done by Chen & Chen (2018) [95], Liu et al. (2022) [110], etc., this discovery also confirms the crowding out effect of natural environmental degradation on corporate resource acquisition, providing reasons for the necessity of green transformation for enterprises. Meanwhile, our findings also provide incremental information that the water issue has the same effect as climate change, rather than the highly heterogeneous impact of different environmental issues on businesses, as Bowen et al. (2018) believed [111].

However, we should also be cautious of the finding because the negative impact of current water vulnerability does have a limited impact on the increase in capital costs for enterprises. There may be two important reasons for this, one of which is that the current capital market has not yet attached great importance to the water risks faced by enterprises. But this does not mean that water risk is not important. In fact, some investors have started to examine the impact of water risks faced by companies on their operations. S&P has compiled the Global Water Resources Index to reflect investment opportunities in the current water crisis. Robeco, a portfolio investment bank in Hong Kong, stated that it has begun to consider the impact of water scarcity on semiconductor companies and has made corresponding adjustments in asset valuation for related companies. Some financial news has also reported that the world's largest climate fund managed by Nordea Asset Management will liquidate all its holdings of TSMC stocks by the end of July 2023, as the water usage for TSMC wafer mask layers did not meet expected targets. These business cases indicate that incorporating water risk into investment decisions may be an emerging trend. Secondly, water vulnerability has a potential long-term negative impact on business operations; thus, the significant short-term impacts of water vulnerability on business operations is hard to perceive (except for natural disasters such as sudden floods, which are often considered force majeure and excluded from corporate financing decisions). Therefore, if investors evaluate the availability of financing through the operational status of enterprises, the part that can reflect the impact of water vulnerability is also very limited.

Furthermore, we also investigate the moderating impact of two types of water governance tools, specifically water regulation and water investment. Our research indicates that water regulation is a risk factor that is linked to water vulnerability, because it has a positive moderating effect on the impact of water vulnerability on corporate capital cost. This discovery aligns with the research conducted by Tan et al. (2022), which suggests that external regulatory pressure intensifies the influence of environmental issues on the capital cost of corporations [49]. Meanwhile, the finding also indicates that government regulation, which is generally considered to contribute to the sustainable development of water resources, has benefits with potentially huge costs. In other words, we provide additional evidence supporting the notion that environmental regulations impose economic costs on businesses (Greenstone et al., 2012; Long & Wan, 2017) [78,79]. We believe that environmental regulation would lose its micro realization path and fail if it does not consider its impacts on social subjects such as enterprises, because social subjects cannot recognize and consciously abide by environmental regulation out of their own interests. Therefore, governments should pay attention to the social and economic costs brought by regulation and provide diversified ways to help enterprises and other social subjects adapt to and comply with environmental regulation. For example, our findings endorse the government's decision to expand green credit programs for enterprises, which helps address the capital costs associated with their transition to environmentally friendly practices.

It is self-evident that investment in water conservancy projects, etc., is important for the sustainable development of water resources; our research shows that investing in water resources overall is serendipity to corporations because it has a minor negative moderating effect on the relationship between water vulnerability and the cost of debt, providing empirical evidence that such investment to mitigate water risk brings economic benefits, especially in the context of corporate financing activities. At present, some voices question the necessity of investment in water conservancy, etc., but this study proves the value of this kind of tool from a commercial perspective; that is, improving natural conditions can stimulate economic growth by reducing the financing cost of enterprises, so as to enhance economic vitality and promote regional development (Kling et al., 2021; Huang et al., 2018) [48,49].

Moreover, we thoroughly analyze the aforementioned relationships using various sub-samplings and discover intriguing findings. Companies that use a significant amount of water could have put water adaptive management strategies in place, making them immune to water vulnerability. They seem to be less affected by water regulatory pressure, and investments in water infrastructure may generate short-term harms that prevent them from accessing financing. Industries that do not need significant amounts of water are vulnerable to water conditions and are influenced by government policies and investment for water resources. Their carelessness in managing water resources might be the cause of this. The findings align with the principles of the Natural Resource Dependence Theory, which posits that the deterioration of ecosystems diminishes the dependability of natural resource provisions, thereby heightening the environmental unpredictability encountered by businesses. (Tashman, 2021; Tashman & Rivera, 2016) [10,11]. There is a paucity of choices for enterprises to deal with natural resource scarcity since neither external organizations nor themselves can control the supply of natural resources, and they cannot internalize this supply via partnerships, mergers, or acquisitions. To successfully manage the negative implications of ecological uncertainty, enterprises must reduce their dependency on resources (Tashman & Rivera, 2016) [11]. When it comes to dealing with ecological uncertainty, our study shows that symbolic change initiatives, like trying to modify company identity, do not work. But by adopting eco-friendly practices, such as improving water resource management, businesses may increase their ability to deal with ecological uncertainty.

For businesses, water vulnerability is a major concern. Businesses should work together to ensure a steady supply of water. Businesses that do not use significant amounts of water should make it a top priority to collaborate with other social actors, such as residents in the local communities and business partners, about water risk and use water adaptive management strategies. Private companies should pitch in to solve water issues and divide up the load when it comes to water management. Furthermore, the current lack of stringent government water regulations has not significantly affected enterprises, and it has also failed to increase businesses' awareness of water-related issues. Enhancing the regulatory framework for water management is necessary, but it is also crucial to take into account the adverse consequences for enterprises when intensifying water regulation in the future. Additionally, water investments often have a positive effect in reducing regional water vulnerability, but there can be some adverse consequences for enterprises as a result of the internalization of such expenditures. Companies that implement water adaptive management practices have the potential to mitigate this cost problem, thereby gaining a competitive advantage.

7. Limitation and Future Research

This study is constrained by certain restrictions. Initially, we made an effort to include as many widely used indicators for assessing water vulnerability as feasible, but there is a lack of consensus on what these indicators should be. At present, there are many methods to evaluate water vulnerability. One is the single index evaluation method, such as the amount of water resources per capita. The defect of this method is that it can only reflect one aspect of water vulnerability. For example, the amount of water resources per capita can only reflect water scarcity to a certain extent. Thus, comprehensive evaluation methods become mainstream. The comprehensive assessment method requires the assessment framework to be set in advance, but the current assessment framework of water vulnerability is diverse, including the DPSIR framework for environmental assessment and the VSD framework proposed by the IPCC. The VSD framework only included three dimensions—sensitivity, exposure, and adaptability—while some scholars have further proposed the disaster dimension to be the fourth, which was also the water vulnerability assessment framework used in this study. At the same time, in order to improve the accuracy of the assessment, scholars have shifted from using statistical data to using remote sensing data, making water vulnerability assessment increasingly complex. However, the reason why the more advanced remote sensing measurement methods are not used in this study is that the main purpose of this study is not to propose a new method to evaluate water vulnerability but to strengthen the dialogue and connection between water resource management research and business research. Of course, we are still aware of the shortcomings of this paper in the assessment of water vulnerability. Thus, we mentioned that this study is only an attempt to perform interdisciplinary research. It is hoped that, in the future, more accurate data of water vulnerability data assessed by hydro-scientists can be used to study its impact on enterprise behavior decision-making and its economic consequences.

Furthermore, despite our efforts to utilize a comprehensive dataset encompassing all publicly listed companies in the Chinese A-share market, there is still a possibility of a selection bias due to the fact that listed firms represent only a small portion of all companies in China. Hence, it is advisable to use caution when interpreting our findings in relation to Chinese companies in general.

Additionally, our analysis reveals that water investment only negatively moderates the relationships between water vulnerability and the cost of debt at a slight significance and have no significantly moderating effect on the relationships between water vulnerability and the cost of equity. However, we have read the current literature and failed to find a better explanation. Thus, future research could perform further investigations to obtain a more robust and reasonable explanation.

Finally, this report represents a preliminary investigation into the microeconomic effects of water vulnerability. Given the aforementioned constraints, it is imperative that further investigations are conducted to substantiate the conclusions presented in this work. Hence, it is advisable to take caution when relying on the findings presented in this paper.

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