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Technical Report



Taiwan drought

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1. Introduction

“That Taiwan, one of the developed world’s rainiest places, should lack for water is a paradox verging on tragedy”

(Zhong and Chang, 2021)



This picture taken on March 16, 2021 shows an aerial view of the dry Ai Liao River bed in Taiwan's Pingtung county. (Image credit: Sam Yeh / AFP)

Taiwan Province of China is one of the wettest places in the world, with an annual rainfall of 2,600 mm, 70 per cent of which is brought to the island by seasonal typhoons (Unabiz, 2021). However, for the first time in 56 years, rain-soaking typhoons failed to make landfall, marking the first half of 2021 as one of the worst drought periods in the island's history (Wang, 2021). With water reservoirs below 5 per cent of their capacity, the local authorities ordered water rationing for more than one million households and businesses. The low levels in the reservoirs also affected the functioning of hydroelectric power plants, forcing outages that impacted both industries and consumers (Berry, 2021).

This water rationing was not without controversy, especially for the island's most water-intensive industries: rice farming and semiconductor manufacturing. Technological industries, like semiconductor manufacturing, were instructed to slash water usage by up to 15 per cent (Wang, 2021), while some 74,000 ha of rice fields (24 per cent of

the total planted area) were completely cut off from water and irrigation, destroying the second annual yield (Reidy, 2021). Although both sectors endured water rationing measures, difficult choices had to be made and the highly profitable semiconductor industry, with the Taiwan Semiconductor Manufacturing Company (TSMC) producing nearly 25 per cent of the world’s semiconductors and 92 per cent of the most advanced chips used in products like smartphones and automotive artificial intelligence, was kept afloat at the cost of the agricultural sector (Wang, 2021; Reidy, 2021; Schoolov, 2021).

Typhoons

The geographical position of Taiwan in the western North Pacific makes it particularly susceptible to tropical cyclones or typhoons during the boreal summer and fall. Furthermore, the island is located exactly where typhoons bifurcate towards northern or western trajectories (Liang and others, 2017; Hung and others, 2020). Consequently, it registers an annual two to four typhoons, which despite representing a mounting risk of extreme rainfall and flooding to the local communities, are also considered indispensable to the island’s water resources (Unabiz, 2021). In fact, water availability depends on the occurrence of typhoons, which induce some 70 per cent of the island’s rainfall (Unabiz, 2021; Hale, 2021), to function, and any change in their paths could affect the island in several ways, as evidenced during the period 2020-2021, when not a single typhoon made landfall there during the typhoon season (Figure 1) (Davidson, 2021).

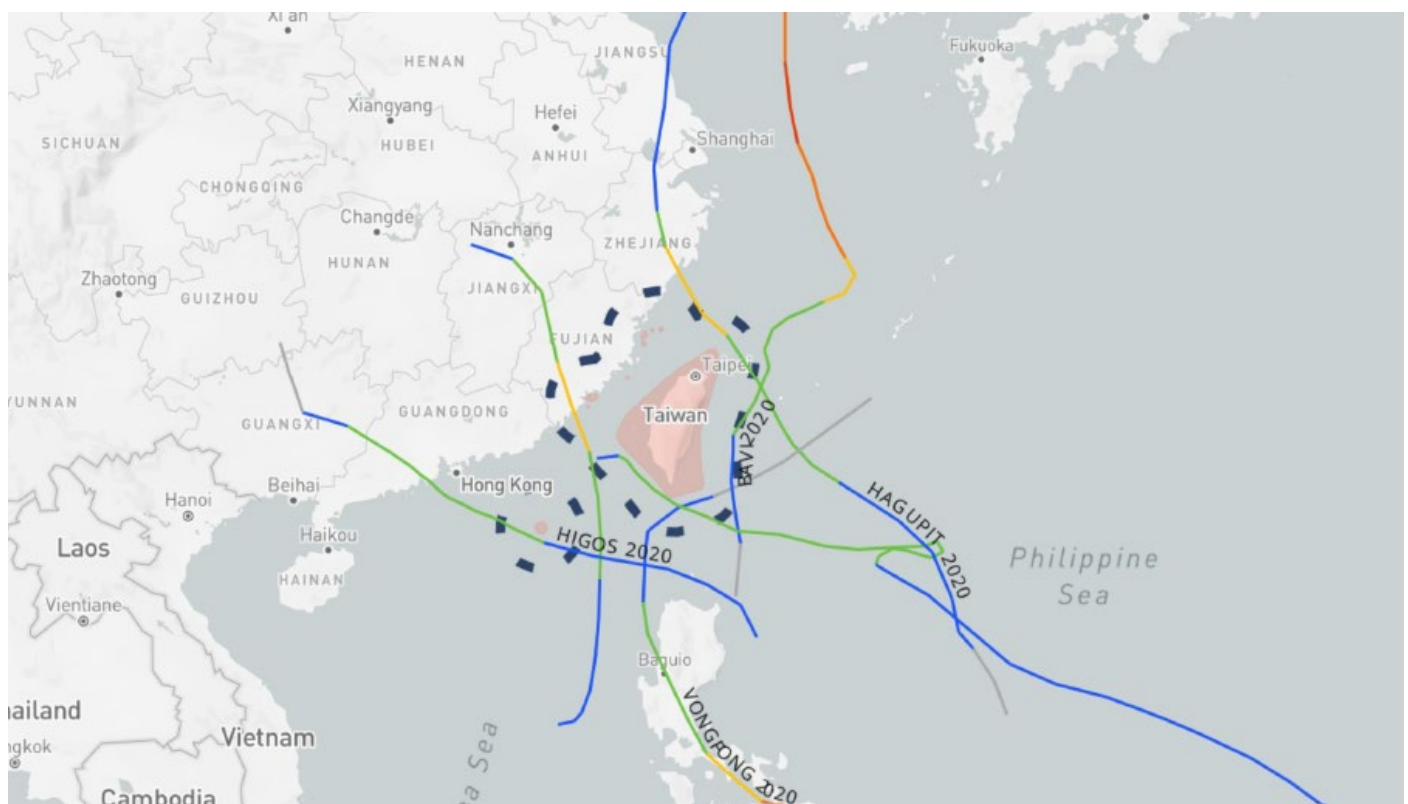


Figure 1: Typhoon tracks around Taiwan Province of China during the typhoon season 2020-2021. Source: National Oceanic and Atmospheric Administration NOAA (2022).

2. Impacts

2.1 Livelihood loss

The water shortage and resulting water stringent measures affected many water-dependant livelihoods. The agricultural sector, using more than two-thirds of the island's water, especially for the twice-yearly cultivation of rice and tropical fruit (Hale, 2021), was particularly affected.

Gripped by drought, local authorities shut off irrigation across some 74,000 ha of farmland (around a fifth of the island's irrigated land), heavily impacting the crop yield and livelihoods of farmers (Zhong and Chang, 2021). Irrigation water cuts mainly impacted rice but also affected the production of corn, soybean, buckwheat, forage grass, sweet potatoes, peanuts and leafy vegetables (Reidy, 2021). The shut-off of irrigation especially affected rice harvest on the island. For thousands of years, rice grown in the south and western plains has been a major food staple (Hsing, 2016). As there was no water for rice, which normally needs large amounts of water, rice grains could not mature, thus reducing quality. This meant rice farmers could only sell their harvest for fodder, fetching lower prices than usual (Jensen, 2020). The local authorities offered farmers \$500 in compensation per ha of land affected by the irrigation shut-off (Jensen, 2021). Still, farmers fear a long-term loss of livelihoods as the thwarted harvest because of the drought may also encourage customers to seek other suppliers, further depressing the earnings of the farmers (Zhong and Chang, 2021).



Boats sit at a pier on Sun Moon Lake with low water levels during an island-wide drought, in Nantou, Taiwan May 15, 2021. (Image credit: REUTERS / Annabelle Chih)

Due to the drought, the 2021 tea harvest was 50 per cent less than in 2020. Tea farmers' livelihoods were further impacted by a pest infestation, an unexpected side effect of the drought, adding an extra challenge to the income of these farmers, who are paid based on the daily weight of collected tea leaves (Brownlee, 2021).

Water shortages also affected the tourism sector and related livelihoods. Popular lakes used for recreation have partially dried up and seen a significant drop in tourist visits (Lai, 2021). The Sun Moon Lake, for instance, one of the biggest sources of fresh water and an important tourist draw, saw its water level plunge by 12 m compared to last year, setting a new record low (Week In China, 2021). This affected tourism in the area and, consequently, related livelihoods. Boat rentals on the lake, for example, experienced a 90 per cent drop during the drought (Lai, 2021).

Finally, despite the diversion of still available water towards chip production, water shortages have affected people working in the tech industry. Due to temporary shutdowns of some factories and an increasing risk of droughts in the island, tech companies are starting to plan to move out of the island, which in the long term could potentially affect the 3 million people employed in the sector, possibly forcing them to change their livelihoods (Housset and Fung, 2021). The increased drought risk has recently seen personal computing, component systems and mobile device manufacturing moving to mainland China (Feigenbaum, 2020), while the automotive supplier Bosch just opened a \$1.2 billion chip factory in Dresden, Germany, as a result of the global microchip shortage (CNBCTV18, 2021).

2.2 Water insecurity

According to United Nations Water (UN-Water), water security is the “capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socioeconomic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (UN-Water, 2013). Although being one of the wettest places in the world, Taiwan is classified as an area of scarce water resources (Kastner, 2015). Accordingly, the water resources per year per person on the island is one sixth of the global average (Shuhui, 2021). The island, heavily relies on the annual typhoon season, which induces some 70 per cent of the rainfall in the territory, to bring enough rainwater to meet its needs (Unabiz, 2021; Hale, 2021).

As rain-soaking typhoons failed to make landfall in 2020, the island faced a situation of water insecurity. The capacity of its reservoirs in the central and southern regions fell below 5 per cent (Lee and Blanchard, 2021), resulting in water shortages that were particularly severe in western region, where most people live (Lee and others, 2021).

As a result of the water scarcity, the local authorities imposed water rationing for over one million households and businesses in central Taiwan (Wang, 2021). In areas with the severest water shortages and restrictions, including the island's second-biggest city of Taichung (2.8 million inhabitants), households were cut off from their water supply for two days a week (Lai, 2021).

Additionally, due to the low water levels, hydropower plants did not generate sufficient electricity, which caused disturbances to the power supply, leading to two major blackouts in May 2021 (Lee and Blanchard, 2021).



A man scoops water from a bathtub, where he stores water amid water rationing during an island-wide drought, in Hsinchu, Taiwan. March 12, 2021. (Image credit: Ann Wang / REUTERS)

Exacerbated by climate change, water shortages will continue to threaten the island. A recent report shows that by the end of the century, the rainfall that feeds reservoirs could diminish by up to 25 per cent in the northern parts and by 50 per cent in the central and southern parts of the island (Barbiroglio, 2021).

3. Drivers

3.1 Atmospheric warming

In the past few decades, global surface temperatures have increased significantly, disturbing the global hydrological cycle, as evidenced by the occurrence of extreme flood and drought events (Huang and others, 2022; Yeh, 2021) and shifts in the path of tropical cyclones around the world (Knutson and others, 2019). The years 2020 and 2021 have been ranked as the second and sixth warmest years since 1880 (Figure 2) (Earth Observatory, 2022). During those two years, not a single typhoon landed on the island in the expected typhoon season, which was a first in nearly 60 years. Consequently, a drought event was extended for 18 months (Jensen, 2020; Davidson, 2021; Huang and others, 2022).

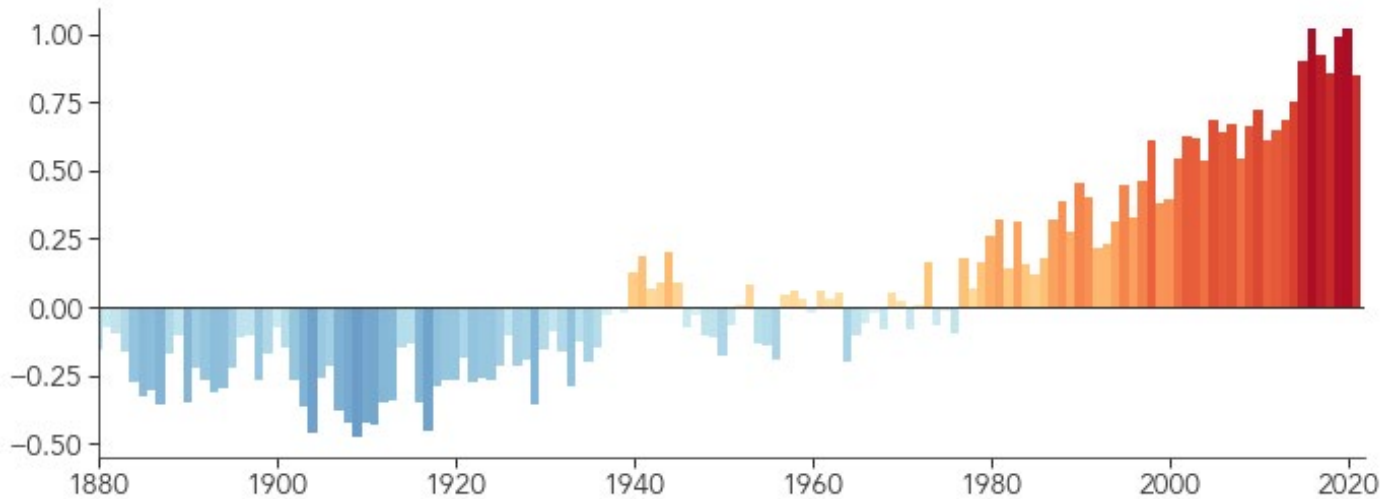


Figure 2: Global temperature anomalies (°C) from 1880 to 2021. Source: Earth Observatory (2022).

Drought is understood as a period where exceptional and sustained lack of water takes place in a region, affecting its hydrological cycle (Van Loon and others, 2016; Meza and others, 2021). Although droughts are not uncommon for the island, droughts tend to occur for just a couple of months per year and are easily forgotten due to subsequent rain events between May and September (Hsu, 2021). However, from June 2020 to May 2021, the island only received a third of the annual precipitation average (approximately 807 mm of the expected annual 2,600 mm) (Guo, 2021).

Due to atmospheric warming, extreme weather conditions are predicted to increase and the potential for worse droughts lies in store (Lin, 2021). Rising ocean temperatures, on the one hand, lead to stronger typhoons, with potentially more devastating impacts; however, on the other hand, atmospheric warming diverts typhoons away from the island in a more northerly direction, meaning fewer typhoons will hit, making dry spells and droughts more frequent (Lin, 2021).

3.2 Vulnerable infrastructure

Water in Taiwan is an underinvested utility (Week In China, 2021). Lack of proper infrastructure on the island presents an important factor in driving drought events. For one, it is plagued by leakages (Unabiz, 2021), meaning a lot of water is dispersed and wasted. At the end of 2015, the island’s water leakage rate reached 16.6 per cent, adding up to 1 billion tons of water going to waste per year (American Institute in Taiwan (AIT), 2017). By 2020, the rate was 13.9 per cent (Tang, 2021), which despite the decrease still represents an important loss of water, amounting to over twice the capacity of the Shimen Reservoir – the island’s third largest reservoir (AIT, 2017) – and showing that although leakage contention strategies seem to have worked, there is still room for further improvement.

Water leakages occur as a result of outdated infrastructure. For instance, much of the water consumption of the agricultural sector is delivered through irrigation channels that date back to the Japanese colonial era of 1895 to 1945. This outdated and leaking infrastructure means that only about a quarter of water flow reaches agricultural fields (Week In China, 2021). The deterioration of pipelines is also related to the material with which they are constructed. For budget reasons, many of the island's pipelines are made of polyvinyl chloride and have a life expectancy of 20 years. A recent investigation suggests that over 80 per cent of current pipes are past their life expectancy (AIT 2017), showing the urgency of investing in water infrastructure

Storage of water is another issue related to the island's lack of proper infrastructure (Unabiz, 2021), which results in most (50 billion of the annual 80 to 90 billion m³ of rainfall) rainwater being lost due to run-off and flowing directly into the ocean (Kaye, 2011; Chang, 2021). Reservoirs, which have been built as the main sources of fresh water, considering the island's mountainous topography, suffer from sedimentation because of steep geographic features and loose soil structure exacerbated by earthquakes, deforestation (Kaye, 2011; Lu and Liu, 2018) and concentrated rainfall, washing the sediments into reservoirs (AIT, 2017; Hale, 2021). Despite cleaning efforts, sediment in the existing reservoirs take up to 30 per cent of the capacity, making it very difficult to keep up with sediment disposal. These high sedimentation rates not only decrease water storage capacity (see section 3.3) but also affect the life expectancy of a reservoir (AIT, 2017), aggravating the island's infrastructural problems.



This aerial photo taken on March 25, 2021 shows two water trucks next to a construction site to receive underground water in Taichung, central Taiwan. (Image credit: Sam Yeh / AFP)

3.3 Deforestation

Deforestation, i.e. the conversion of forested land to other uses, has exacerbated drought impacts in Taiwan as it has increased sedimentation in water reservoirs and thereby reduced their water-holding capacity before a drought hits. Deforestation destabilizes soil and contributes to increased siltation as debris flows into reservoirs. This, in turn, reduces water storage capacity and exacerbates drought impacts (Lu and Liu, 2018).

The island's economic development in catchment areas has significantly contributed to deforestation. The Shimen Reservoir, for instance, was affected by the expansion of Lalashan peach production, which emerged as the national peach brand, resulting in patches of forest being cleared. Additionally, with this expanded production, road networks and infrastructure were developed, again resulting in the clearing of forested land. The growing of ginger and tourism in the area have also significantly contributed to forest clearing (Lu and Liu, 2018). A study found that deforestation and road building resulted in 10 times as many landslides, which crumble into rivers and ultimately reservoirs, and 100 times the amount of affected areas (Lu and Liu, 2018).

Indeed, many of the island's reservoirs have accumulated sediments over the years. This increased sedimentation as a result of deforestation in turn results in a reduced storage capacity of reservoirs. In fact, of the 6.2 billion tons of water that can be held by the island's reservoirs, sediments take up some 30 per cent of capacity in six of its 19 reservoirs (AIT, 2017; Lu and Liu, 2018; Hale, 2021).

3.4 Pollution

The contamination of water represents an additional driver, reducing the amount of usable water and thereby exacerbating the challenge of water scarcity. The island's rapid economic development has increased the amount of generated wastewater, which contains industrial toxins, agricultural fertilizers and pesticides. Also, domestic wastewater (e.g. water from washing machines and bathrooms) has increased and contributes to pollution as it is seldom treated (Crook, 2022). In fact, only some 4 per cent of the island's territory is served by sewage systems, meaning much of the generated wastewater flows directly into its rivers and lakes, which in turn contaminate groundwater and limits its use, exacerbating water shortages (Kastner, 2015; Crook, 2022). A study focusing on 14 major rivers in Taiwan concluded that by 2016, 65 per cent of the island's rivers were moderately polluted, and the remaining 35 per cent were lightly polluted (Putri and others, 2018). Some 90,000 factories and hundreds of landfills are believed to be located near rivers, demonstrating the extent of the problem (Kastner, 2015).

Because so much groundwater has been contaminated, water is pumped in areas where it is cleaner, in generally excessive quantities. This in turn leads to land subsidence, with some areas in central and southern parts of the island having already sunk to two m below sea level, which destroys infrastructure and damages farmland due to saltwater intrusion during typhoons (Kastner, 2015).

4. Root causes

4.1 Insufficient risk governance

The drought during 2020 and 2021 exposed several of the island's vulnerabilities linked to water management and risk governance and how poorly-designed water policies can lead to major issues when water is in short supply (Lai, 2022; Aviso and others, 2021). The local authorities are yet to engage in comprehensive planning where the allocation of water among industrial, agricultural and residential users is assessed from a systemic water resource management perspective, and where the reasonable use of resources is of utmost priority (Lin, 2021). For example, the island's water authority, which is in charge of controlling water outflow, works under the economic affairs delegation. This could potentially raise a conflict of interest between basic services (i.e. water provision) and the highly profitable semiconductor industry, generating 14 per cent of the island's GDP (Indonesia Window, 2021). Indeed the semiconductor industry was kept from harsh water restrictions at the cost of imposing stricter irrigation shut-offs on the agricultural sector (Kastner, 2015; Huang, 2021).

Furthermore, insufficient investment in infrastructure to prevent leakages and secure proper storage of water (see section 3.2) represents a major challenge for water security on the island (Barbiroglio, 2021). The drought drew attention to the need for replacing leaking pipelines, removing sediment from reservoirs and diversifying water infrastructure (e.g. by utilizing wastewater plants and artificial lakes).

4.2 Undervaluing environmental costs

The water prices in Taiwan represent a clear case of undervaluing environmental costs. The island enjoys some of the lowest water prices in Asia (Fitch Ratings, 2021), with a ton of water costing \$0.37, which is half the cost of water in South Korea, four times lower than the U.S. price and less than 10 per cent of what Europeans pay (Kastner, 2015; Sui, 2021).

As the islanders spend only 0.6 per cent of their disposable income on water, compared to 2.9 per cent in Japan (Kastner, 2015), households and industries are not encouraged to consume consciously. The notoriously low water prices are in fact believed to contribute to excessive water consumption (Sui, 2021; Fitch Ratings, 2021), which is at a daily 271 l per capita and above the average American and European daily water usage (Kaye, 2011). Furthermore, as recycled water currently costs only \$0.23 less than tap water per m³, there is little incentive to invest in recycling (Kastner, 2015). Taxpayers are thus believed to pay for the water that is then wasted due to its low price (The News Lens Staff, 2021).

The cheap water prices and little incentive for conscious consumption hide the real costs of water (The News Lens Staff, 2021) and further exacerbate the impacts of droughts, coming at an environmental cost. The pumping of water, for instance, has resulted in land subsidence (Kastner, 2015). Some places in central and southern part of the island, where average precipitation is higher and groundwater withdrawal has historically been high (Liu, 2013), have already sunk below sea level (see section 3.4).



This aerial photo taken on March 17, 2021 shows the Zenwen Dam in Chiayi county, southern Taiwan. (Image credit: Sam Yeh / AFP)

4.3 Human-induced greenhouse gas emissions

Increasing human-induced greenhouse gas emissions are affecting the global climate as well as typhoon patterns. According to the Intergovernmental Panel on Climate Change, climate change has already begun to affect the intensity of typhoons and a roughly 5 per cent increase in maximum wind speed is forecast with 2°C warming (Potts, 2021). Furthermore, climate change is altering the pathway of typhoons across the Asia Pacific, pushing them northwards (Hale, 2021). Indeed, the historical average of three to four annual typhoons in the area has already started to fall; since 2010, an average 2.5 typhoons have made landfall (Jensen, 2020; Hale, 2021). This trend is expected to continue under current greenhouse gas emission rates, and the north-western Pacific Ocean will be the planet's first ocean with decreased tropical cyclone activity (Jensen, 2020).

Human-induced climate change will also dramatically increase exposure to water shortages, especially in the northern parts of the island, which includes the most populated metropolitan areas of Taipei and Taoyuan (Barbiroglio, 2021).

4.4 Global demand pressures

Around the world, tech and auto industries are experiencing supply chain disruptions, especially in terms of semiconductors, pressuring the semiconductor industry to ramp up supply (Barrett, 2021; Cheung, 2021). This global demand for chipsets has put particular pressure on the economy as the island's semiconductor industry occupies 63 per cent of the global market, with TSMC the leader (Barrett, 2021; Cheung, 2021). In fact, TSMC alone produces around 24 per cent of the world's semiconductors and 92 per cent of the most advanced chips used in electronics like smartphones, TVs and cars (Schoolov, 2021).

Responding to the rising global demand for semiconductors has increased the water consumption of this water-intensive industry. An average semiconductor factory uses some 20,000 tons of water per day (Barrett, 2021). The global demand pressure and consequent ramping up of chipset production thus presents a root cause of the drought on the island.

Between 2015 and 2019, TSMC's purchase of municipal water supplies increased 71 per cent (Barrett, 2021). As the COVID-19 pandemic hit, and the demand for electronic products increased as a result of lockdown measures (Ziady, 2021), the global run for microchips skyrocketed, putting extreme pressure on the island's industries (Wang, 2021). Additionally, with car sales bouncing back faster than expected after carmakers were forced to temporarily shut down factories due to the pandemic, production was ramped up; and with TSMC producing about 80 per cent of the microcontroller units used in cars, pressure increased to supply the industry (Ziady, 2021).

In summary, with much of the semiconductor supply coming from Taiwan, the global run for chipsets has pressured the island's industry to ramp up production at the cost of using its scarce water resources.

5. Big picture

The drought in Taiwan Province of China exemplifies the challenges of water stress and related risk across value chains that could emerge as a result. It also shows stark choices that governments and authorities may have to face in rationing water resources (Fitch Ratings, 2021). By 2020, it was estimated that at least 2.3 billion people were living in water-stressed countries, and by 2030, it is projected that around 107 countries will not be on track to have sustainably managed water resources (UN-Water, 2021). Water management in a changing climate is incredibly important to ensure the life, health and prosperity of people and ecosystems on our planet. Therefore, integrated solutions are needed.

6. Solutions

Given that droughts and dry spells will become more frequent in the future the island will need to speed up its actions, with water resource management being a pressing task (Barbiroglio, 2021; Lin, 2021). A number of solutions are presented below to address different root causes and drivers and decrease the impacts of droughts and dry spells.

6.1 Let nature work

Ecosystem conservation and restoration, particularly watershed restoration, are examples of “Letting nature work,” with plenty of benefits for the region. Considering the amount of natural land cover lost to agriculture and development activities, several of the island’s wetlands, rivers, reservoirs and dams have been degraded, compromising ecosystem services such as water supply and hazard regulation, particularly for droughts like the one registered between 2020 and 2021 and floods, which are frequent during the rainy season (Lin and others, 2020). Measures to protect and restore the environment are considered priorities for the island (AIT, 2017).

The local authorities have already invested \$57.98 billion in the “Forward-looking Infrastructure Development Program,” which includes a \$2.8 billion budget for sustainable water environments. The project, which is to be implemented in three phases from 2017 to 2022, foresees ecological conservation and restoration of reservoir watersheds among other measures.

Restoring watersheds can bring numerous benefits to reduce drought risk and relieve drought impacts, both by regulating the water cycle and by stabilizing soil, which in turn reduces potential reservoir sedimentation (see section 3.3).

Forests are an integral part of the global water cycle and vital for water security. Forested watersheds, in fact, provide 75 per cent of our fresh water globally and supply high-quality water to 90 per cent of the world’s largest cities (Food and Agriculture Organization of the United Nations, 2013). Healthy forest ecosystems at the same time can stabilize the ground, thus preventing sediment run-off that can clog vital water reservoirs, which exacerbated the impacts of the drought. Additionally, forests provide numerous other services, such as air regulation, food provisioning, and recreational value to mention a few, which can reduce people’s vulnerabilities and help them cope with the impacts of drought.

Conserving and restoring the island’s forests, especially along watersheds, i.e. “Letting nature work,” thus brings multiple benefits. The Nature Conservancy’s Urban Water Blueprint, in fact, sees forest protection as well as reforestation as a watershed conservation solution with medium to high potential of reducing nutrient and sediment loads in Taipei’s reservoirs and weirs (The Nature Conservancy, 2022).

6.2 Innovate

Climate-smart agriculture is a landscape approach that seeks to enhance resilience, increase productivity and reduce emissions in a sustainable and innovative way (World Bank, 2018). For the island specifically, so-called smart-rice cultivation is an example of an innovate solution, where the main focus is to promote the use of rice varieties that are tolerant to both flood and drought extremes without losing their nutritional value (Bin Rahman and Zhang, 2022). This is not just about rice seeds but also concerns smart production and management, which include the use of specific machines that can help to optimize harvesting activities and other improvements related to drip irrigation systems (instead of traditional sprinkler systems), thus helping to reduce water losses.

For the past few years, the local authorities have been promoting a digital transformation for the agricultural sector as a response to climate change impacts. The main goal is to make farmers more resilient to weather extremes, such as prolonged drought periods, where high temperatures compromise crop production, increase pest infestations and generate shifts in weed flora, affecting agricultural development and farmers' well-being (CIER Taiwan, 2022). An example of such initiatives is the "Smart Agriculture Program 2017-2022," implemented by the local authorities with two main strategies: "smart production" and "digital service," wherein the integration of sensing technology, intelligent mechanical equipment, the "internet of things" and big data analysis, among others, can help not only to optimize the production and management of cropland but also to create a better working environment for farmers, attracting young people to the island's aged agricultural field workforce (Liu, 2021; Taiwan Agricultural Research Institute, 2022).

Additionally, private companies have invested in artificial intelligence approaches to help farmers. For example, there are apps designed to help rice farmers monitor multiple environmental variables via mobile devices. Factors like humidity, wind speed and direction, temperature and precipitation are recorded twenty-four seven and uploaded to management platforms such as the "Cloud-based smart agricultural solution." This, in combination with other information related to policies or market forecasts, can help rice farmers to holistically improve their agricultural operations according to standards while stabilizing production and sales within the consumer market (The National Development Commission, 2019).

6.3 Consume sustainably

Sustainable consumption and optimal resource allocation across economic sectors can help reduce the impacts of droughts (Aviso and others, 2021). The semiconductor industry is incredibly water intensive; a typical manufacturing facility can use between 2 and 4 million gal per day (Baskaran, 2017). Given the intense water usage and dependency of the semiconductor industry, showing good stewardship of water resources will also be key for managing water-related business risks (Baskaran, 2017). Large-scale water recycling presents a workable solution (Aviso and others, 2021), but increased use of recycled water would need to go hand in hand with increasing water prices, as the island's currently extremely low water prices (currently the cheapest in Asia) have discouraged investments in related infrastructure projects (Kastner, 2015; The News Lens Staff, 2021). According to the company's corporate social responsibility report, TSMC recycled 86 per cent of the water from its manufacturing processes in 2019 (Zhong and Chang, 2021; Barrett, 2021) and conserved 3.6 million tons more than in 2018. Yet compared to the 63 million tons of water it consumed across its facilities in 2019, the amount of water conserved is still small (Zhong and Chang, 2021) and efforts should be ramped up.

Similarly, the agricultural industry, which accounts for 72 per cent of the island's water consumption (Lin and Syngle, 2021), could adopt adaptation strategies to sustainably consume water resources. Practices such as precision irrigation or switching to low-water footprint crops could help the agricultural sector in reducing its water consumption (Aviso and others, 2021).

At the household level, one strategy to promote sustainable consumption could be to encourage water responsibility among users through practices such as paying attention to time spent bathing, cleaning water towers regularly and increasing awareness about tap and bottled water consumption (Yu and others, 2021). To this end, the island's water authority has been implementing strategies to enforce water resource protection, encouraging water saving behaviours and the use of products with water-saving labels while increasing water education among users (Wang and others, 2019).

6.4 Plan for risks

With climate change leading to a shifting typhoon pattern and droughts becoming increasingly frequent, the island will need to plan for drought risk and factor it in in management strategies (Lin, 2021).

First of all, in order to be able to manage it, the authorities, but also industries and academia, needs to endorse risk assessments that allow more comprehensive management of drought risk and the establishment of water resource management strategies with reasonable utilization and allocation of water among all users (Lin, 2021).

Certainly, seeing the role of vulnerable infrastructure in exacerbating drought impacts, updating infrastructure presents part of the solution to reduce the island's drought risk. Drought events recorded on the island between 2020 and 2021 evidenced the importance of functioning water storage and distribution infrastructure so as to not waste water resources (Lin and Syngle, 2021). Updating the cleaning process for reservoirs is one aspect of this, as techniques employed on the island are considered antiquated and there is a need to speed up cleaning with sedimentation reaching some 30 per cent of reservoir capacity (AIT, 2017; Tang, 2021; Hale, 2021).

In 2020, the island reached record levels of sedimentation removal, as some 14.4 million m³ of sediment were removed from reservoirs, corresponding to a 2.6 times greater removal than average dredging efforts (Cheng-hui, 2021). The local authorities have already announced a 10-year \$5.67 billion investment in infrastructure to remove sediment to restore reservoir capacity and to replace leaking pipelines, among other measures (Tang, 2021). This project's investment choices will strongly influence the resilience of the island's economy to water stress (Fitch Ratings, 2021).

6.5 Conclusions

Taiwan has relied on the consistency of typhoons to supply water resources to meet its needs; and it was caught unprepared for the consequences of a shifting normality, with less typhoons making landfall. The recent water crisis has evidenced the need to climate-proof the island's economy (Aviso and others, 2021) and the importance of conserving and equitably allocating natural resources.

Although there are possible engineering solutions to address droughts and dry spells, such as desalinization plants and cloud seeding initiatives, the solutions identified here and described above are a selection of those that could potentially help in an integrated way. As such, in order to deal with the complex array of drivers and root causes behind drought events, these solutions are envisioned as part of a solution package (see 2021/2022 Interconnected Disaster Risks report). Behind this concept, the main idea is that each solution complements another and synergies are utilized. For example, as watershed restoration (Let nature work) takes place and more awareness is raised for farmers' protection, comprehensive climate-smart agriculture approaches (Innovate) could be implemented to develop cultivated land in a sustainable way, with less farmland coverage in the watershed. These measures would need to be complemented by investments in water infrastructure (Plan for risks) to increase water use efficiency. Improved water infrastructure could also benefit ecosystem restoration and optimize water recycling for smart farmland. In this way, the solution package for the lack of cyclones and consecutive drought implies increasing synergies and co-benefits in parallel with reducing potential trade-offs as much as possible.

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This picture taken on March 17, 2021 shows low water levels at Zengwen Dam in Taiwan's Chiayi county. More than one million households and businesses in Taiwan's heavily industrialised central regions were put on water rationing on April 6, 2021, as the island battles its worst drought in 56 years.

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