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Impact of Extreme Drought Climate on Water Security in North Borneo: Case Study of Sabah

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Abstract: For countries in Southeast Asia that mainly rely on surface water as their water resource, changes in weather patterns and hydrological systems due to climate change will cause severely decreased water resource availability. Warm weather triggers more water use and exacerbates the extraction of water resources, which will change the operation patterns of water usage and increase demand, resulting in water scarcity. The occurrence of prolonged drought upsets the balance between water supply and demand, significantly increasing the vulnerability of regions to damaging impacts. The objectives of this study are to identify trends and determine the impacts of extreme drought events on water levels for the major important water dams in the northern part of Borneo, and to assess the risk of water insecurity for the dams. In this context, remote sensing images are used to determine the degree of risk of water insecurity in the regions. Statistical methods are used in the analysis of daily water levels and rainfall data. The findings show that water levels in dams on the North and Northeast Coasts of Borneo are greatly affected by the extreme drought climate caused by the Northeast Monsoon, with mild to the high risk recorded in terms of water insecurity, with only two of the water dams being water-secure. This study shows how climate change has affected water availability throughout the regions.

Keywords: drought; climate change; water security; water demand; water resources; water scarcity; remote sensing; satellite imagery; weather pattern; hydrological system

1. Introduction

Water resources are the core medium of the environment through which we feel the direct impacts of climate change [1], whereby abnormal weather can lead to water scarcity. Extreme interannual variability of seasonal rainfall and prolonged dry seasons due to climate change pose water shortage challenges to local communities in terms of meeting their water demands. Droughts exacerbate water scarcity and cause negative impacts to people's health and productivity [2]. Abnormally dry weather due to extreme drought can cause a serious imbalance in water cycles that changes the precipitation and evaporation processes, atmospheric water vapor circulation, and soil moisture availability [3], resulting in low water volumes in streams, rivers, and reservoirs. At the same time, the current demand for water exceeds supply, exacerbating the problem even more. This is due to overpopulation and overextraction from human activities. There is also a direct impact on the groundwater recharge process, due to climate change causing abnormal rainfall patterns and an increase in temperature, affecting the amount of water in the ground [4]. In the studied area, groundwater is not the main water resource for dams; however, the increased deficit of water resources at the surface and the low rainfall for recharge are associated with climate change—in particular drought events—putting more pressure on the groundwater resources. Climate change could become an additional challenge to groundwater resources in particular, and even more for transboundary aquifers, where it impacts different political borders and boundaries, which could create intrusions and conflicts over the watersheds borders [5]. It is difficult enough to adapt to the increasing severity of climate change for countries whose watersheds and river basins lie wholly within their political territories and boundaries. However, for some countries whose water resources cross borders, this means multiple political entities share the water resources under challenging extreme climate conditions [6,7].

In turn, this creates inequalities in the distribution, allocation, and use of the water aquifers, which could be a cause of political targeting and rivalry for some nations [8]. Consequently, water tensions and disputes are generally resolved diplomatically, often involving cooperation and negotiations between states. Regarding international watershed agreements, an estimated 300 have been produced between border states with shared rivers [9–11]. However, none of these transboundary watershed agreements have included shared groundwater basins [11]. Groundwater has been left out and excluded, yet an estimated 99% of the earth's accessible freshwater is found in aquifers and about two billion people rely on aquifers as their sole source of water [12]. Nevertheless, a positive development came in 2010, when an agreement was reached for the Guarani aquifer in South America. The Guarani Aquifer Agreement was signed by four countries—Brazil, Uruguay, Paraguay, and Argentina—and set forth a series of principles and objectives for sustainable management of the groundwater [13]. This agreement allows each country to exercise sovereign territorial control over its own portion and border of the Guarani Aquifer System in accordance with the norms of international law [14]. The existence of the international agreement is an important force in stimulating an alliance between states to address the transboundary aquifer's issues as a shared resource, thus producing better knowledge about shared groundwater. However, the agreement has not entered into force.

The dearth of knowledge and the difficulties of managing hidden resources could be forces that promote international groundwater cooperation [15]. There is limited information and knowledge on the real groundwater dimensions and the geological characteristics and strata that contain these water reserves, territories, and borders regarding their exploration rates and their roles in regional development of aquifers [16]. There is also a lack of interest in multiactor partnerships and international projects, which could be the cause of the setbacks and stagnation of the Guarani Agreement [17]. Overexploitation of groundwater can diminish the surface water availability, subsidence, and saline water intrusion. This is aggravated by changes in the climate system, which have greater implications for the hydrological cycle, as water resources are the core and essential elements in the entire system and are vulnerable environment components in terms of water availability, timing, quality, and demand [18]. On the other hand, most transboundary water agreements are based on the assumption that future water supply and quality will not change. Additionally, most treaties and international agreements have failed to include an adequate mechanism to address the changing climate conditions [7,19]. In many cases, adapting to climate change will require changes in the institutions and policies that have been put in place under international treaties. As noted by McCaffrey [20], the treaty laws themselves would not ordinarily permit unilateral modification or withdrawal under the changing circumstances; they would only respond within the framework of the existing treaties to climate change [21].

In this regard, transboundary agreements, or international treaties and principles related to sharing water, need to take on new forms and arrangements, where the old agreements may need to be renegotiated within the current context to include the need to change climate components [22]. The existing treaties and agreements should explore the degree and handling of the strain of future pressure [23], particularly on climate change, and offer strategies for reducing this pressure, especially for shared watersheds. Climate change will certainly alter the form, intensity, and timing of water demand, precipitation, and runoff, meaning past treaties and agreements may no longer be adequate for the present pressures of climate change [24]. These difficulties increase following wet seasons with low rainfall, which worsens the El Nino effect, especially in tropical countries where this causes high water stress and threats to the water supply for affected communities. Due to climate change, water availability is becoming less predictable in many areas, especially in the case of abnormal weather changes. Increased drought periods and higher temperatures are projected to affect the distribution of rainfall, the river flows used for water availability, and the groundwater, and to further deteriorate water quality, causing deleterious effects on the water supply [25]. The warming of the climate affects multiple different aspects of the global climate system, especially the surface temperature equilibrium, which in its current state will disrupt the temperature balance and cause global weather disruption, over the long term leading to climate change, significantly altering the hydrological balance, cycle, and processes [26,27].

Irregularities in rainfall and warming can be seen over the last two decades due to climate change, affecting the annual precipitation and daily temperatures [28], which has caused severe several flooding events and shoreline inundations along the coasts [29]. Additionally, there have also been prolonged incidences of dry periods in recent years that have increased the frequencies of dams bursting and forest fire incidences due to increased hot and dry spells, which has led to more than 7000 cases of forest fires being reported each year, with an average of 300 daily cases [30]. Due to prolonged dry spells, water levels in many rivers and damns across the nation have dropped to critical levels, creating a nationwide water crisis due to heat waves, drought, and complete lack of rain [31,32]. Severe drought events cause multiple water shortages, water cuts, and disruptions to quality of life components for millions of citizens. Other effects include agricultural losses, reduced hydropower supply, and indirect impacts encompassing losses to industry, export earnings, and a severe food supply deficit [33–35]. Such events are projected to happen with greater frequency in the future as surface temperatures follow the global trend of continuous warming [36].

The effects of drought can be deleterious. Marcos-Garcia et al. [37] stated that drought is a major natural hazard that can be costlier than any other natural hazard. Smith and Katz [38] mentioned that the global economic losses caused by droughts are significantly higher than that of any other natural disasters, estimated at a cost of around $6–8 billion USD every year. At the national level, droughts can devastate agriculture, ecology, and the economy. On a regional scale, drought can lead to greater instances of fires and significantly deplete water supply reservoirs and groundwater levels, leading to a variety of socioeconomic and environmental impacts [39]. Even though Southeast Asian nations—especially Sabah in Northern Borneo, Malaysia—are countries that are abundant in water resources, they are nevertheless facing a looming water crisis due to increasing demand, unmatched water supply, lack of effective river basin and water resource management, and a growing population [40]. With the expectation that drought events will happen with increased frequency and intensity in the future due to the exacerbating effects of climate change [41], Malaysia is currently ill-equipped and ill-prepared to face the effects [42,43]. In light of this issue, there is a pressing need to assess the degree of vulnerability towards drought to prepare strategies for drought mitigation.

Water scarcity is one of the most significant natural disasters affecting society and it is an important environmental issue that needs to be addressed. It was defined originally by Falkenmark and Lindh [44] as the finite nature of water supplies in terms of the number of people that compete to be sustained by a single flow unit of water measuring 10^6 m^3/year, with gross water demand of 1000 m^3 per capita/per year [45], which is based on the annual water resources and population [46]. The physical amount approach is used across the globe to examine water resource availability by applying the threshold to indicate water scarcity. However, Mehta [47] disagreed and portrayed water scarcity using the absolute or volumetric term and by only using physical measures, arguing that scarcity is not only about the natural water conditions, but instead is usually mediated and influenced by socio-political constructs and institutional processes. It is important to distinguish the fact that water scarcity can be due to real biophysical scarcity, can be constructed through manufactured political influence and policy processes, or can be due to a combination of socio-political, discursive, and institutional factors.

The issues of constructed water scarcity and the dependency of the market on environmentalism were brought forward by Garrets [48], who utilized neoliberalization in his main agenda. In his findings, neoliberal water governance was found to play a significant role in overtaking discourses of mismanagement and politics in water governance. He discussed how neoliberal policies and mechanisms form a backdrop for the importance of drought factors in the context of water scarcity and in achieving justice. This highlighted the application of government rules or market-mediated private decisions, which are always political in their implications, consequently influencing socio-environmental acceptance and changes [49,50]. In this regards, this particular research also dealt with constructed scarcity, which leaves many facing constant disruption to their water supply due to socio-political problems and inefficient water resource management, adding to the problem of increasing water demand due to the growing population and accelerating climate change impacts. Hussein [51] identified the construction of a narrative around water scarcity for his case study in Jordan, which was mainly due to water insufficiency and water mismanagement. He explained how the narrative of water insufficiency was constructed by external factors from the government as a result of water scarcity. This situation mainly results from either conserving the water supply and maintaining the status quo for the current water uses, or through mismanagement and increasing the efficiency of the water sector for economic purposes. This is related to the work by Jeremy [52], who stated that the resilience and sustainability of water resources depend on the level and intensity of conflict resulting from political power, global trading, and the major challenges associated with climate change. According to him, resource scarcity can occur at the regional, local, or national level, depending on the different priorities and the meaning of scarcity that is applied.

In line with his, in his case studies Hussein [53] presented conflicts of water scarcity and interdependence among water-sharing countries, which have created complex conflicts over shared water resources and which will escalate as a result of growing populations and urbanization, as well as the negative consequences of climate change. The literature addressed the interstate conflicts over water resources that are shared across political borders—referred to as transboundary water conflicts [54,55]. Political geography determines transboundary water conflicts and cooperation among water-sharing states; physical geography determines the water supply characteristics in a transboundary basin; and economic geography identifies the parameters of water demand in a particular basin experiencing conflict [54]. However, political geography has been given priority in transboundary water interactions. In the regard, the political perspective has two well-defined approaches, namely hydropolitics and critical hydropolitics [53]. The hydropolitics literature systematically focuses on the nature and dynamics of interstate conflicts and cooperation over transboundary water resources, which are dominated by the role of politics. Critical hydropolitics is more state-centered, focusing on socio-ecological networks that have developed around the transboundary water resources, which can be within one nation state or can transcend the water-sharing states' borders. This combines elements of political and human–environment geography networks, and can mislead efforts to resolve transboundary water conflicts [55].

As for the term water security, there is no consensus among researchers on the definition. Indeed, the use of the term has increased rapidly across a wide range of disciplines in the last decade as the endpoint of climate change. Despite water security being a cornerstone of contemporary environmental and resource management, Lankford [56] indicates that the growing number of scholars, policymakers, and international organizations that have adopted the term and concept in framing water-related issues has led to an apparent divergence in the different frameworks of water security. Lankford [57] has described water security "as the sufficiency and equity of water resources, viewed as a transitive space for community, individual, or system movements as a result of natural and human water-related drivers, alongside demand and supply in water allocation". Zeitoun et al. [58] found that water scarcity is open to different interpretations and has different meanings across different disciplines, depending on the subject area, such as agriculture, engineering, fisheries, public health, anthropology, environmental science, and water resource studies. On the other hand, this has led to diverse methodological and analytical approaches towards the evaluations of water security [59]. Zeitoun et al. [60] defined water security "as a degree of equitability and balance between the interdependencies of the related security resources (water resources, energy, climate, and food) that play out within the web of socio-economic and political forces at multiple spatial levels, highlighting water's centrality".

The actual framework of the broad disciplines is associated with one feature of the analysis in terms of the factors or characteristics that make it more or less vulnerable to the future impact of the stressor event [61]. One of the essential elements of this research on water security has to do with what Bakker [62] defined as an acceptable level of water-related risk to humans and ecosystems, coupled with the availability of sufficient water quantity and quality to support the continuity of livelihoods, national security, human health, and ecosystem services around the world. In this particular case, this study aims to analyze the water security within conventional dams in the water supply system in the Malaysian state of Sabah, which is in the northern part of Borneo. This is because in the existing literature, there are comparatively very few studies similar to those cited above that are located in Sabah. For instance, although the National Hydraulic Research Institute of Malaysia (NAHRIM) has undertaken several hydrological studies over the years, out of their many publications, there has only been one that has focused specifically on the eastern states of Sabah and Sarawak, as compared to five that focused on or were specifically set in the peninsula states [63]. This is not to say that Sabah and Sarawak have been completely neglected, as they are no doubt included in NAHRIM's many studies that encompass the whole of Malaysia, but only demonstrates that when it comes to more region-specific research, the Bornean states tend to be overlooked in favor of the Malaysian peninsula, meaning they are lacking in data.

This lack of data is even more apparent when considering the fact that Sabah by itself constitutes 22.37% of the land area in Malaysia [64] and contains a large portion of the ecological megadiversity of the Bornean rainforest [65,66], which can be seen as the most important water basin in the country. Thus, research should not be focused on the Malaysian peninsula alone but instead should include Malaysian Borneo, not only to obtain a balanced view of the impacts and implications at a national level, but also to advise policymaking decisions. Seeing the trends in water supply can help governments gauge if further development may be needed, when and how much may be needed, and make appropriate planning decisions ahead of time to minimize ecological and sociological impacts. Therefore, this study attempts to provide a picture of water supply availability and vulnerability relating to drought events in the northern part of Borneo by studying the water levels in dams that supply water for consumption and how they are affected during periods of abnormally low rainfall. Consequently, this paper is important because it provides a way forward to achieve Sustainable Development Goal (SDG) 6, which relates to improving access to water and sanitation in national and transboundary settings, taking into account three important factors—the power of asymmetry, climate change, and increasing risk. In this case study, there are multiple levels involved at which the water is being managed, with different geo-political and administrative boundaries. Therefore, implementing integrated water resource management from the SDG 6.5 framework [67,68] is very essential at this point to enhance cooperation at all levels, so that better adaptive governance can be achieved. At the same time, allocation of the water resources in Sabah is more asymmetric than in the peninsula states.

2. Materials and Methods

2.1. Study Area

The study area is Sabah in the northern part of Borneo, as it is one of the regions currently facing water scarcity and continuous increasing demand for water. It has been plagued with problems and inefficiencies in water resource supply and management, with nonrevenue water (NRW) reaching as high as 56.3% in these regions [69]. Additionally, North Borneo is an equatorial part of the world that has abundant water resources, with a tropical rainforest climate that experiences a high year-round level of rainfall of approximately 2600 mm of annual precipitation [34], with a rainfall volume of around 950 km^3 [70]. This shows the significance of the amounts of runoff in rivers and streams, which have higher reliability as water sources year round. However, the region is, nevertheless, facing a looming water crisis, especially due to the southwest monsoon season, which causes weather changes that often bring about prolonged and extreme drought. This occurs every year in this region, resulting in 4 to 6 months of dry water dams and decreased yield conditions. The problem is aggravated more by the increasing water demand due to increases in population and economic activities, insufficient water supply, and ineffective water resource management [71,72]. Thus, this research is important to obtain a view of the impacts and implications of the drought events in the northern part of Borneo on the water resources in Sabah, especially on how abnormally dry periods affect the water levels in the major supply dams.

In this research, there are six major water supply damns involved, which were divided into main regional clusters throughout the state. These represent the entire northern part of Borneo, which comprises west, southeast, and northeast coastal regional water dams. The dams are of different types and have different methods of water abstraction. Dam C is a 100% off-river storage (ORS) dam that is located on the Northeast Coast of Borneo. It was built in 2009 and has the largest capacity of all the dams. It has a storage capacity of 35 million cubic meters (MCM) and a maximum water level of 30 m. Its critical level is at 67% capacity, which is 23.5 MCM or 26.50 m. Dam D is a 100% impounded dam and is the newest, having been built in 2012. It has the second-largest storage capacity at 31.3 MCM, and a maximum water level of 34 m. Its critical level is 58% capacity, which is 13.5 MCM or 29.0 m. Dam A is a combination dam, with 30% of its water abstracted directly from river flow and 70% from impoundment. It is located on the West Coast and was originally built in 1997 and upgraded in 2007. Its storage capacity is the third-largest, with a capacity of 23.78 MCM and a maximum water level of 130.5 m, and with a critical level at 38.48% capacity, which is 13.83 MCM or 120.0 m. Dam B is also a hybrid dam, with 55% of its water coming from river flow and 45% from off-river storage. It was built in 2008 and is located on the West Coast, with a total storage capacity of 10.51 MCM and a maximum water level of 27.0 m. Critical indicators for dam B are 50% capacity, which equals 5.83 MCM or 20.03 m.

Dam E gets 100% of its water from impoundment and is relatively old dam located on the Southeast Coast of Borneo. It was built in 1985 and later upgraded in 1998. It has a much smaller capacity, with a storage capacity of 1.32 MCM and a maximum water level of 80.0 m. Its critical level is at 41.31% capacity, which is equal to 0.77 MCM or 75.50 m. Finally, dam F was built in 1986. It employs a mix of 55% water abstraction from river flow, with the remaining 45% coming from impoundment. It has the smallest capacity out of the 6 dams at 0.67 MCM. Its maximum water level is 55.50 m. Its critical level is at 43.13% capacity, which is 0.38 MCM or 53.65 m water level. This information was obtained directly from the National Water Supply Department. These dams were selected as research targets because they are the major and active dams used for municipal water supply for the entire area of Sabah in Northern Borneo. They are constantly monitored and have up-to-date, day-to-day data available. As main municipal water supply sources, these dams constitute key components in evaluating water security from a conventional supply perspective.

2.2. Dam Water Level and Rainfall Analysis

For the analysis of the impact of extreme drought events on water levels and risk assessment of the water security of the dams, data for the dam capacities and specifications, daily water levels, and daily rainfall recorded at each dam were involved. Six major water damns in different regions were observed and analyzed to assess the water level trends and patterns for each dam, along with the rainfall variability across all dam areas to determine the specific drought period events on an individual basis. According to Ahmad et al. [73], the average annual rainfall in Sabah in Northern Borneo is around 2630 mm. The determination of the drought period was conducted using statistical methods for rainfall data to detect unusually low rainfall for the available period of time. From the raw daily rainfall data, monthly rainfall was calculated and the mean monthly rainfall was derived. The individual monthly rainfall values were then compared against the mean to obtain the percentage deviation from the mean, which was then evaluated to identify periods of significantly low rainfall. From there, the drought period was identified. The working definition was devised to overcome the limitations, such as lack of historical data for comparison, as well as lack of a universal standard or threshold for drought. There is a need for better guidelines that are simple, practical, and more functional to determine abnormal drought periods using limited data, such as rainfall data. Therefore, this is the main aim of this research.

It is important to note that the trends are observed based on the specific period of drought occurrences and the short-term changes within the stated timespan for greater accuracy. Previous studies in the literature, such as Odeh et al. [74–76] and Mohammed et al. [4], have done extensive work dealing with drought management and dams, mostly focusing on groundwater and long-term impacts, which involved the use of many databases with complex and technical application of conceptual modeling and visualization approaches, such as GIS and remote sensing. On the other hand, these could be the biggest limitations for some regions for which datasets are absent, which lack historical data for long-term analysis and comparison, or which have problems with accessibility relating to the databases and information. In this research, the advantage of using a more targeted and specific drought period for the detection of significant, abnormally low rainfall, and short-term changes on the actual day of the drought event is emphasized. This approach could provide a specific timespan with a well-defined interval that presents the sensitivity of small or even extreme changes in rainfall and the resulting effects on the water dams. This is done to achieve greater accuracy and a more simplified methodology and evaluation, specifically to overcome analysis limitations, such as the lack of a database. At the same time, the research can be seen as more functional in determining the abnormal drought events, especially when using limited data, such as for rainfall. This reveals that many different methodology approaches and frameworks were adopted by other previous authors due to the lack of universal standards and thresholds for drought vulnerability assessment research.

To achieve this, we identify low rainfall periods, for which the percentage deviation from the mean monthly rainfall is calculated for each month at each dam. If the percentage deviation shows a significant negative value (<−50%) or has a negative deviation for 2 months in a row with a cumulative value of <−50%, it can safely be said that these are periods of abnormally low rainfall. These effects will also be taken as cumulative, as even if the rainfall level meets the mean for a particular month immediately following a succession of dry months, it will not be enough to restore the system equilibrium, especially if it is followed by another dry month. Hence, the working definition of drought for this study is an extended period of rainfall or lack thereof (≥2 months) that is significantly lower than the mean (<−50% deviation or cumulative value <−50% for both months). The drought is considered to be finished when rainfall equals the mean in two successive or alternating months, or is significantly higher than the mean (>50% deviation). Using the drought period that was previously identified, the water level trends for dams within the drought period were studied. This was done to find out the extent to which the drought event affected the water levels of the dams, and how resilient the dams were as water supply sources with regards to being able to maintain a continuous supply of water during the drought event. As an extension of this, a risk assessment of the dams was carried out, where their level of risk for water insecurity was evaluated by calculating the number of days a particular dam spent in a water-insecure state, wherein the water level fell below critical levels.

3. Results and Discussions

Figure 1 below shows the water level during the specific drought period for each major regional cluster of water dams in the study area. The red vertical lines denote the drought period. Overall, the results show that the effects of drought on the water levels for each of the dams were clear and pronounced.

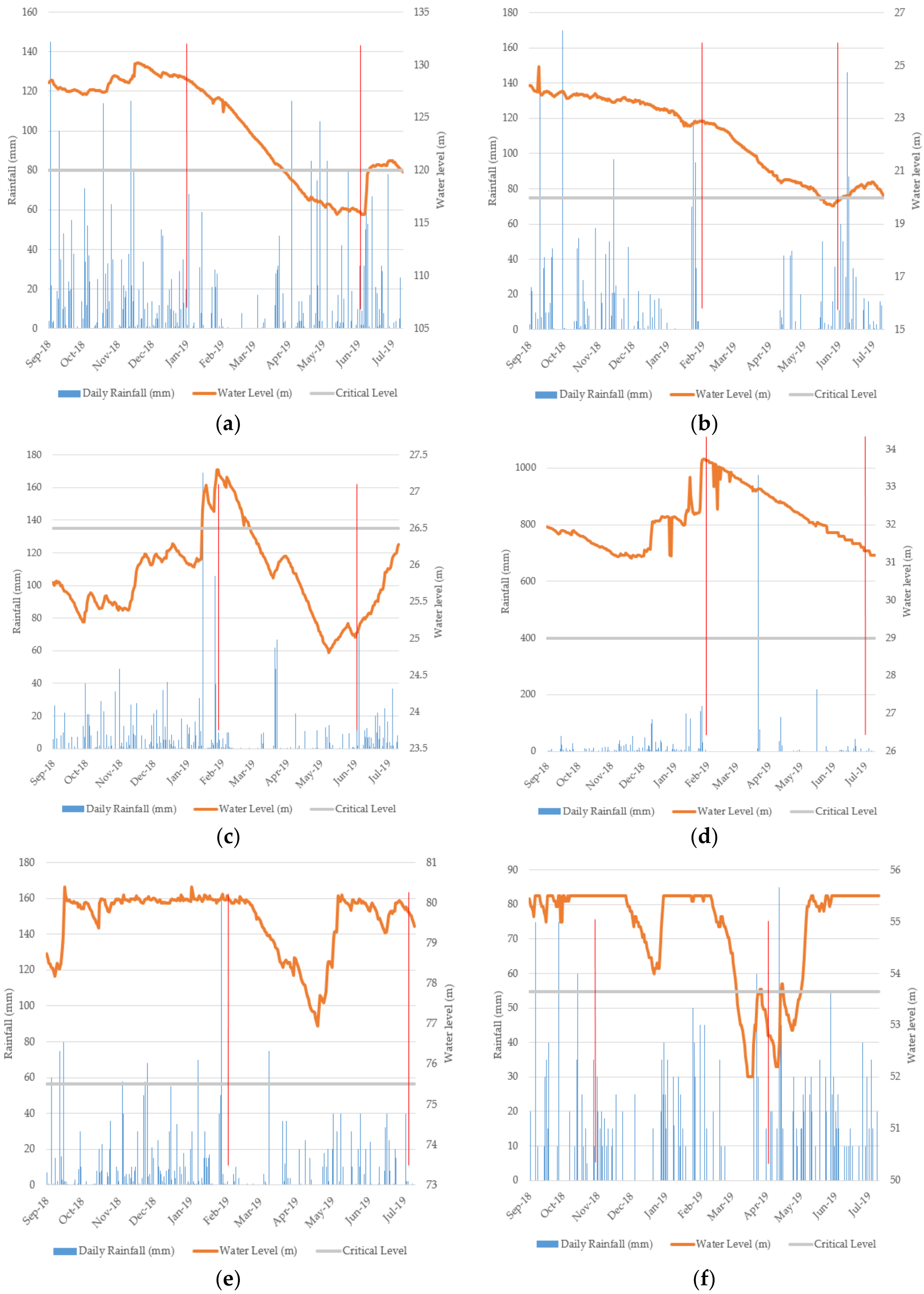

Figure 1. Water levels in meters (m) during the specific drought period denoted with red vertical lines for each of the major water dams in each region: West Coast (**a**,**b**); Northeast Coast (**c**,**d**); Southeast Coast (**e**,**f**).

All dams showed sharp and significant drops in water levels during the drought periods. In Figure 1, both West Coast water dams show sensitivity to drought periods and rainfall. Within the drought durations beginning in January, the water level in dam A markedly decreases from almost 130.0 m down to below the critical water level, reaching around 115.0 m by the end of the drought in June. Increased rainfall at the end of April and through May managed to stabilize the downward trend to a flatter gradient, but the water level in dam A was already below critical levels. It is clearly shown that the drought has a severe effect on water levels in water dam A and it takes some time for the dam to recover to its initial levels. Likewise in dam B, during the drought period it received almost no rain for the entire months of February and March. Correspondingly, the water level decreases at a higher rate than usual during this period. Several days of rainfall in April slightly increase the water level for a while, but the subsequent dry days lead to a further decrease. Near the end of the drought, the water level falls to a critical level before recovering and increasing again after the end of the drought. In comparison with the other dams, dam B is more secure in terms of its supply, as it is less affected by drought effects and does not stay below critical levels for as long as the others.

For the Northeast Coast water damns, it can be seen that the water levels in both major dams correspond closely to rainfall frequency and intensity. During periods of frequent and more intense rainfall, the dam shows a net increase in water level. However, regarding the overall trend, damn D does not seem as sensitive to rainfall as dam C. For instance, during late March, there was an extremely intense rainfall event, for which 975.00 mm of precipitation was recorded. However, the water level in the dam barely shifted. The same thing also occurred in mid-May, when a high rainfall event occurred, however this did not cause a significant change in water level. This indicates that while rainfall can influence the water level in the dam to some extent, the dam itself is not primarily reliant on rainfall as a water source. As with dam A, there is a spike in the water level that corresponds to frequent rainfall, as compared to high or heavy rainfall. This is within a short period and only had a small effect on the water level. For example, in June, a dense cluster of frequent rainfall days caused a sharp increase in the water level of up to 5 m, while occurrences of heavy rainfall below 60.00 mm did not seem to affect the water level. Overall, it can be seen that the water levels in the dams are more affected by consistent rainfall rather than heavy, short rainfall.

On the other hand, throughout the drought period from February to May, the water levels in the Northeast Coast water dams plummet during periods of very little to no rain. This is especially obvious in February to mid-March and April to May for dam C. Water levels show a consistent steep decline throughout this period, falling from a peak of close to 27 m to the lowest point of 25 m, well below the critical level. The drought has a crippling effect, causing the dam to undergo the most drastic decline during this period. If the drought had been more prolonged, the dam might have failed and been shut off due to chronic shortage of water. For dam D, from February to June in the drought period, the water reserves steadily decreased. At the beginning of the drought, they stood at around 33.6 m, while at the end of June the level had fallen to almost 31 m. Fortunately, dam D did not fall to critically low water levels and was still able to function with a comfortable margin. Similar to dam E, water levels never fall to a critical level throughout the entire drought period, indicating that the dam is very adequate at supplying water for local demand. The presence of some rainfall kept the water level filled to full capacity; although this slightly decreased in June due to the continuous days without rainfall. It then quickly recovered once the rainfall frequency increased again, meaning dam E is relatively water-secure.

In determining the effects of rainfall patterns and drought occurrence on water levels in the major important water dams, statistical method regression analysis was used with a nonlinear equation, which used the polynomial power curve in order to get the best fit curve for the regression equation to further explain the relationship between water levels in the dams with rainfall yield in this study. The polynomial equation is very powerful for explaining extreme behaviour in datasets, showing the actual complex effects or the relationship between an independent variable and a dependent variable, especially in real-world scenarios [77]. This relationship does not exist in a single direction and may affect other variables, especially those that are not accounted for in the research. The polynomial best fit curve in the regression line is used data points that fluctuate greatly, such as in this case, where the water levels in the dams drop drastically due to the drought period, especially with abnormal rainfall data and short-term changes to the water level; thus, it could capture the pattern for extreme short-term values in that exact period of time [78]. Overall, from the model summary obtained from Figure 2, a much stronger relationship of rainfall with water level can be seen for all the dams from the different regions of the study area with the higher order of the equation powers using the polynomial equation when compared to the linear regression equation. The R^2 values were mostly <0.001, ranging from 0.0004 to 0.0043, which is the drawback of linear statistical analysis. However, in this research, using the polynomial equation and analysis resulted in better and more superior results, with R^2 values ranging from 0.425 to 0.8105, showing from weak to strong positive relationships for all the water dams, with significance values of $p < 0.05$ and $p < 0.01$ after the best fit curve analysis was performed for the data points [50] involved in this research. Additionally, the obtained R^2 values were recorded mostly at more than >40%, indicating that most of the percentage values of the rainfall amount explained the yield and availability of water resources in the regions' water dams.

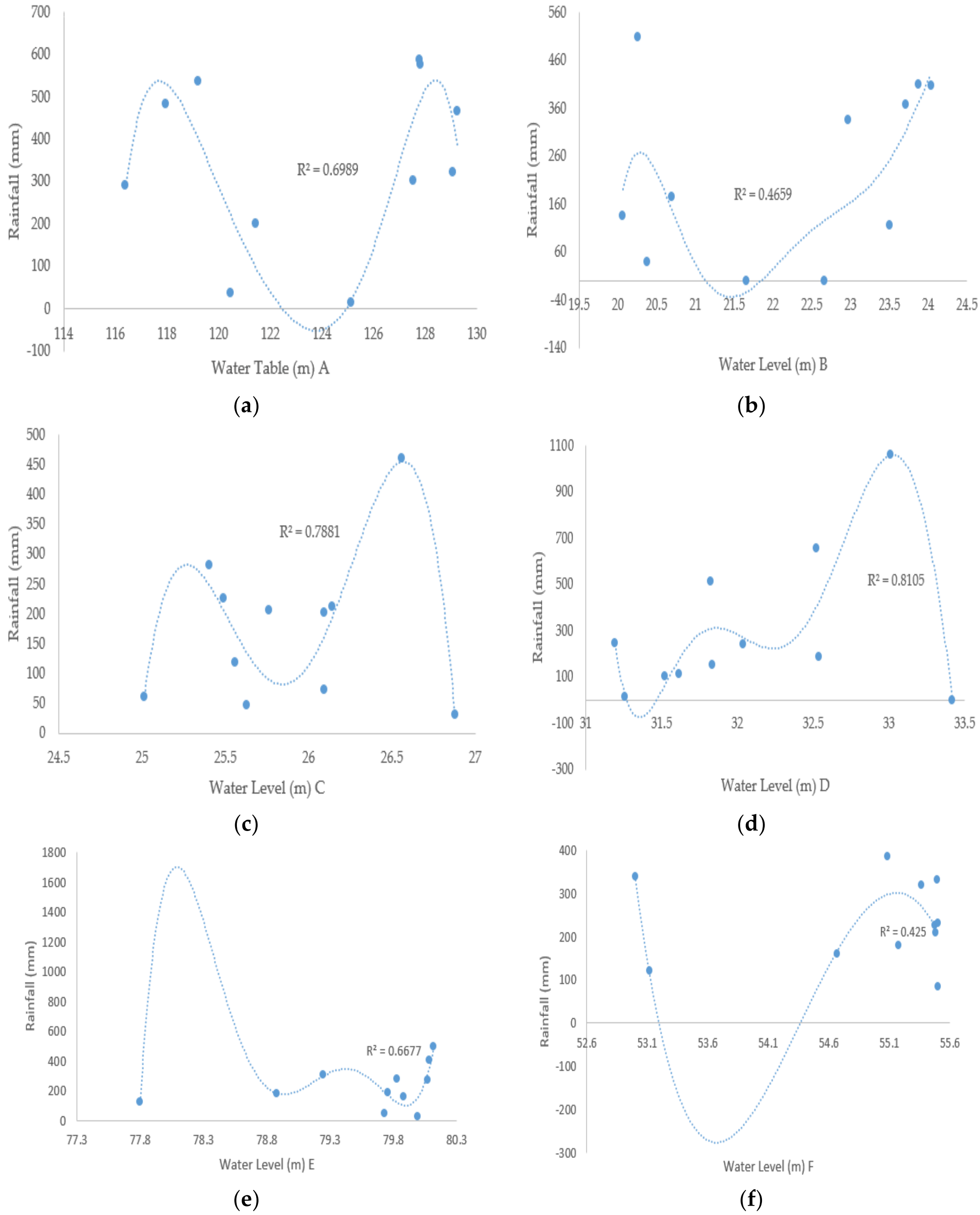

Figure 2. Model summary of polynomial equation analysis for the dependent variable (water level, m) against the independent variable (rainfall, mm) at: (**a**) water dam A; (**b**) water dam B; (**c**) water dam C; (**d**) water dam D; (**e**) water dam E; and (**f**) water dam E.

For the risk assessment level of the dams, based on the water level indicators marked by the National Water Guideline from the Water Supply Department, the numbers of days that the water level at each dam categorized as good, alert, or critical are analyzed and tabulated in Table 1 below. From Table 1, the North Borneo of Sabah, Malaysia dams ranked from most at risk to least are as follows:

i. Dam C (Betotan, North East Coast of Borneo)
ii. Dam A (Babagon, West Coast of Borneo)
iii. Dam F (Timbangan, South East Coast of Borneo)
iv. Dam B (Telibong II, West Coast of Borneo)
v. Dams D and E (Milau and Sepagaya, North and South East of Borneo)

Table 1. Water level status day count for all six major dams for the specific drought period from September 2018 to July 2019.

	Dam					
Water Level Indicator	**C**	**D**	**A**	**B**	**E**	**F**
Number of days at good * level	20	314	199	212	314	231
Number of days at alert * level	23	0	38	83	0	29
Number of days at critical * level	271	0	77	19	0	54
Percentage of days at critical level	86.31%	0%	24.52%	6.05%	0%	17.20%

* As determined by the National Water Supply Department.

Further analysis of the risk factors for water insecurity for each of the water dams is essential for assessing the water insecurity, such as their sensitivity to rainfall and how severely they were impacted by drought.

The results of the analysis are compiled in Table 2. The results show that dam C is an extremely water-insecure dam, having spent 86.31% of nearly 11 months (271 days) with water levels at or below the critical level. This shows that the dam either has a problem of undersupply or overdemand. Dam C can be seen to be extremely vulnerable during periods of drought, where it drops so far below the critical level that if the drought had been more prolonged, it would likely have become unable to function. Thus, this is a significant problem for the Northeast Coast region. One way to mitigate the risks is to either tap an alternative source for water supply, such as groundwater, or consider constructing new intake points on other nearby rivers or tributaries for water abstraction. Alternatively, interbasin transfer could be considered, where water is transferred to the dam from other reservoirs with surplus raw water.

Table 2. Risk factor assessment based on drought impact and rainfall sensitivity for water supply.

Dam	Risk Factors		
	Water Supply	**Sensitivity to Rainfall**	**Impact of Drought**
C	- Very water-insecure - Below critical 86.31% of the time - Undersupply or overdemand	- High - Water level corresponds closely to rainfall frequency and intensity	- High - Significant net loss of water - Water levels fell to the lowest point during drought
A	- Slightly water-insecure - Water levels below critical 24.52% of the time (only during drought)	- Moderate - Water level unaffected by rainfall <60 mm and isolated heavy rainfall	- High - Water levels fell most sharply to critical during drought
F	- Slightly water-insecure - Water levels below critical 17.20% of the time	- High - Changes in water level directly parallel to rainfall events	- High - Smaller capacity means less tolerance for drought events
B	- Mostly water-secure - Water levels below critical 6.05% of the time (only during drought)	- Low - Water level not particularly sensitive to rainfall	- Moderate - The water level did not sharply decrease during drought
E	-Water-secure - Water levels adequate to meet demand even through drought	- High - Changes in water level directly parallel to rainfall events	- Low - Smaller tolerance for drought events offset by adequacy of water supply
D	- Water-secure - Water levels adequate to meet demand even though drought	- Moderate - Not particularly sensitive to rainfall	- Moderate - Water level decreased but not to a critical level

Dam A was the next most at risk, having spent 24.52% of the time or 77 days at a critical level. As seen in Figure 1, the critically low water level was mainly due to the effects of a long period of drought. Under normal conditions, the water level in dam A would be considered adequate. Therefore, risk mitigation for dam A is mainly focused on increasing its tolerance to extreme drought events, either by decreasing demand through educating the public to conserve water, or by performing water rationing during drought events. Dam F had 17.20% or 54 days at a critical level during the same period. The reason dam F is at risk is because its small capacity makes it less tolerant to sudden environmental changes, and therefore places it at risk for extreme weather events, especially drought. A way to reduce these risks for dam F is to upgrade it to a larger capacity so that it has a larger buffer for drought events. Dam B spent 6.05% of the time or 19 days at a critical level. This is not particularly significant in comparison to the other at-risk dams but indicates that there is room for improvement. The issues for this dam are similar to dam A, facing water stress only during drought; hence, the mitigating strategies are the same as for dam A, which are educating the public and water rationing during drought. Finally, dams D and E are not at risk, having never dropped to critical water levels during the period of this study. Even during a drought, while their water levels did decrease, they did not drop low enough to reach critical levels. This is good, as it shows that they are robust water supply sources that are capable of tolerating droughts of a similar extent and period as the one studied in this research.

The level of risk for water supply insecurity in each region where water supply is served by a dam, as discussed above, is visually produced and represented as a remote sensing map in Figure 2 below. In comparison to the rest of the major water dams in these regions, dam F is seen as more volatile and prone to dramatic changes in water levels. This is most likely due to its much smaller capacity, which may cause it to have less latency in absorbing the effects of water stress. The study area for dam E is also very prone to significant risk in the case of a prolonged drought event. This could be because this area had more dry periods compared to rainy periods. In February and March, a long period of no rain led to a swift and steep decline in the water level, falling extremely quickly below the critical level. After this, increasing rainfall led to a quick spike in late March, but fell again in April due to low rainfall. Water levels declined once again, particularly in December, following the lack of rainfall in this area.

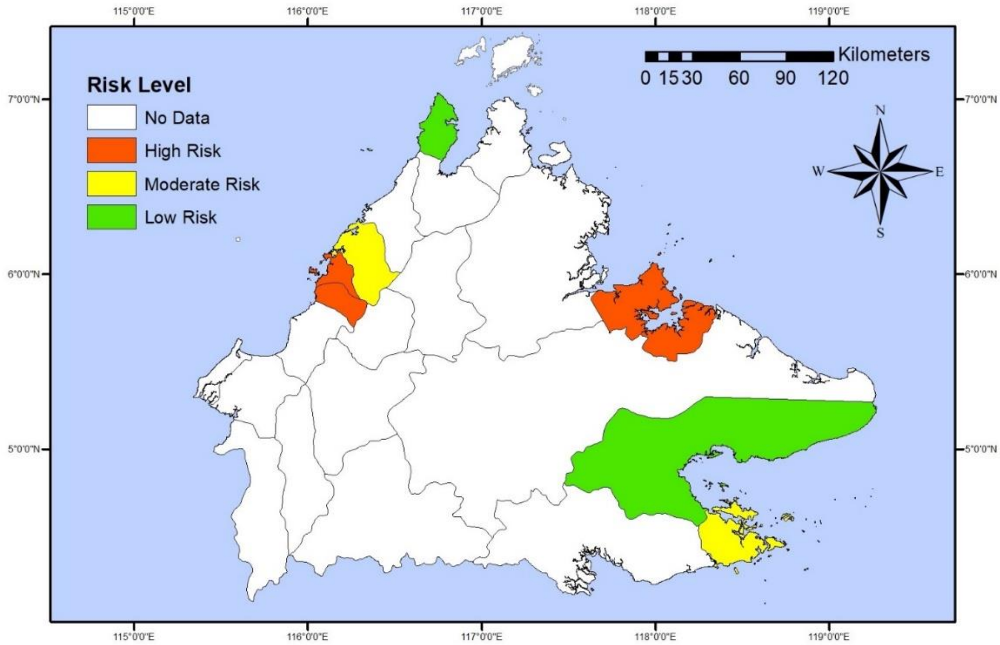

Figure 3 Risk level map showing the degree of risk for water insecurity for each major region in the study area, produced using ArcGIS ArcMap 10.4.1.

The authors of [79] stated that the Southeast Coast of Sabah in North Borneo is prone to a long dry season from February to May due to monsoonal seasonal changes, such as the El Nino warm phase event. The typical El Nino phenomenon is responsible for a negative Southern Oscillation Index (SOI) value, making the air pressure in the South Pacific weaken and creating a difference in pressure that is much lower than normal. This then replaces the cold current and upwelling of the South American coast by warm currents, therefore dramatically increasing sea surface temperatures and rainfall in the eastern and central Pacific Ocean [80–82]. In contrast, the anomalously high pressure over the Northern Borneo region leads to more stable air conditions and a marked reduction of rainfall. The drought events vary greatly in strength, duration, and spatial character, and only the stronger events tend to lead to significant drought in the Northern Borneo region [40,42,69]. Rainfall tends to be lower than normal over the whole of an event, but the timing of intense drought varies within the Indonesian region, with differences in rainfall regime related to the positions of localities relative to the equator, coastlines, and mountain ranges [83–85], along with atmospheric and large-scale oceanic aspects [86–88]. Increasing temperature is offset by reducing the precipitation, resulting in a net reduction of runoff to the water surface. There is significant regional heterogeneity in how climate change impacts Borneo Island, as the northeast, southwest, and interior of the East Coast of the island are projected to experience a decrease in precipitation with overall temperature increases, implying that these areas will experience greater water stress, especially from ecosystem services such as forests, which have a major effect on the stable water supply in these regions [89]. The seasonality of the precipitation changes due to the abnormal monsoon seasons that affect Borneo will result in a drier dry season due to climate change.

Mohammad et al. [4] stated that drought is an environmental phenomenon that is associated with the deficit of water resources in a specific region for a specific period of time and with short-term changes, which are more significant for this particular study. Drought is not only limited to existing or long-term events and pattern conditions. It can occur over a specific time and specific area, at the same time as the existence of microclimate conditions. This is a better and clearer definition of abnormally dry weather conditions [90] within a specific drought event. Bhuiyan et al. [91] found that drought measurement parameters are not linearly related to one another, and showed that it is common for one factor to identify drought in a particular place, while another drought factor may indicate a normal condition at the same place and time. This particular case study covered a large area, thus showing regional differences in meteorological conditions. Therefore, it is not very accurate to use generalized long-term periods for drought events, as some areas may experience rain while other areas are dry.

For this reason, a regional approach is taken to determine drought periods for the area surrounding each dam. With the determination of relative drought deviations based on the percentage of the average rainfall in an area, we can more clearly define the period of drought that has occurred by studying rainfall patterns and identifying periods of abnormally low rainfall. Due to the lack of a baseline because of the limited data, drought determination can also be conducted through this approach by determining unusually low rainfall for the available time period. At the same time, there are various climatic condition variables. Dracup et al. [92] stated that of the factors affecting water resources, generally rainfall is the major factor, along with temperature, soil moisture, and vegetation cover in the area [93,94]. Rainfall directly causes drought and affects water resources through affecting the soil moisture, streamflow, runoff water, dam storage, and water levels [95]. Studying the changes in quantities of precipitation over a specific time and area is an important approach for evaluating the climatic change, which has a direct impact on the water level, specifically through the intake and recharge of the water balance equation [96].

Other trends that have been noted by this study are the decrease in recharge and discharge rates related to water yield from the dams within the region, as shown by the decreased impacts of the water level due to rainfall drought. There is also an increase in the imbalance between the water dam storage in the region, with evolving demands for water in the case study, particularly relating to water availability and water needs. This indicates the need for new dams or more storage for future water resources, with better national water planning and development that is more environmentally friendly and economical, integrated with better management and maintenance of the existing and new storage facilities. A method for prioritizing the detected at-risk dams and determining the appropriate funding structure is needed to ensure that the water dams are safe and improved [97]. Dam failure emergency response plans also need to be designed and implemented. Metrics for the level of hazard associated with a dam also need to be embraced by organizations and agencies at both federal and state levels. These metrics use risk-based frameworks, including dam age, dam efficiency, potential causes of failure, and mechanisms for more dynamic water supply infrastructure management. For quantification of risk-based analysis, this research will help by providing information on the potential hazard ratings of the water dam conditions.

In addition to water release or transfer from the dams, the design also has to integrate the analysis results from climatic data and hydrological records, such as streamflow information [98]. The hydrologic data from the dam need to be collected during the anomalously dry period, which has never been done before, and monitored the whole time, especially with the occurrence of catastrophic droughts and floods that are larger than events considered in the design scopes for the existing dams. Furthermore, no dam design guidelines exist, including the use of stochastic models that consider the quasi-periodic, interannual, and multi-decadal variations in rainfall, streamflow, and climatic conditions, as well as extreme hydrologic events such as drought. Water dam design normally only considers the operational aspects of the dams. An appropriate set of climate scenarios is required, ranging from single runoff events to seasonal of streamflow anomalies that need to be explored for the portfolio of water dams and the surface water reservoirs under drought scenarios. While much research has been conducted on climate change scenarios, future research should consider more specific cases in terms of both the spatial correlation of climate projections for the river basins and variations in short-term periods in the context of hydrological extremes. No such national or regional analysis has considered water resource management with this range of climate scenarios to date [99].

Research on shorter timescales is needed for either individual or sequential severe drought events, along with the significant risk that is interconnected to the reservoir systems. The risk associated with such extreme weather changes over a short period of time and space in response to changing climatic conditions must be quantified to improve risk characterization and conjunctive reservoir management [100]. The use of databases with risk-based portfolio settings based on water storage levels and management could be another new strategy to prioritize which water dams require more attention and protection in terms of monitoring, maintenance, and future response planning. A water dam and storage portfolio for each region, including information on the reservoir holding capacity, is also proposed in this study to give a proper view of the critical reserves of water in each different area, which varies regionally. This strategy could be used to manage climate-induced drought risk for dams that respond not only to water withdrawal, but also dry periods with recurrent climates. Anomalies should be addressed and considered in order to optimize water reservoir development and management [101]. Monitoring water storage using a metering approach for the current conditions of the water reservoirs and storage infrastructure, along with different operation approaches and varying design dam capacities, is a strategy that could be used to assess which dams need to be maintained or expanded, or if new dams or other mechanisms may be needed to deal with water supply imbalances from a regional perspective, in order to optimize the water supply infrastructure.

Coordination of management and institutional roles is needed for mutual understanding of the interbasin water transfers and rights. These roles need to be co-designed so that a more dynamic framework of smarter management can be achieved by utilizing the information from storage assessments. Capacity expansions under different climates require a water dam risk mitigation strategy that considers both structural and nonstructural measures. Given the likelihood of significant financial outlays for restoring, removing, or replacing the water dams, proper organization and management is needed to understand the potential roles of partnerships in financing and operating water infrastructure, especially in the regions or states that have different border or administrative authorities for water resources. The water supply infrastructure identified in this particular research case study is fragmented and managed by different governments and agencies, each responsible for a distinct component, with little or no interaction or coordination amongst them. The arrangement is due to the fact that land, forests, and water are within individual state's jurisdictions, according to the State List in the Federal Constitution [102]. Since there are various agencies involved using different administration approaches, this inevitably creates overlapping enforcement between these agencies. A holistic approach is needed to overcome the issues of state–federal administration. The legislature must seriously consider more comprehensive and mutual legislation, which should address these concerns.

4. Conclusions

It was found that all dams showed a sharp and significant drop in water level during the drought periods, with water levels for dams C, A, F, and B falling below the critical level. Only the water levels for dams E and D did not fall below the critical level throughout the entire drought period of the study timespan, demonstrating a higher tolerance to drought events. The determination of the specific drought periods in this research based on each individual basis and for each dam gave greater accuracy and stronger regionality effects that were found to be more significant for the wide variability in the dry periods and rainfall between different regions. It was also found that the dams in the northern and northeastern regions of the study area had water levels that followed monsoonal trends, with increases resulting from the Northeast Monsoon. The overall risk for water insecurity for the dams in descending order from highest to lowest risk was: dam C > dam A > dam F > dam B, and finally dams D and E. The related recovery times varied. Dam C, in the Northeast Coast region, is extremely water-insecure, with water levels remaining below the critical level even outside of the drought period for the majority of the data timespan. It is strongly recommended that mitigation measures be taken to bolster the water supply in the climate-change-affected regions.

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References

1. Warner, J.; Johnson, C.L. Virtual water, real people: Useful concept or prescriptive tool? *Water Int.* **2007**, *32*, 63–77.
2. FAO. *Climate Change, Water and Food Security*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2011.
3. Zhang, Q.; Sun, P.; Li, J.; Xiao, M.; Singh, V.P. Assessment of drought vulnerability of the Tarim River basin, Xinjiang, China. *Theor. Appl. Climatol.* **2014**, *121*, 337–347.
4. Mohammad, A.H.; Jung, H.C.; Odeh, T.; Bhuiyan, C.; Hussein, H. Understanding the impact of drought in the Yarmouk Basin, Jordan: Monitoring droughts through meteorological and hydrological drought indices. *Arab. J. Geosci.* **2018**, *11*, 103.
5. Sindico, F. The Guarani aquifer system and the international law of transboundary aquifers. *Int. Community Law Rev.* **2011**, *13*, 255–272.
6. Cooley, H.; Christan-Smith, J.; Gleick, P.H.; Allen, L.; Cohen, M. *Understanding and Reducing the Risks of Climate Change for Transboundary Waters*; United Nations Environment Programme: New York, NY, USA, 2009.
7. Gleick, P.H. How much water is there and whose is it? In *The World's Water 2000–2001: The Biennial Report on Freshwater Resources*; Island Press: Washington, DC, USA, 2000.
8. Gleick, P.H. Water and conflict. *Int. Secur.* **1993**, *18*, 79–112.
9. United Nations (UN). *Integrated River Basin Development*; UN Publications: New York, NY, USA, 1958.
10. United Nations (UN). *International Rivers*; Pergamon Press: Oxford, UK, 1978.
11. Wolf, A.T.; Natharius, J.; Danielson, J.; Ward, B.; Pender, J. International river basins of the world. *Int. J. Water Resour. Dev.* **1999**, *15*, 387–427.
12. UNESCO. *Methodology for the Assessment of Transboundary Aquifers*; UNEP: Nairobi, Kenya, 2009.
13. Da Sila, L.P.B.; Hussein, H. Production of scale in regional hydropolitics: An analysis of La Plata River Basin and the Guarani Aquifer System in South America. *Geoforum* **2019**, *99*, 42–53.
14. Villar, P.C. International cooperation on transboundary aquifers in South America and the Guarani Aquifer case. *Revita Bras. De Politica Int.* **2016**, *59*, 1609.
15. Gun, J.V.C. *The Agriculture Groundwater Revolution: Opportunities and Threats to Development*; Cromwell Press: Trowbridge, UK, 2007.
16. UNESCO. *Atlas of Transboundary Aquifers: Global Maps, Regional Cooperation and Local Inventories*; UNESCO: Paris, France, 2007.
17. Cassuto, D.; Samppaio, R.S.R. Hard, soft & uncertain: The Guarani aquifer and the challenges of transboundary groundwater. *Colo. Nat. Resour. Energy Environ. Law Rev.* **2013**, *24*, 1–42.
18. Kristin, E.J.; Ashton, P.J. Adapting to change in transboundary rivers: An analysis of treaty flexibility on the Orange-Senqu River Basin. *Int. J. Water Resour. Dev.* **2008**, *24*, 385–400.
19. Goldenman, G. Adapting to climate change: A study of international rivers and their legal arrangements. *Ecol. Law Q.* **1990**, *17*, 741–802.
20. McCaffrey, S.C. The need for flexibility in freshwater treaty regimes. *Nat. Resour. Forum* **2003**, *27*, 156–162.
21. Fischhendler, I. Legal and institutional adaptation to climate uncertainty: A study of international rivers. *Water Policy* **2004**, *6*, 281–302.

22. Hussein, H. The Guarani Aquifer System, highly present but not high profile: A hydropolitical analysis of transboundary groundwater governance. *Environ. Sci. Policy* **2018**, *83*, 54–62.
23. Cooley, H.; Gleick, P.H. Climate-proofing transboundary water agreements. *Hydrol. Sci. J.* **2011**, *56*, 711–718.
24. Kundzewicz, Z.W.; Mata, L.J.; Arnell, N.W.; Doll, P.; Jimenez, B.; Miller, K.; Oki, T.; Sen, Z.; Shiklomanov, I. The implications of projected climate change for freshwater resources and their management. *Hydrol. Sci. J.* **2008**, *53*, 3–10.
25. IPCC. *Climate Change 2014: Synthesis Report*; Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; IPCC: Geneva, Switzerland, 2014.
26. Kwan, M.S.; Tangang, F.; Liew, J. Projected changes of future climate extremes in Malaysia. *Sains Malays.* **2013**, *42*, 1051–1059.
27. Chenoli, S.N.; Jayakrishnan, P.R.; Abu Samah, A.; Ooi, S.H.; Ahmad Mazuki, M.; Lim, C.H. Southwest monsoon onset dates over Malaysia and associated climatological characteristics. *J. Atmos. Sol. Terr. Phys.* **2018**, *179*, 81–93.
28. Ali Khan, M.M.; Shaari, N.; Achmad Nahar, A.; Baten, M.; Nazaruddin, D. Flood impact assessment in Kota Bharu, Malaysia: A statistical analysis. *World Appl. Sci. J.* **2014**, *32*, 626–634.
29. Sammathuria, M.K.; Ling, L.K. Regional Climate Observation and Simulation of Extreme Temperature and Precipitation Trends. In Proceedings of the 14th International Rainwater Catchment Systems Conference, Kuala Lumpur, PWTC, Malaysia, 3–6 August 2009.
30. Abdulah, N.; Jusoh, J.; Kassim, A. *Country Reports—Malaysia. Capacity Development to Support National Drought Management Policy*; Integrated Drought Management Programme (IDMP): Hanoi, Vietnam, 2014.
31. Alagesh, T.N. Sungai Tembeling drying up in heatwave. *New Straits Times*, 8 March 2019.
32. NST. Dry weather to last until May; water shortage in 6 states. *New Straits Times*, 24 March 2019.
33. Sim, L.L.; Chung, C.; Izahar, N. Too many unplanned water cuts. *The Star*, 3 August 2019.
34. Tham, J.V. 7 Klang Valley Districts Will Face Water Cuts up to 84 Hours Next Week. *Says*, 16 July 2019.
35. Boo, S.-L. Water cuts to hit Petaling Jaya. *Malay Mail*, 18 March 2019.
36. Chu, M.M. Xavier: Longer droughts expected, Malaysia's water industry in dire straits. *The Star*, 25 July 2019.
37. Marcos-Garcia, P.; Lopez-Nicolas, A.; Pulido-Velazquez, M. Combined use of relative drought indices to analyze climate change impact on meteorological and hydrological droughts in a Mediterranean basin. *J. Hydrol.* **2017**, *554*, 292–305.
38. Smith, A.B.; Katz, R.W. US billion-dollar weather and climate disasters: Data sources, trends, accuracy and biases. *Nat. Hazards* **2013**, *67*, 387–410.
39. Zhang, Q.; Zhang, W.; Chen, Y.D.; Jiang, T. Flood, drought and typhoon disasters during the last half-century in the Guangdong province, China. *Nat. Hazards* **2011**, *57*, 267–278.
40. Abdul Rahman, H. Water Shortage in Malaysia: Again? *Malays. Consum. Law J.* **2014**, *1*, 115–128.
41. Easterling, D.R.; Meehl, G.A.; Parmesan, C.; Changnon, S.A.; Karl, T.R.; Mearns, L.O. Climate extremes: Observations, modeling, and impacts. *Science* **2000**, *289*, 2068–2074.
42. Kua, K.S. Water crisis: The price of populism. *The Star*, 28 July 2019.
43. Malay Mail. CM denies Melaka to declare emergency over water shortage. *Malay Mail*, 19 September 2019.
44. Falkenmark, M.; Lindh, G. How can we cope with the water resources situation by the year 2015? *AMBIO* **1974**, *3*, 114–122.
45. Falkenmark, M. Freshwater: Time for a modified approach. *AMBIO* **1986**, *15*, 192–200.
46. Falkenmark, M. The massive water scarcity now threatening Africa: Why isn't it being addressed? *AMBIO* **1989**, *18*, 112–118.
47. Mehta, L. Whose scarcity? Whose property? The case of water in western India. *Land Use Policy* **2007**, *24*, 654–663.
48. Garreth, A.S.E. Justice, Neoliberal natures and Australia's water reforms. *Trans. Inst. Br. Geogr.* **2015**, *40*, 479–493.
49. Garreth, A.S.E. Shifting constructions of scarcity and the Neoliberalization of Australian water governance. *Environ. Plan. A Econ. Space* **2013**, *45*, 1873–1890.
50. Garreth, A.S.E.; Bulkeley, H.A. Heterotopia and the urban politics of climate change experimentation. *Environ. Plan. D Soc. Space* **2018**, *36*, 350–369.
51. Hussein, H. Lifting the veil: Unpacking the discourse of water scarcity in Jordan. *Environ. Sci. Policy* **2018**, *89*, 385–392.

52. Jeremy, A. The sustainability and resilience of global water and food systems: Political analysis of the interplay between security, resource scarcity, political systems and global trade. *Food Policy* **2011**, *36*, 3–8.
53. Hussein, H. Whose 'reality'? Discourses and hydropolitics along the Yarmouk River. *Contemp. Levant J.* **2017**, *2*, 103–115.
54. Hussein, H. Yarmouk, Jordan and Disi Basins: Examining the impact of the discourse of water scarcity in Jordan on transboundary water governance. *Mediterr. Politics* **2019**, *24*, 269–289.
55. Hussein, H.; Grandi, M. Dynamic political contexts and power asymmetries: The cases of the Blue Nile and the Yarmouk Rivers. *Int. Environ. Agreem. Politics Law Econ.* **2017**, *17*, 795–814.
56. Lankford, B.A. *Resource Efficiency Complexity and the Commons: The Paracommons and Paradoxes of Natural Resources Losses, Wastes and Wastages*; Earthscan Publications: Abingdon, UK, 2013.
57. Zeitoun, M.; Lankford, B.; Bakker, K.; Conway, D. *Water Security—Principles, Perspectives and Practices*; Routledge, London, UK, 2013.
58. Zeitoun, M. *Power and Water in the Middle East: The Hidden Politics of the Palestinian-Israeli Water Conflict*; I.B. Tauris Publications: London, UK; New York, NY, USA, 2008.
59. Lankford, B.A. Resource centered thinking in river basins: Should we revoke the crop water requirement approach to irrigation planning? *Agric. Water Manag.* **2004**, *68*, 33–46.
60. Zeitoun, M. The global web of national water security. *Glob. Policy* **2011**, *2*, 286–296.
61. Cook, C.; Bakker, K. Water security: Debating an emerging paradigm. *Glob. Environ. Chang.* **2012**, *22*, 94–102.
62. Bakker, K. *Privatizing Water: Governance Failure and the World's Urban Water Crisis*; Cornell University Press: Ithaca, NY, USA; London, UK, 2010.
63. Ho, K.; Tang, D. Climate change in Malaysia: Trends, contributors, impacts, mitigation, and adaptations. *Sci. Total Environ.* **2019**, *650*, 1858–1871.
64. Bernama. Water in six dams in Sabah may soon run out. *New Straits Times*, 5 March 2019.
65. Miwil, O. With drying rivers, Sabah has just two months of water reserves. *New Straits Times*, 27 February 2019.
66. Jiffar, S. Kota Belud declares drought. *New Straits Times*, 1 March 2019.
67. Menga, F. Hydropolis: Reinterpreting the polis in water politics. *Political Geogr.* **2017**, *60*, 100–109.
68. Hussein, H.; Menga, F.; Greco, F. Monitoring transboundary water cooperation in SDG 6.5.2: How a critical hydropolitics approach can spot inequitable outcomes. *Sustainability* **2018**, *10*, 3640.
69. Ministry of Natural Resources and Environment Malaysia (MNRE). *Malaysia Biennial Update Report to the UNFCC*; Ministry of Natural Resources and Environment Malaysia: Putrajaya, Malaysia, 2015.
70. Tang, A. Group: Nation not prepared for water crisis. *The Star*, 27 July 2019.
71. Zack, J. Water disruption to hit more than 370,000 after pollution shuts down Selangor treatment plant. *The Star*, 28 September 2019.
72. Che-Ani, A.I.; Shaari, N.; Sairi, A.; Zain, M.F.; Tahir, M.M. Rainwater harvesting as an alternative water supply in the future. *Eur. J. Sci. Res.* **2009**, *34*, 132–140.
73. Ahmad, F.; Ushiyama, T.; Sayama, T. *Determination of Z-R Relationship and Inundation Analysis for Kuantan River Basin*; Malaysia Meteorological Department: Petaling Jaya, Malaysia, 2017.
74. Odeh, T.; Mohammad, A.H.; Hussein, H.; Ismail, M.; Almomani, T. Over-pumping of groundwater in Irbid governorate, northern Jordan: A conceptual model to analyze the effects of urbanization and agricultural activities on groundwater levels and salinity. *Environ. Earth Sci.* **2019**, *78*, 40.
75. Odeh, T.; Salameh, E.; Schirmer, M.; Strauch, G. Structural control of groundwater flow regimes and groundwater chemistry along the lower reaches of the Zerka River, West Jordan, using remote sensing, GIS and field methods. *Environ. Geol.* **2009**, *58*, 1797–1810.
76. Odeh, T.; Rodiger, T.; Geyer, S.; Schirmer, M. Hydrological modeling of a heterogeneous catchment using an integrated approach of remote sensing, a geographic information system and hydrologic response units: The case study of Wadi Zerka Ma'inn catchment area, northeast of the Dead Sea. *Environ. Earth Sci.* **2015**, *73*, 3309–3326.
77. Baldock, J.; Bancrodt, K.P.; William, M.; Shedrawi, G.; Field, S. Accurately estimating local water temperature from remotely sensed satellite sea surface temperature: A near real-time monitoring tool for marine protected areas. *Ocean Coast Manag.* **2014**, *96*, 73–81.
78. Souza, C.R.G. Coastal erosion and the coastal zone management challenges in Brazil. *J. Integr. Coast. Zone Manag.* **2009**, *9*, 17–37.

79. Yusof, K.M.; Azid, A.; Shirwan, M.A.S.; Samsudin, M.S.; Syuhada, M.A.; Nurul, L.A.; Jamalani, M.A. The evaluation on artificial neural networks (ANN) and multiple linear regression (MLR) models over particulate matter (PM_{10}) variability during haze and non-haze episodes: A decade case study. *Malays. J. Fundam. Appl. Sci.* **2019**, *15*, 164–172.
80. Blunden, J.; Arndt, D.S.; Hartfield, G. State of the Climate in 2017. *Bull. Am. Meteorol. Soc.* **2018**, *99*, 1–310.
81. El Jazouli, A.; Barakat, A.; Khellouk, R.; Rais, J.; El Baghdadi, M. Remote sensing and GIS techniques for prediction of land use land cover change effects on soil erosion in the high basin of the Oum Er Rabia River (Morocco). *Remote Sens. Appl. Soc. Environ.* **2019**, *13*, 361–374.
82. Gerlak, A.K.; House-Peters, L.; Varady, R.G.; Albrecht, T.; Zúñiga-Terán, A.; de Grenade, R.R.; Scott, C.A. Water security: A review of place-based research. *Environ. Sci. Policy* **2018**, *82*, 79–89.
83. Kao, S.C.; Govindaraju, S.R. A copula-based joint deficit index for droughts. *J. Hydrol.* **2010**, *380*, 121–134.
84. Lillesand, T.; Kiefer, R.W.; Chipman, J. *Remote Sensing and Image Interpretation*; John Wiley & Sons: Chichester, West Sussex, United Kingdom, 2014.
85. Mekonnen, M.M.; Hoekstra, A.Y. Four billion people facing severe water scarcity. *Sci. Adv.* **2016**, *2*, 17–23.
86. Davey, M.K.; Anderson, D.L.T. A comparison of the 1997/98 El Nino with other such events. *Weather* **1998**, *53*, 295–310.
87. Wolter, K.; Timlin, M.S. Measuring the strength of ENSO events: How does 1997/98 rank. *Weather* **1998**, *53*, 315–324.
88. Walsh, R.P.D.; Newbery, D.M. The ecoclimatology of Danum, Sabah, in the context of the world's rainforest regions, with particular reference to dry periods and their impact. *Philos. Trans. R. Soc.* **1999**, *354*, 1869–1883.
89. Johnson, J.A. *Assessing the Impact of Climate Change in Borneo*; World Wildlife Fund Environmental Economics Series; Washington D.C., USA, 2012.
90. Rossi, G. *Drought and Drought Mitigation in Europe*; Kluwer Academic Publisher: Dordrecht, The Netherlands 2000.
91. Bhuiyan, C.; Singh, R.P.; Kogan, F.N. Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. *Int. J. Appl. Earth Obs. Geoinform.* **2006**, *8*, 289–302.
92. Dracup, J.A.; Lee, K.S.; Paulson, E.G. On the definition of droughts. *Water Resour. Res.* **1980**, *16*, 297–302.
93. Jain, S.K.; Keshri, R.; Goswami, A.; Sarkar, A. Application of meteorological and vegetation indices for evaluation of drought impact: A case study for Rajasthan, India. *Nat. Hazards* **2010**, *54*, 643–656.
94. Bandyopadhyay, N.; Bhuiyan, C.; Saha, A.K. Heat waves, temperature extremes and their impacts on monsoon rainfall and meteorological drought in Gujarat, India. *Nat. Hazards* **2016**, *82*, 367–388.
95. Jones, R.; Chiew, F.; Boughton, W.; Zhang, L. Estimating the sensitivity of mean annual runoff to climate change using selected hydrological models. *Adv. Water Resour.* **2005**, *29*, 1419–1429.
96. Ho, M.U.; Lall, M.; Allaire, N.; Devineni, H.H.; Kwon, I.; Pal, D.; Wegner, D. The future role of dams in the United States of America. *Water Resour. Res.* **2017**, *53*, 982–998.
97. Barnett, T.P.; Adam, J.C.; Lettenmaier, D.P. Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature* **2005**, *438*, 303–309.
98. Steinschneider, S.M.; Ho, E.; Cook, R.; Lall, U. Can PDSI inform extreme precipitation: An exploration with a 500-year long paleoclimate reconstruction over the U.S. *Water Resour. Res.* **2016**, *52*, 3866–3880.
99. Cook, E.R.; Seager, R.; Heim, R.; Vose, R.S.; Herweijer, C.; Woodhouse, C. Megadroughts in North America: Placing IPCC projections of hydroclimatic change in a long-term paleoclimate context. *J. Q. Sci.* **2010**, *25*, 48–61.
100. Russo, T.A.; Lall, U. Depletion and response of deep groundwater to climate-induced pumping variability. *Nat. Geosci.* **2017**, *10*, 105–108.
101. Pulido-Velazquez, M.; Marques, G.F.; Harou, J.J.; Lund, J.R. *Integrated Groundwater Management: Concepts, Approaches and Challenges*; Springer: Cham, Switzerland, 2016.
102. Razman, M.R.; Payus, C.; Jahi, J.M. Control of river pollution in protecting ecology and human habitat: Legislative review in Malaysia. *Int. J. Malay World Civiliz.* **2010**, *28*, 227–240.