REPORT ON CLIMATE CHANGE IMPACTS IN PENANG

PENANG GREEN AGENDA 2030

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About PGC

Penang Green Council or PGC is established in 2011 by Penang State Government. As a State Government Linked Company, PGC seeks to nurture, facilitate and co-ordinate environmental causes in Penang. We aim to enable, empower and enrich all stakeholders to practice sustainable development that protects the environment and quality of life.

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Abstract

This report advances a broad and detailed discussion about the impacts of climate change on the state of Penang through a systematic review of scientific papers and existing research. This has never been attempted before. The resulting document aims to provide a comprehensive understanding of climate change issues for both the government as well as the wider society. The topics include but are not limited to natural disasters, resource security and public health. These are presented in the form of direct and indirect impacts based on events that may have already occurred or that may potentially take place in the future. Direct impacts are the explicit responses of the natural environment to climate change, such as the rise in sea levels, extreme weather events, general warming and the warming of the oceans. The indirect impacts discussed are associated with the combined effects of existing environmental and health issues that cause knock-on effects on local communities, and are matters that largely relate to the population from public health and socioeconomic standpoints. Prior to the examination of state-level issues, the report reinforces the fact that climate change is indeed happening worldwide. The situation is becoming increasingly dire as global projections overwhelmingly predict upward trends of global temperatures and extreme weather events. This report compiles, analyses, synthesises and interprets information gathered from published documents such as scientific and social science papers, conference proceedings, books, reports from credible agencies (from Penang, Malaysia and at the international level), articles from newspapers and web pages. Having an adequate knowledge and understanding of the multiple issues related to climate change will allow Penang's residents and policymakers to better prepare for future climate change events and make informed decisions to mitigate them.

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1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as ‘a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods’ (UNFCCC, 1992). The Earth’s history has demonstrated that the climate system has changed over time due to natural causes such as variations in solar radiation and volcanic eruptions. However, human activities, particularly the burning of fossil fuels, have significantly accelerated global warming processes by releasing huge amounts of greenhouse gases (GHG). GHG emissions trapped in the Earth’s atmosphere affect the global climate and cause an increase in extreme weather events (WHO, 2018).

This warming is demonstrated in Fig. 1, where a sharp increase in global temperature anomalies can be observed that ‘remains consistent with a long-term trend towards global warming’ (Rohde, 2021). An annual study from the Berkeley Earth research organisation based on historical data and large data sets of current climate conditions concluded that the year ‘2020 was nominally the second warmest year since 1850’ and that from 2015 the ‘last six years have included all of the six warmest years directly observed’ (ibid.). Since climate change impacts are expected to be extensive over the coming decades, in-depth studies on weather patterns and their impacts have become more crucial than ever.

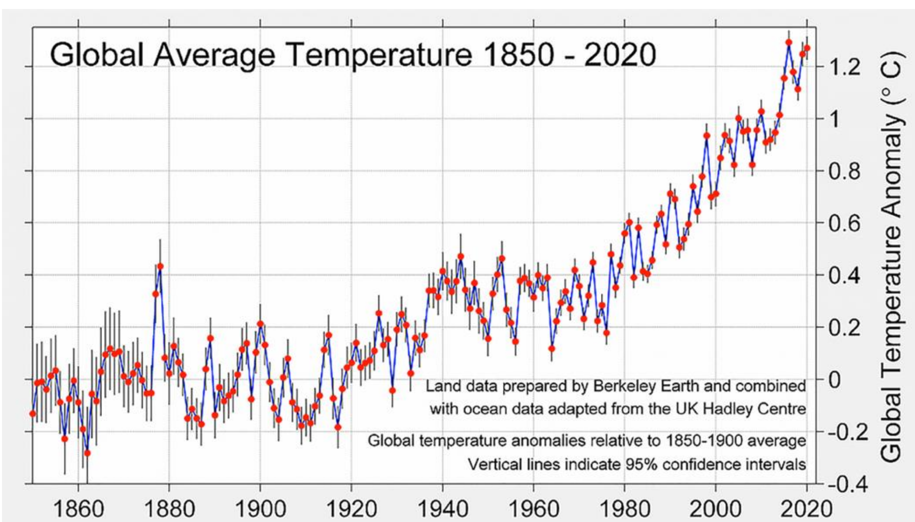

Fig. 1 Global average temperature, 1850–2020

Source: (Rohde, 2021)

The Intergovernmental Panel on Climate Change (IPCC) has reported that the critical threshold for extreme events (e.g. droughts and floods) lies between 1.5°C and 2°C of warming based on different climate models and projections, with climate change strongly influencing both the intensity and frequency of storms. This 1.5–2°C warming would boost storm surges and coastal flooding, damaging infrastructure and risking ecological systems (IPCC, 2018). The warmer it gets, the riskier it becomes for low-lying areas, coastline and islands. Fig. 2 shows that the world is moving towards a 2.8–3°C increase in temperature by 2100 even if countries prove successful in implementing their various climate policies that are already enacted (Stylianou *et al*., 2020). This warming would propel the Earth towards catastrophic weather conditions.

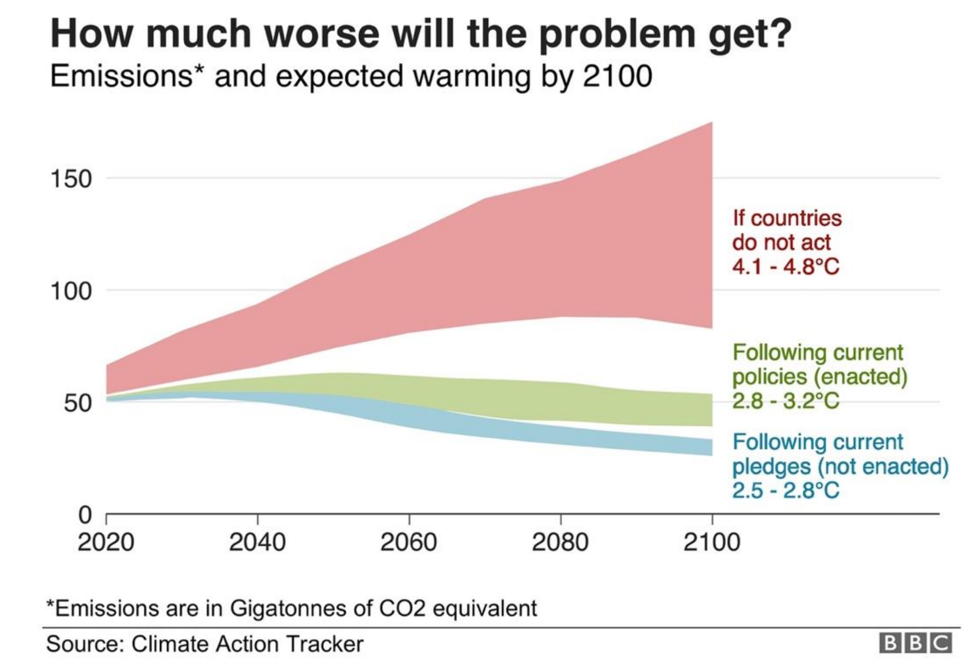

Fig. 2 Estimation of global emissions and expected warming by 2030

Note: Y axis: Gigatonnes of carbon dioxide (CO_2) equivalent

Source: (Stylianou *et al*., 2020)

The World Health Organisation (WHO) has estimated that from 2030 to 2050 an additional 250,000 deaths will occur every year due to the effects of climate change, including 'malnutrition, malaria, diarrhoea and heat stress', and by 2030 '[t]he direct damage costs to health … is estimated to be between USD2–4 billion' per year (WHO, 2018).

In Southeast Asia, various studies indicate that global warming has already had an impact on regional temperatures. The climate in mainland Southeast Asia exhibits pronounced periodic variability that is strongly linked to the El Niño Southern Oscillation (ENSO) phenomenon (Nicholls *et al*,. 2005; Singhrattna *et al*., 2005) where over a span of several years alternating periods of warming (El Niño) and cooling (La Niña) occur, raising or lowering sea surface temperatures in the tropical Pacific Ocean. These oscillations in turn impact rainfall and winds in Southeast Asia and other regions. A study which looked into the 15 hottest April months from 1980 to 2016 shows that long-term steady warming trends have increasingly contributed to hot surface air temperatures caused by the ENSO phenomenon as well as other factors (Fig. 3) (Thirumalai *et al.*, 2017). It is likely that continued warming in the region and El Niño activities will bring on more extreme weather in the future (ibid.).

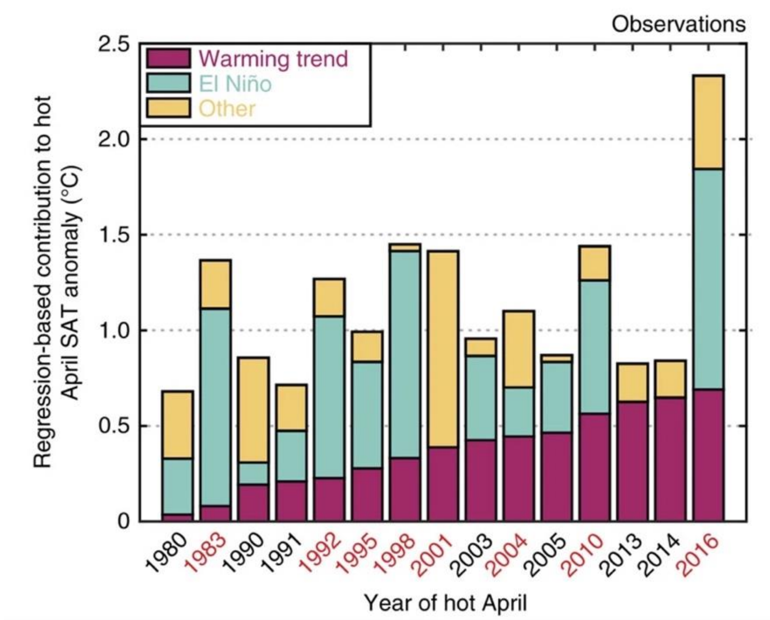

Fig. 3 Relative contributions of El Niño and long-term warming trends to the surface air temperature (SAT) during the 15 hottest April months in Southeast Asia

Source: (Thirumalai *et al*., 2017)

1.1 The Direct and Indirect Impacts of Climate Change

Climate change can affect communities directly by altering the physical environment and indirectly by transforming human interactions with that environment, in the process amplifying the direct impact. Fig. 4 highlights the direct and indirect impacts of climate change as explored in this report. Direct impacts are the physical effects arising from extreme events fuelled by rising temperatures. Changes in climate systems can intensify droughts, storms and heatwaves and accelerate sea level rises and ocean acidification. Indirect impacts occur as responses to changes in the environment and in natural resources (WHO, 2018), often exacerbated by pre-existing environmental and health issues.

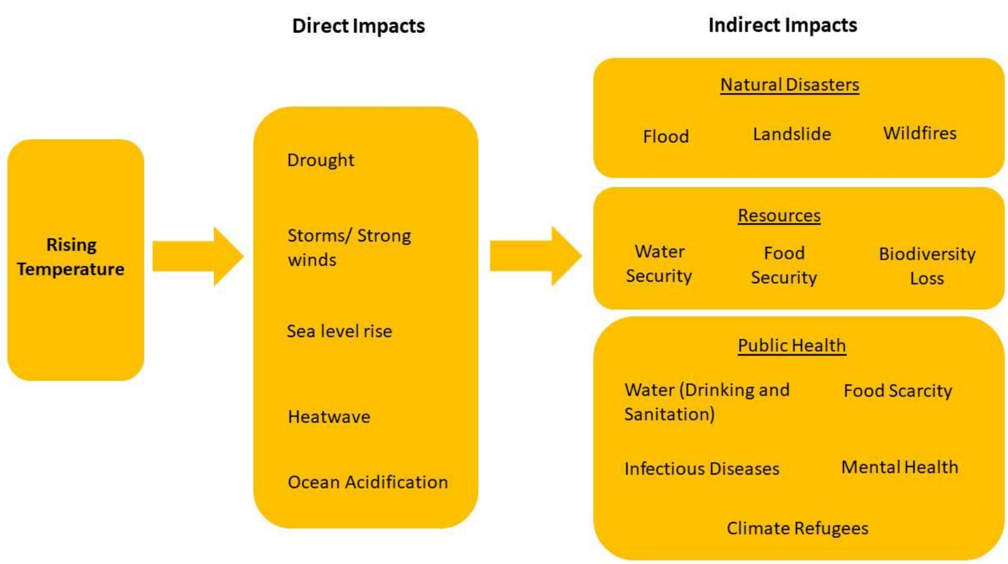

Fig. 4 Direct and indirect impacts of climate change

2 Impacts of Natural Disasters

The International Federation of Red Cross and Red Crescent Societies (IFRC) defines natural hazards as 'naturally occurring physical phenomena caused either rapid or slow onset events which can be geophysical …, hydrological …, climatological …, meteorological … or biological' (IFRC, n.d.). Climate change is recognised as one of the aggravating factors that 'will result in increased frequency, complexity and severity of disasters' (ibid.). While some natural variability may partly contribute to the occurrence of natural disasters, anthropogenic interferences are recognised as a major factor directly affecting weather and climate systems, increasing the exposure and vulnerability of a specific area and its local communities (Fig. 5).

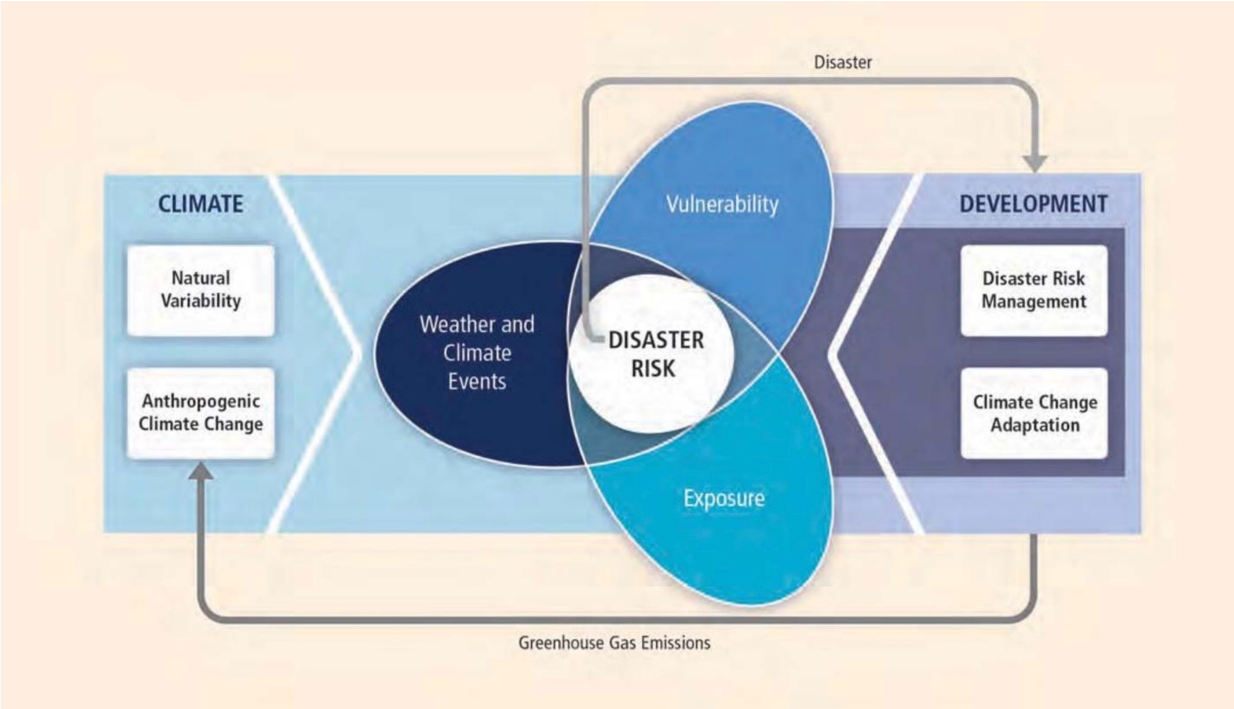

Fig. 5 Schema of key factors influencing natural disaster risks

Source: (IPCC, 2012)

From 1990 to 2018, 1.6 million deaths due to natural disasters (extreme weather and temperatures, floods, droughts, landslides, fires, earthquakes and volcanic activity) have been documented globally (Ritchie and Roser, 2020). Natural disasters tend to pose higher risks to low- or middle-income countries and can wipe out a significant portion of their gross domestic product (GDP), despite these countries contributing less to climate change. Higher temperatures along with lower humidity and rainfall contribute to heatwaves and droughts, while the reduction in soil moisture amplifies these hot extremes, leading to hotter and drier conditions that can cause disastrous consequences (Science Daily, 2020). Another issue of concern is the rise in sea levels, and the increasing frequency of climate change-related events in recent times has been anticipated since 1970 (Nakićenović *et al.*, 2000).

Globally, there 396 were major natural disasters recorded in 2019 with the breakdown of the type of disasters shown in Fig. 6. These disasters resulted in 11,755 deaths, affected the lives of 95 million people and caused damage worth USD130 billion. At the regional level, Asia recorded 40 per cent of disaster events with 45 per cent of total deaths (CRED, 2020). Floods, droughts and storms caused direct and indirect damage; some major events even caused long-lasting damage such as biodiversity loss and a reduction in arable or liveable land.

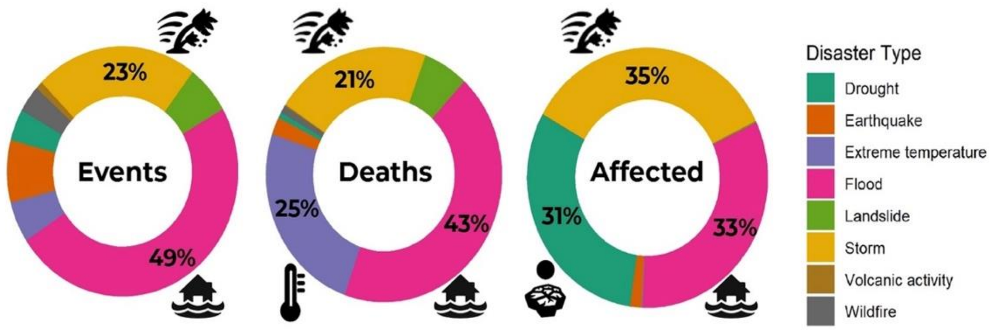

Fig. 6 Proportion of global natural disaster events, deaths and people affected by disaster types in 2019

Source: (CRED, 2020)

Malaysia lies just north of the equator and the local weather systems are largely governed by biannual monsoons (Suhaila and Jemain, 2012). These are the northeast monsoon (NEM) that blows from November to February or March and the southwest monsoon (SWM) which comes in May and lasts till August or September. There are two transitional periods in between the monsoon periods (Deni *et al.*, 2010; Zin *et al.*, 2010; Tangang *et al*., 2012). However, climate change-induced erratic rainfall patterns and rising temperatures have been observed in Malaysia through studies of historical data (Suhaila and Jemain, 2012; Sammathuria and Ling 2009) similar to those seen in other Asian countries such as China (Zhang *et al.*, 2009). In addition, the past two decades have seen increasing occurrences of extreme weather events such as high temperatures, high rainfall and prolonged dry spells (Tang, 2019). It has also been observed that the co-occurrence of dry spells and periods of heavy rainfall within the same year is an emerging weather pattern in Malaysia (Khor, 2015).

Fig. 7 presents a multiple climate hazard index chart for Southeast Asia where a higher index number indicates a higher vulnerability level to climate hazards, including tropical cyclones, floods, landslides, droughts and sea level rise (Yusuf and Francisco, 2009). Malaysia, especially its northern areas, is shown to have a medium vulnerability to these climate change-related hazards. The study by Yusuf and Francisco (2009) also notes that there are hazard hotspots in southern Thailand that are likely to become even more prone to floods and droughts, which could also negatively affect northern regions of Malaysia.

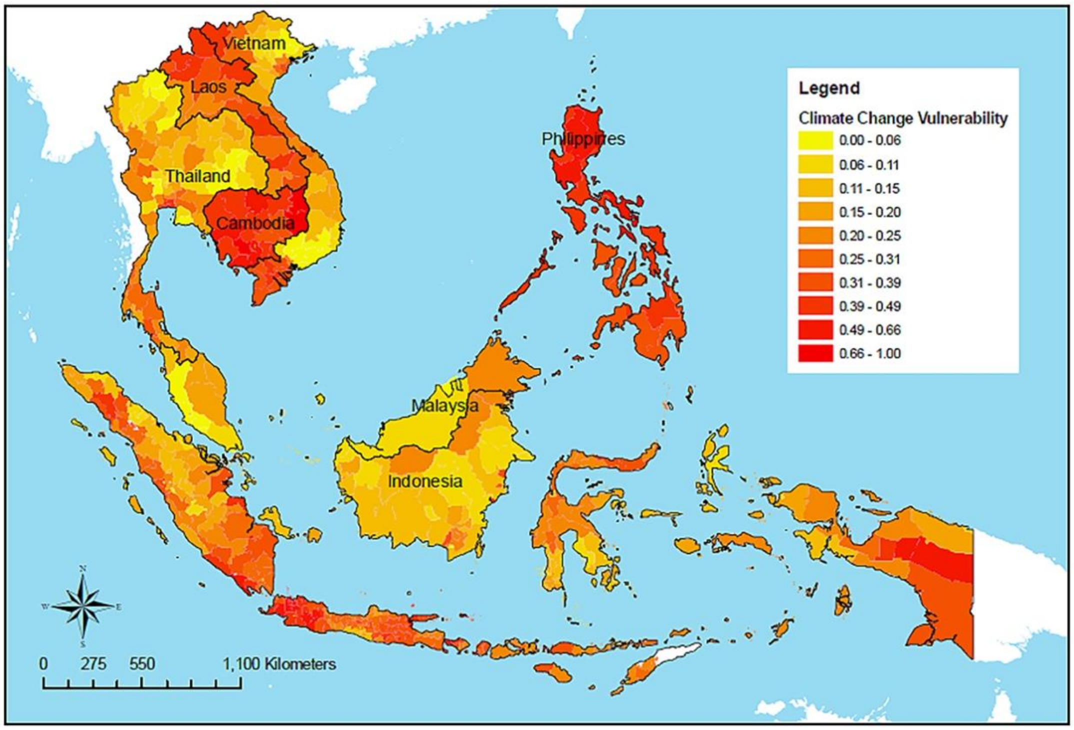

Fig. 7 Multiple climate hazard map of the Southeast Asian region

Source: (Yusuf and Francisco, 2009)

Currently, there is a lack of in-depth studies available on how these climate change scenarios will affect Penang specifically, which presents a great challenge in determining how Penang's environmental and local weather patterns will change in the future.

Another factor to observe are the recorded changes in land and sea surface temperatures. In 2009, the Malaysia Meteorological Department (MMD) projected temperature increases of 1.0–3.5°C for East Malaysia and 1.1–3.6°C for peninsular Malaysia, up to the year 2095, along with prediction that annual rainfall will decrease significantly, especially for Sabah (Sammathuria and Ling, 2009; Tang, 2019). The direct and indirect impacts of climate change, such as floods, droughts, storms, heatwaves and a rise in sea levels, are discussed below starting with those that Penang is most likely to experience.

2.1 Floods

Floods are one of the most common natural disasters in Malaysia. Between 1998 and 2018, floods were responsible for 70 per cent of natural disaster-induced damage in the country, with more than 770,000 people affected and 148 killed with estimated losses of approximately RM5.82 billion (Zurairi, 2018). In the past, intense rainfall and flooding naturally arose from convective systems or monsoon seasons, combined with low-lying flat terrain. However, deforestation adversely impacts the role of forests as natural flood control systems (Chan, 2003). With deforestation a much higher proportion of rainfall becomes surface run-off, flows into rivers and other water bodies, leading to floods. In addition, rapid development within or near river basins generates even more run-off and reduces river capacity, resulting in an increase in frequency and magnitude of floods (Chan, 2012). A flood can also be worsened or caused by the expansion of impermeable surface areas, soil erosion and landslides that increase sediment load in surface run-off, clogged waterways, the high volume of surface flow accumulated downstream and 'limited capacity to channel off discharge' (Kam, 2017).

Another important factor is the increase of rainfall intensity which is 'the ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period' (FAO, n.d.). It is usually expressed 'in depth units per unit time, usually as mm per hour (mm/h)' (ibid.). As Fig. 8 shows, rainfall in northern peninsular Malaysia, including Penang, has increased in recent years compared to the base years. This is potentially due to climate change. In Penang the annual rainfall per hour has increased from an average of 31 mm in the 1990s to 180 mm currently, representing a six-fold increase (Zairil, 2019).

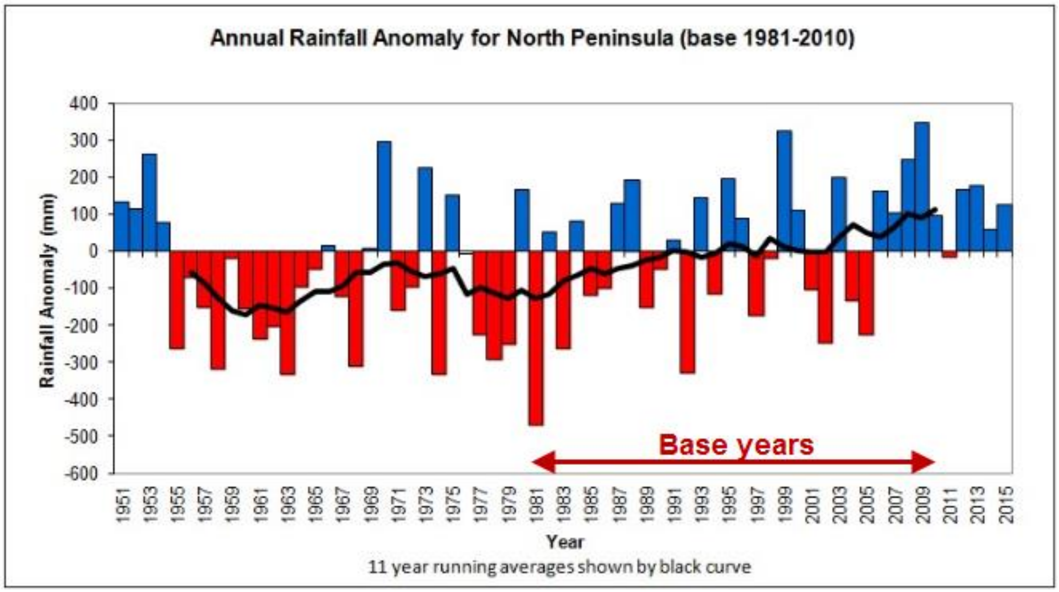

Fig. 8 Yearly rainfall anomalies in northern peninsular Malaysia

Source: (MMD, 2017)

In September 2017, a devastating flood in Penang caused 100 locations to be affected, and displaced more than 1,000 victims. The water level rose from 0.3 m to 0.5 m in certain areas (Yaakob, 2017). Again in November the same year, an intense storm and high tides caused one of the state's worst floods with water levels reaching 0.3 m in certain areas and over 3,000 people in Penang having to be evacuated (Teoh, 2017; Yaakob, 2017). This particular flood affected almost 100,000 households (Awani, 2017) and almost paralysed the state with 'up to 372mm of rainfall [falling] overnight in some areas, equivalent to 1½ months of rain' (Teoh, 2017). In October 2019, the state saw another flash flood affecting Seberang Perai Tengah due to heavy rainfall, with homes and roads being flooded by 0.3–0.74 m and 0.1–0.45 m of water, respectively (*New Straits Times*, 2019).

2.2 Droughts

Droughts are prolonged periods of below average rainfall and can cause water scarcity, forest fires, damage to natural habitats, reduced crop yields or even total crop failures, increased mortality rates and other public health issues. These will in turn bring about inflation of food costs, land degradation and forced migration. A higher unpredictability of droughts adds to the woes of farmers, affecting local crop yield and threatening food security (Yohannes, 2016).

More drought events are expected to occur across peninsular Malaysia and these are expected to affect the northeastern region, including Penang (Chan and Ghani, 2016). Another review of Malaysia's future water security notes that it has been projected that the potential for drought occurrences will be higher, specifically in 2028, 2029, 2034, 2042 and 2044 (Rasyikah, 2018). As for rainfall, it has been projected that from 2006 to 2099 peninsular Malaysia would experience higher intensity in short duration rainfall and lower intensity in long duration rainfall (Noor *et al.*, 2018).

Penang is a water-insecure state as it depends heavily on water resources that originate from neighbouring Kedah. The reservoirs in Kedah and Penang have to cater to a combined total of 3.95 million people. During the dry season, Penang has had to resort to cloud-seeding operations, and each such operation costs up to RM27,000, based on MMD records from 2015 to 2020 (MMD, 2020). In 2016 alone, 17 cloud-seeding operations were conducted (Table 1), which potentially amounted to a cost of RM459,000. The highest temperature anomaly was recorded in 2016 (Fig. 3 and Fig. 9), caused by the El Niño event that happened in 2015 and 2016 (Rohde 2021). Consequently, the effect on Penang is seen in the high number of cloud-seeding operations needed then to mitigate the drought conditions. In April 2020, the effective capacity recorded at the Air Itam, Teluk Bahang and Muda dams was 33.3 per cent, 20.9 per cent and 4.4 per cent respectively (Dermawan, 2020). In addition, the water level at Sungai Muda, normally at 2 m, also dropped to 1.29 m, below the critical level of 1.5 m (ibid.). By May 2020, six cloud-seeding operations had already been carried out (Table 1).

Table 1 Frequency of cloud seeding in Penang from 2015 to 2020

Year	2015	2016	2017	2018	2019	2020
Frequency of cloud seeding	0	17	0	0	1	6*

Note: *until May 2020

Source: *(*MMD, 2020)

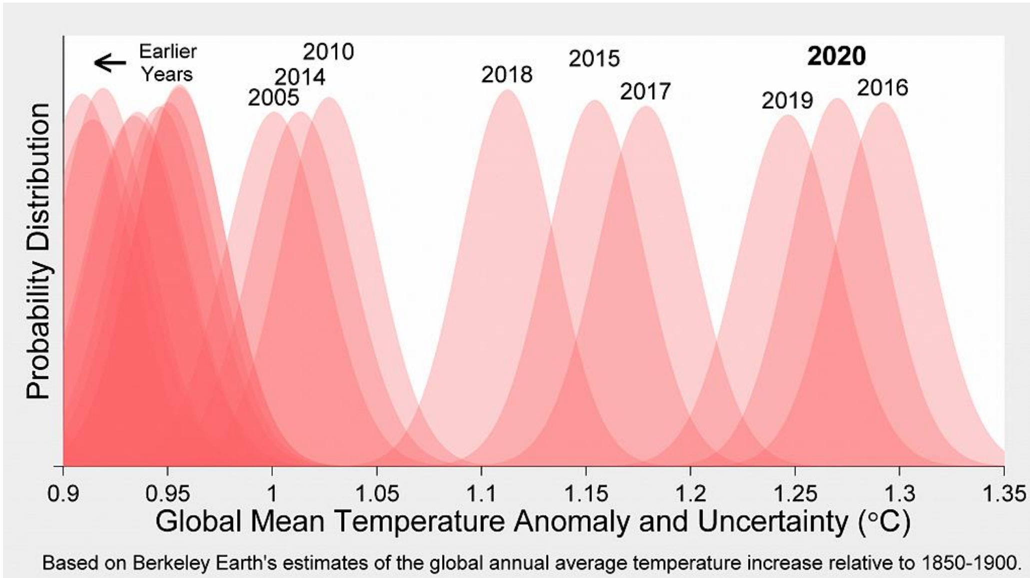

Fig. 9 Global mean temperature anomaly

Source: (Rohde, 2021)

Previously, during a drought, the first sector to be affected in Penang was agriculture, which mainly consists of paddy planting. In early 2020, 1,600 ha of paddy fields belonging to 800 farmers in Penang suffered a shortage of irrigation water, which slowed down the maturing process of the crop (Nasir, 2020). The federal government is currently working on the implementation of a comprehensive river basin management system that is to be implemented in the Sungai Muda basin as part of the National Water Balance System (NAWABS). This is aimed at managing flood waters, providing early warnings of water shortages and acting as 'an operational system for real time decision making and water accounting' (Husain, 2017). Penang is also currently in discussion with the Perak state government and relevant stakeholders for the purchase of raw water from Sungai Perak as an alternative source of water.

2.3 Sea Level Rise

In the last decade, the global sea level has risen by around 3.6 mm per year (The Royal Society, 2020). While total rise in global sea level has been about 21–24 cm since 1880, and nearly a third of that amount came about in the last two and a half decades (Fig. 10) (Lindsey, 2020). Glaciers around the world have retracted at increasingly higher rates (Fig.11). Data from the World

Glacier Monitoring Service (WGMS) has shown consistent changes in glacial mass balances, with glacial mass decreasing by 228 mm per year in the 1980s to 921 mm per year for the period 2010–2018 (Blunden and Arndt, 2019). As shown in Fig. 12, the melting of glaciers has contributed 45 per cent to the rise in sea levels and about 38 per cent is due to thermal expansion. It has been stated that 'glacial shrinkage is past the point of no return' with glacial masses continuing decline even if the global temperatures and GHG emissions do not increase further (Nature, 2018). Ice loss at the poles has accelerated rapidly over the last two decades; 247 billion tonnes of ice were lost per year from the Greenland ice sheet from 2014 to 2016 while 199 billion tonnes of ice were lost per year in Antarctica from 2012 to 2016 (Lindsey, 2020).

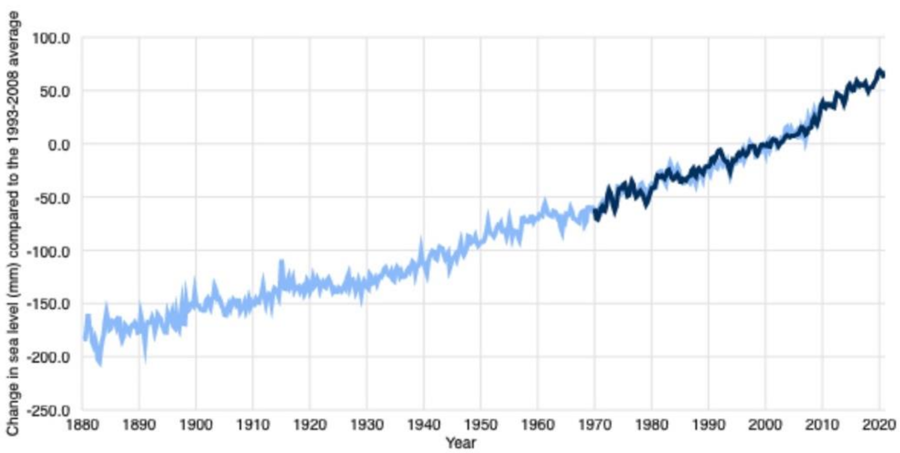

Fig. 10 Changes in sea level from 1880 to 2020

Source: (Lindsey, 2020)

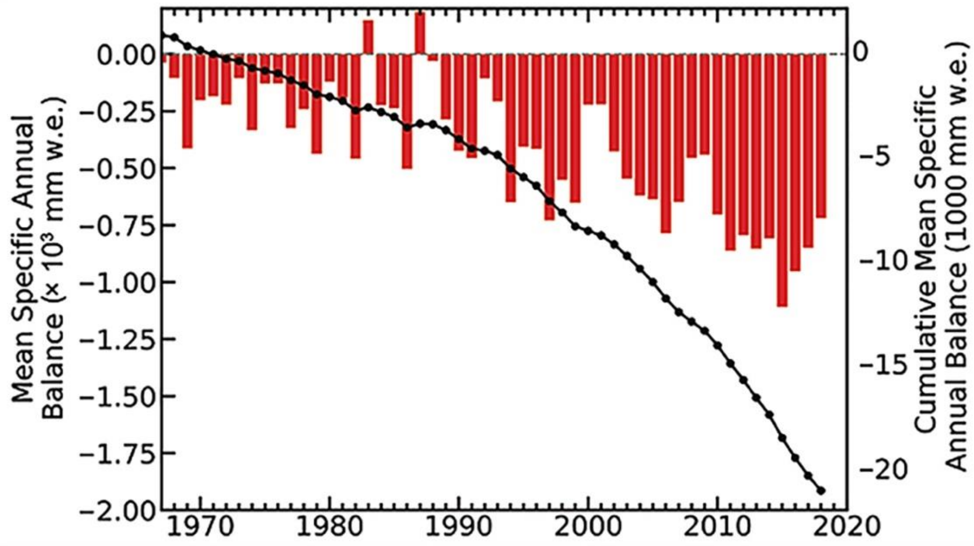

Fig. 11 The mass balance of the WGMS's reference glaciers each year since 1968 (red bars), along with the total mass loss over time (black line)

Source: (Blunden and Arndt, 2019)

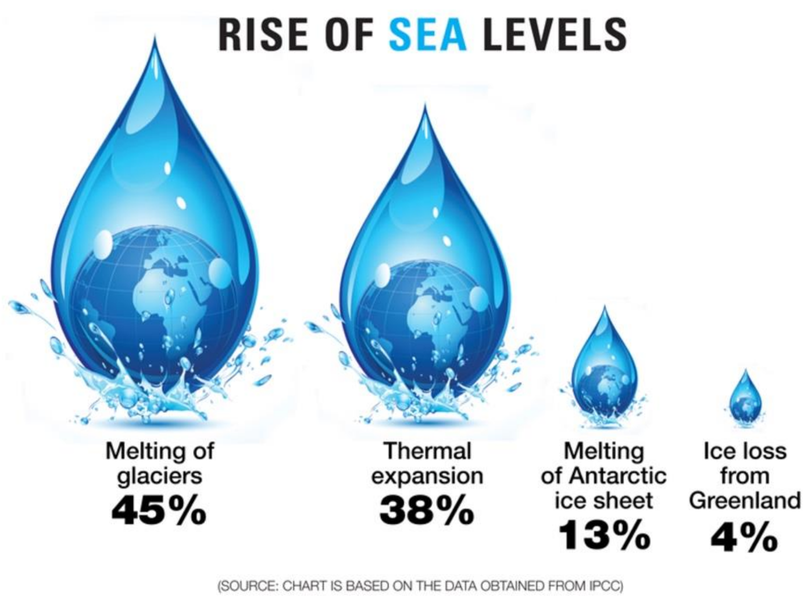

Fig. 12 Sources contributing to sea level rise

Source: (Rising Sea Levels CCP ,n.d.)

A study by the National Hydraulic Research Institute of Malaysia (NAHRIM) on projected sea level rise shows that the west coast of peninsular Malaysia should expect an average sea level rise of 0.07–0.14 m in 2040 and 0.25–0.52 m in 2100 (Ghazali *et al.*, 2018; NAHRIM, 2019). For Penang (Fig. 13), estimations based on projected sea level increases of 0.11 m and 0.68 m for 2030 and 2100 respectively indicate land loss in the Balik Pulau area on Penang Island and around the coastline of the state's mainland (NAHRIM, 2017). In another estimation by Climate Central (2020) 'based on global-scale datasets for elevation, tides, and coastal flood likelihoods', larger areas of Penang's mainland would potentially be inundated by 2050 compared to the NAHRIM projection (Fig. 14). However, it should be noted that the Climate Central's simulation has its limitations as the data used was less accurate for areas outside of the United States and the projection is 'not based on physical storm and flood simulations and do not take into account factors such as erosion, future changes in the frequency or intensity of storms, inland flooding, or contributions from rainfall or rivers' (ibid.).

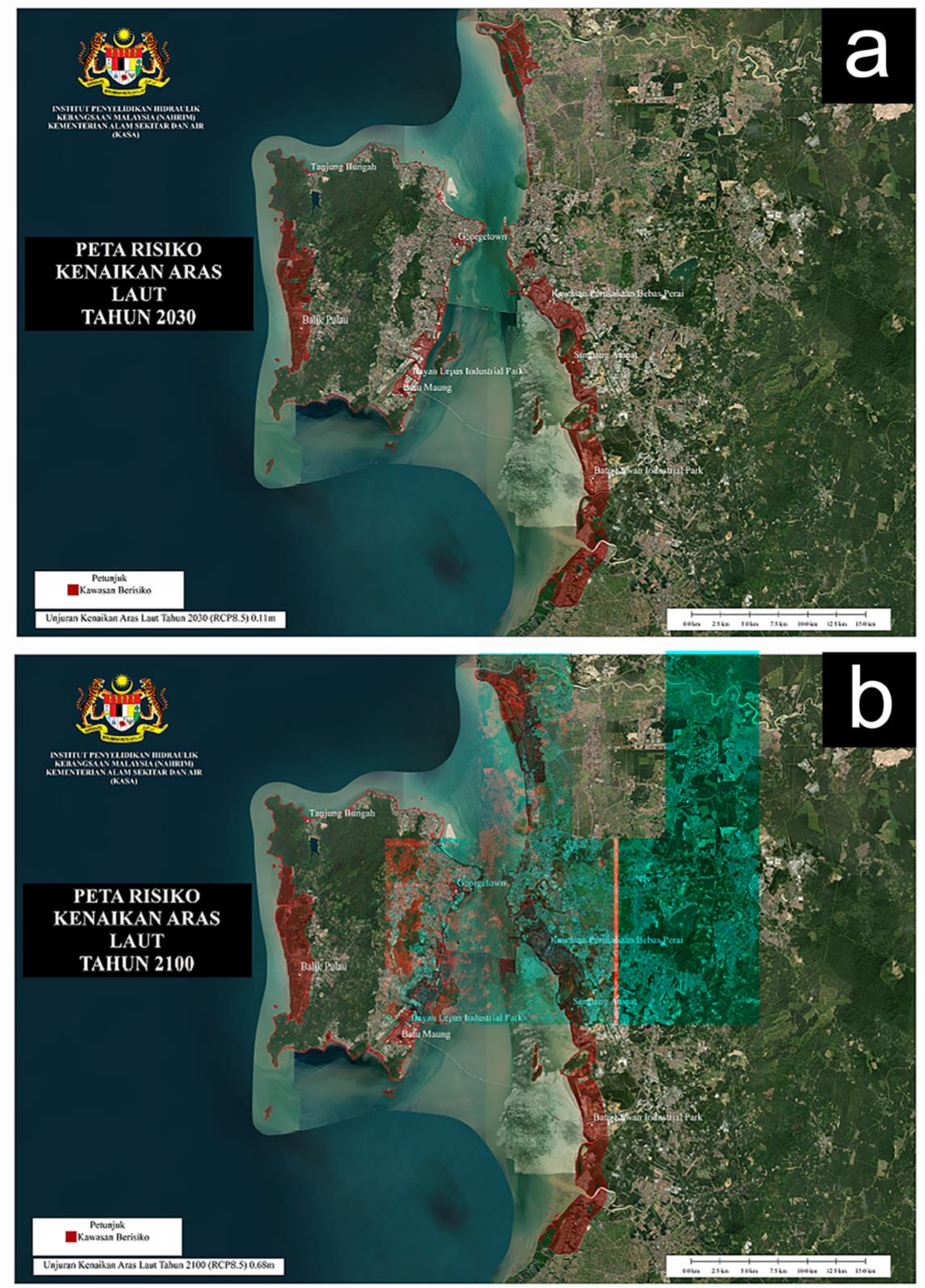

Fig. 13 Risk of ocean inundation in (**a**) 2030 and (**b**) 2100 due to rising sea levels

Source: (NAHRIM, 2017)

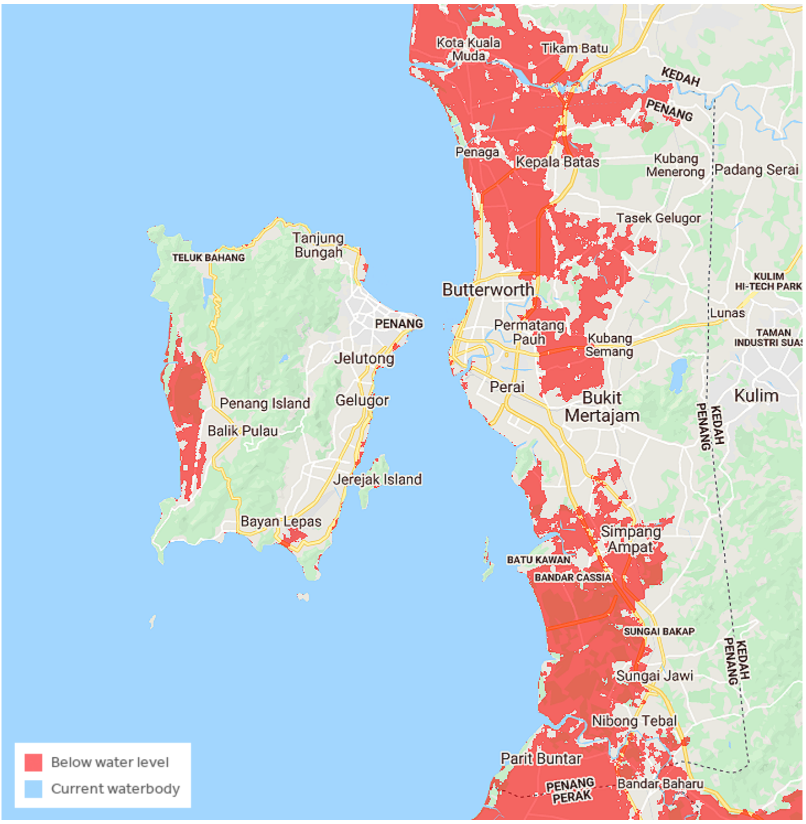

Fig. 14 Land projected to be below the annual flood levels in 2050.

Source: (Climate Central, assessed in April 2020)

Referring to Fig. 13 and Fig. 14, large parts of the areas most at risk from sea level rises and subsequent flooding are in fact paddy fields. Should this happen, Penang's self-sufficiency level (SSL) would be significantly reduced. Prolonged flood events could spark significant social and economic disruptions and conflicts as thousands of people would be displaced. Rising sea levels are an issue that the state government needs to take seriously considering that a significant portion of land in Penang is coastal and low-lying. This also applies to the Penang South Islands (PSI) reclamation project.

2.4 Storms

Located in the equatorial zone, Malaysia is largely shielded from typhoons such as those that affect the Philippines and Taiwan, instead experiencing low-end extreme winds from thunderstorms and monsoons (Holmes, 2001). Nevertheless heavy downpours do occur from time to time with the Madden–Julian Oscillation (MJO) and the ENSO phenomenon mentioned earlier affecting the intensity and frequency of rainfall (Syafrina *et al.*, 2015). It is also important to understand the local weather system is governed by the northeast and southwest monsoons (Wong et. al. 2009; Deni *et al.*, 2010; Zin *et al.*, 2010; Tanggang *et al.*, 2012), which are occasionally associated with heavy rainfall and strong winds of up to 20 km/h (Mohtar *et al.*, 2014).

A simulation of future maximum central pressures of typhoons, done for a 100-year return periods using 10,000 years of simulated data, shows that Malaysia's neighbouring regions could be facing more intense typhoon and tropical cyclone events (Fig. 15) (Mori and Takemi, 2016).

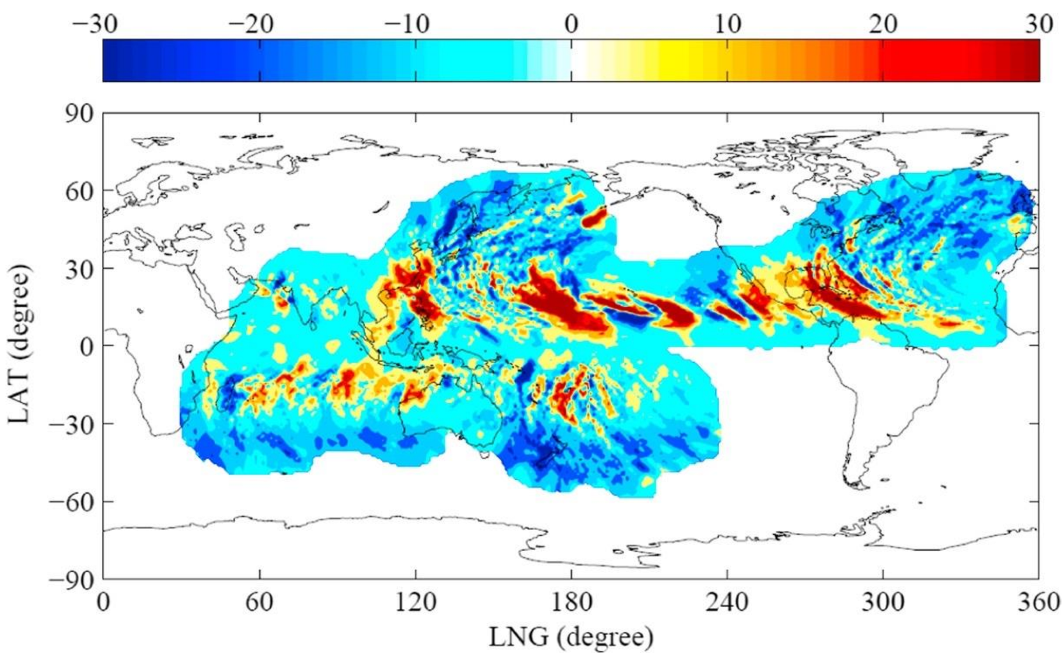

Fig. 15 Simulated future change of maximum central pressure of typhoons with a 100-year return period (pressure deviation in hPa/year)

Source: (Mori and Takemi ,2016)

Storms bring more precipitation, as observed during hurricanes and typhoons such as Hurricane Harvey in the United States in 2017. Climate change increased Hurricane Harvey's precipitation over Houston and surrounding areas of Texas by around 37 per cent (Risser and Wehner, 2017) while another study on the same matter revealed an increase of around 15 per cent (van Oldenborgh *et al.*, 2017). Some of the relevant factors identified were high ocean heat values from 'human-caused climate change' and increased water evaporation in the atmosphere

(Trenberth *et al.*, 2018). These potential increases in rainfall must be factored in for future drainage system planning and flood mitigation schemes in Penang in order to prevent damage to infrastructure and reduce the risks of public health issues and loss of lives.

Penang experiences an average of 184 thunderstorm days (TDs) annually, as reported by the MMD (Protec Power Solutions, 2014), with huge economic damage incurred. For example, the total losses incurred from high winds from 2010 to 2013 in northern Seberang Perai (Seberang Perai Utara) alone reached RM1.6 million (Fig. 16). The Penang Fire and Rescue Department (Jabatan Bomba dan Penyelamat) reported five rescue missions mounted in 2018 due to storms or strong wind events, often related to fallen trees (JBPM, 2018). A study assessing damage done by windstorms in Penang from 2010 to 2013 showed that the highest number of houses damaged among the five districts was in northern Seberang Perai (Seberang Perai Utara, SPU), totalling 538 homes (Majid *et al.*, 2016). This made up 47 per cent of all houses damaged by windstorms, followed by southern Seberang Perai (Seberang Perai Selatan, SPS) (226 houses, 20 per cent), northeast Penang Island (Timur Laut, TL) (137 houses, 12 per cent), central Seberang Perai (Seberang Perai Tengah, SPT) (126 houses, 11 per cent) and southwest Penang Island (Barat Daya, BD) (111 houses, 10 per cent) (ibid.). The highest number of storm and strong wind events were recorded in March, with the second highest number of windstorms occurring in March (ibid.). In 2019, the Ministry of Education estimated that approximately RM20 million worth of damage was caused to schools and educational institutions across seven states as a results of Typhoon Lekima (Dermawan, 2019b).

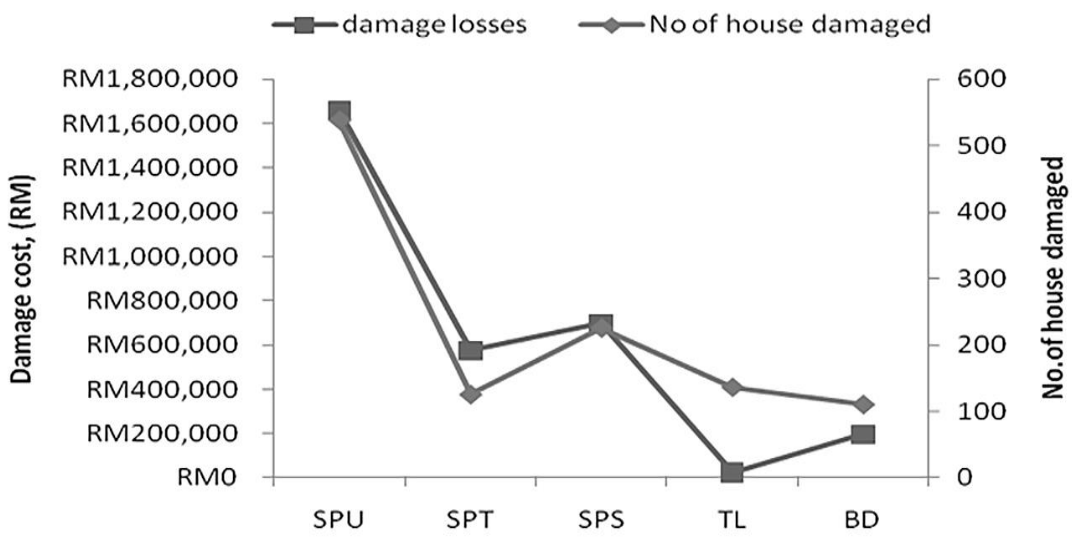

Fig. 16 Number of houses damaged and the costs of damage in each district from windstorms for 2010 to 2013

Note: SPU: Northern Seberang Perai, SPT: Central Seberang Perai, SPS: Southern Seberang Perai, TL: Northeast Penang Island, BD: Southwest Penang Island

Source: (Majid *et al.* ,2016)

2.5 Heatwaves

A heatwave is a natural hazard during which unusually hot weather occurs over several consecutive days. Heatwave events increase the vulnerability of a population and pose significant health risks, resulting in morbidity and mortality in severe cases (Suparta and Yatim, 2019; Anderson and Bell, 2011). Studies have shown that climate change is going to lead to more frequent heatwaves of longer duration and higher intensity (Coumou and Rahmstorf, 2012) with this already happening in many parts of the world. For example, Europe has seen an increasing number of heatwaves in recent years with a summer heatwave in 2019 killing over 2,500 people, particularly in the Netherlands, Belgium and France (Climate Centre, 2020).

As seen in Fig. 17, a projection shows that some locations in Malaysia could face more than 240 days per year where the daily temperature reaches beyond 35^{o}C in the 2050s. By 2090, the vast majority of peninsular Malaysia could be facing the same problem (Chinvanno *et al*., 2009). In peninsular Malaysia heatwaves frequently occur during the southwest monsoon period. In addition, heatwaves are also attributed to El Niño events (see Fig. 9). Moderate El Niño events were recorded from 2002 to 2003 and 2009 to 2010; weak El Niño events happened from 2004 to 2005 and 2006 to 2007. As shown in Fig. 18, Penang has already faced a large number of heatwaves and also recorded high frequencies and durations of heatwaves (Suparta and Yatim, 2019).

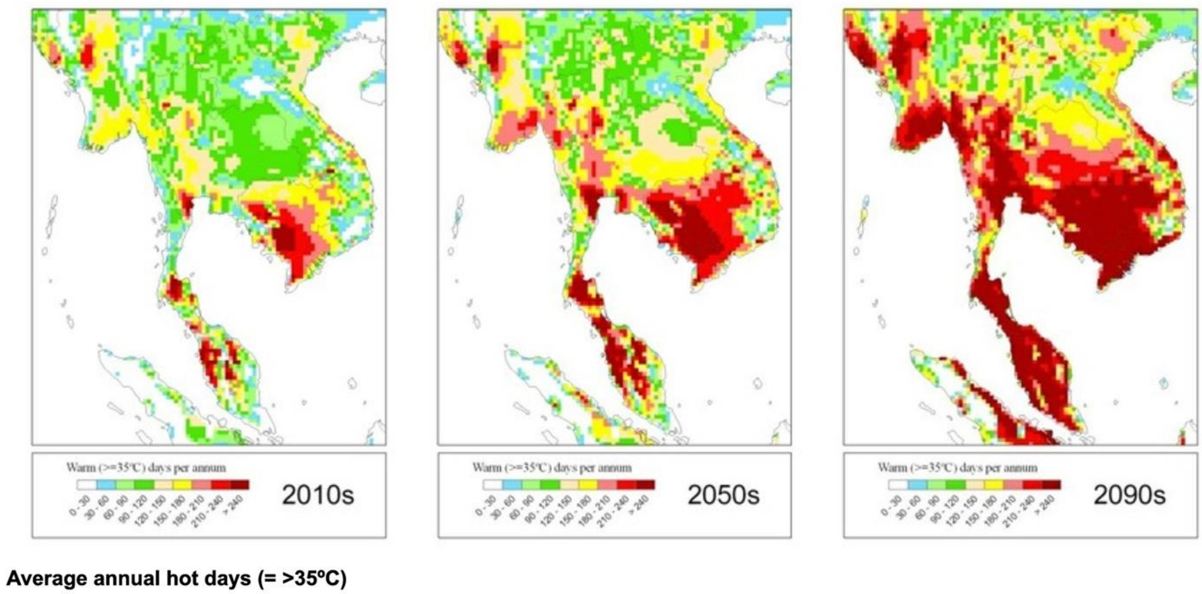

Fig. 17 Projected increase of the number warm days per year in the 2010s, 2050s and 2090s
Source: (Chinvanno *et al*., 2009)

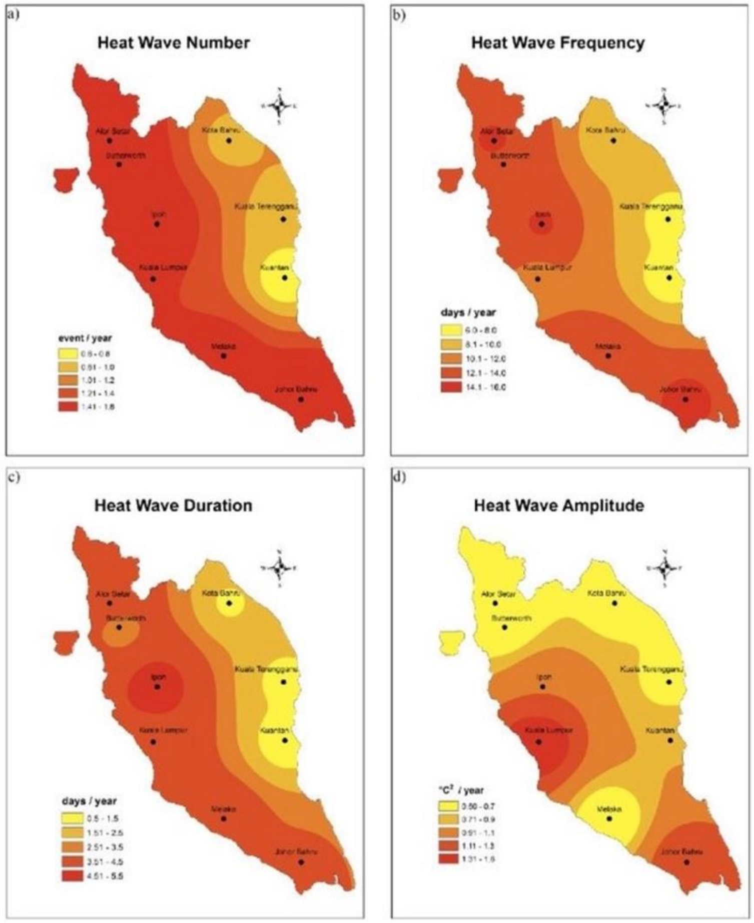

Fig. 18. Spatial distribution patterns of heatwaves in peninsular Malaysia from 2001 to 2010 according to: (**a**) number (**b**) frequency (**c**) duration and (**d**) amplitude

Source: (Suparta and Yatim , 2019)

Exposure to high heat is more concentrated in areas with low vegetation cover such as urban areas, bare land and industrial zones. Urbanisation contributes to warmer temperatures as areas undergoing urban development are stripped of permeable and moist surfaces and vegetation to be replaced with impermeable and dry surfaces such as buildings, roads, pavements and other infrastructure. Utilities (such as air-conditioning units) and motorised vehicles in cities also release heat. Together, they create the urban heat island (UHI) effect (Tan *et al.,* 2010).

The presence of UHIs in Malaysia has been confirmed by multiple studies. As with other countries, the areas in Malaysia most affected by the UHI effect are major urban areas and large cities; locations of concern are Kuala Lumpur, Penang, Putrajaya and Selangor (Fig. 19) (Ahmad and Hashim, 2007; Elsayed, 2012; Morris *et al.*, 2015; Kamal *et al.*, 2019)

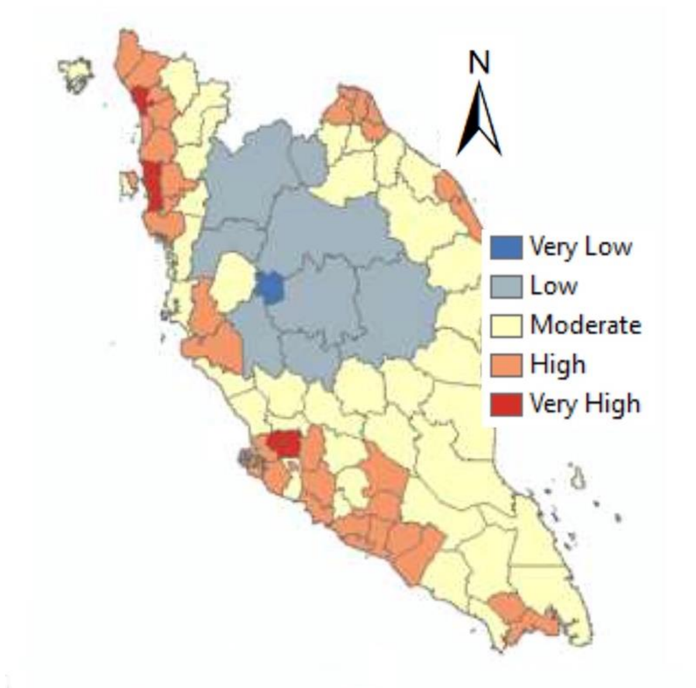

Fig. 19 Heat exposure index for peninsular Malaysia

Source: (Kamal *et al.*, 2019)

As temperatures increase, the greater frequency and intensity of heatwaves would have dire consequences not only for humans but also for animal and plant species that are unable to adapt. In Penang, Think City, a non-profit organisation, has been focusing their efforts on reducing the impacts of the UHI effect via the implementation of nature-based and ecofriendly solutions. Their studies show that heat stress can be reduced by establishing green elements and increased vegetation such as planting more trees along streets, rooftop gardens and blue-green corridors (areas with open watercourses or streams and foliage).

2.6 Landslides

Factors that trigger landslides are processes that loosen and dislodge soil and rock material and include natural erosion, the destabilisation of soil structure along slopes that have been cut or developed, and heavy rainfall which increase surface run-off to send torrents of mud and debris downhill. Landslide activity in Malaysia is commonly tied to annual monsoon seasons when there are prolonged periods of intense rainfall. Although predictions of the exact timing and locations of landslides are not available, methods such as geographic information systems (GIS) remote sensing, soil stability analysis and up-to-date rainfall monitoring are vital for statistical modelling and early warning systems that can better inform decision-making by engineers, government bodies and other stakeholders. Previous statistical modelling has identified regions in Penang most at risk for frequent landslides based on hazard mapping of factors such as land cover, vegetation cover and precipitation (Huqqani *et al.*, 2019). Records have shown that landslides have also happened in relatively low-slope areas (Pradhan and Lee, 2010).

Studies have shown that Penang Island is prone to soil erosion and landslides (Elmahdy *et al*., 2016; Huqqani *et al.*, 2019; Pradhan *et al*., 2012). It was found that one of the natural triggers of landslides is the island's high level of precipitation, which saturates the soil, washing down debris and rock and causing instabilities (Huqqani *et al.*, 2019). It was also observed that '[l]andslides occur when the maximum daily precipitation exceeds 100 mm, with a maximum hourly rainfall of 40 mm' (Pradhan and Lee, 2010). Penang experienced an increasing trend in maximum rainfall from 2014 to 2017 (Fig. 20), and as Penang becomes more exposed and vulnerable to increasing rainfall extremes (Syafrina *et al.*, 2015), the risk of more landslides in the future may undoubtedly increase as well.

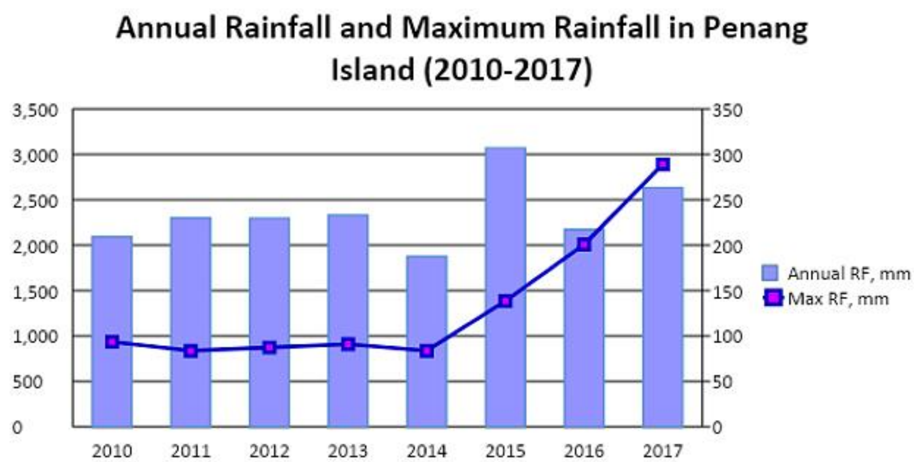

Fig. 20 Annual rainfall and maximum rainfall for Penang Island (2010–2017)

Source: (Chacko, 2019)

For text in box: (Muzamir, 2019)

A devastating landslide tragedy in occurred in late October 2017 at a construction site at Lengkok Lembah Pantai, where hillside development had taken place, killing 11 workers (*The Sun Daily*, 2018b). In October 2018, nine workers died in landslide at Jalan Bukit Kukus in Paya Terubong with a stream running down the hill not far away identified as the cause for the landslide (Bernama, 2018). As it was located too close to the slope, a period of intense rainfall overloaded the stream and contributed to the disaster (ibid.). In June 2019, four workers constructing a retaining wall to control soil movement perished in yet another landslide incident, this time in Tanjung Bungah at Jalan Batu Ferringhi. They were buried five meters deep (Muzamir, 2019). Human interference, including hillside development, might have destabilised slopes and increased the risk of landslides occurring especially during or after periods of heavy rainfall.

2.7 Wildfires

Wildfires are uncontrolled fires fuelled by combustible vegetation, usually occurring in rural areas. Naturally occurring wildfires are relatively less common in Malaysia compared to other parts of the world such as Australia. Peat fires, forest fires and brushfires are more common and are usually on a smaller scale, either started inadvertently or intentionally for land clearing. Based on 2017 statistical records kept by the Fire and Rescue Department Malaysia, Penang had 347 cases of bushfires and 39 cases of forest fires. As the weather gets hotter and drier, the risk of these fires getting out of control will also increase. Globally, wildfires have caused increases in economic damage and from 2014 onwards the cost of this damage has increased (Fig. 21). In 2015, it was recorded that 500,000 people were affected by wildfires.

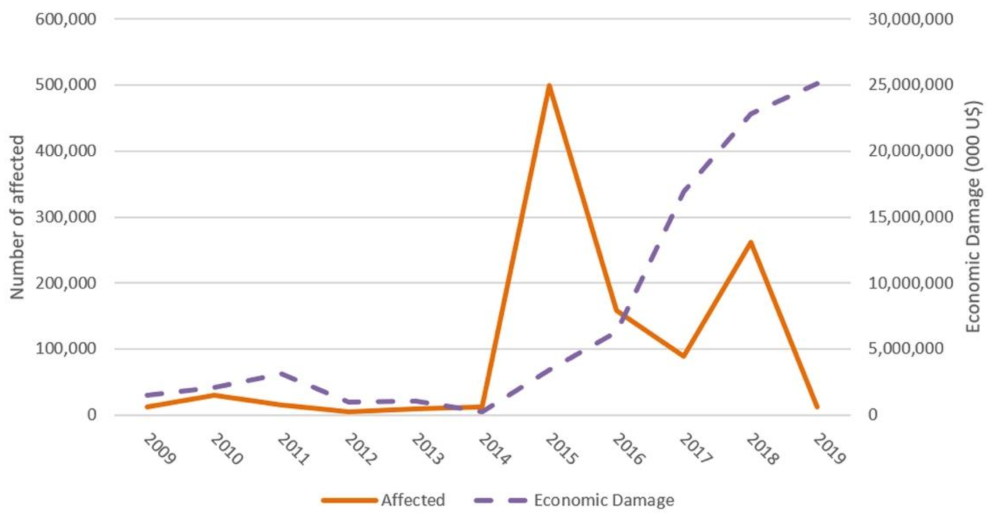

Fig. 21 Annual evolution of economic damage and people affected by wildfires globally
Source: (CRED ,2020)

Preventing and controlling natural wildfires can be difficult given the large swaths of land they may cover, the lack of accessibility and water supply in these areas and the fact that wildfires can be caused by a range of human activities and environmental conditions. Climate change-induced droughts and high winds may exacerbate the challenges in containing these fires. One of the best mitigation methods is through frequent monitoring and identification of hotspots using historical data and real-time satellite data. Based on data provided by Global Forest Watch Fires, 63 events were detected in Penang using visible infrared imaging radiometer suite (VIIRS) fire alerts and moderate resolution imaging spectroradiometer (MODIS) imagery from May 2019 to April 2020 (Fig. 22). When infrared radiation emitted by fires or other thermal anomalies on the Earth’s surface are picked up by the satellites, fire alerts are issued. These early warnings of fire outbreaks could be effective in preventing wildfires and the costly damage incurred by these events.

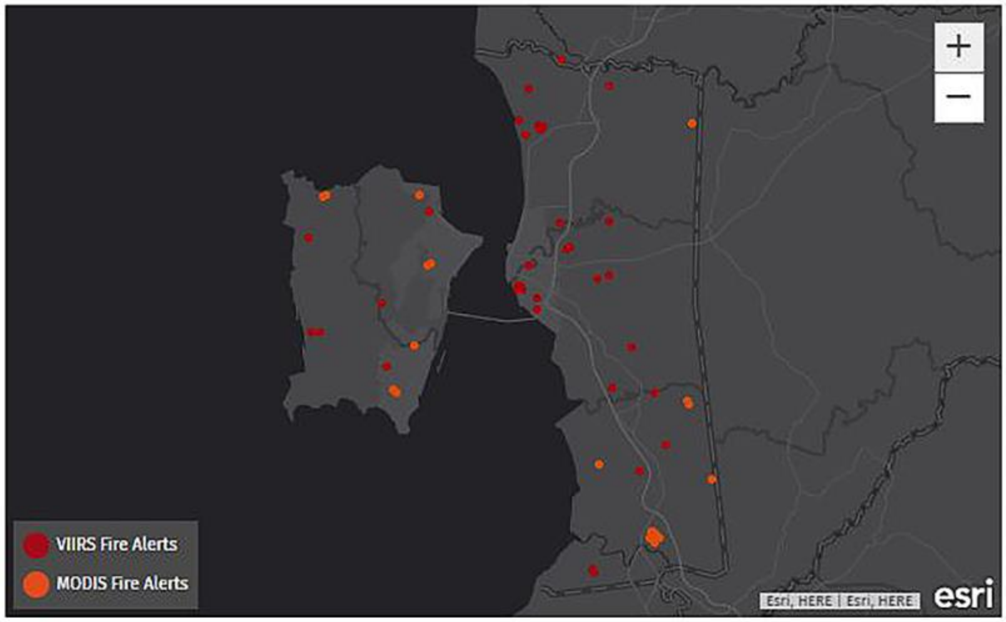

Fig. 22 Distribution of VIIRS and MODIS fire alerts in Penang, 1 May 2019–21 April 2020
Source: (FIRMS, 2020)

3 Impacts on Resources

3.1 Water Security

Extreme climate events give rise to challenges regarding water quality and quantity, with accessibility to clean and reliable water resources being a major concern (Ahmed *et al.*, 2014). A comparison of data from 1978–1980 and 2011–2013 shows that the average water level of rivers in both northern and southern regions of peninsular Malaysia has dropped and these decreases have been associated with changes in the monsoon regimes (Suri *et al*., 2014). In addition, water demand is increasing due to population growth and rapid urbanisation, putting even greater pressure on water resources (Ahmed *et al*., 2014).

As noted earlier, Penang is a water-insecure state as it draws more than 80 per cent of its raw water from the Muda River that originates from catchment areas in Kedah (Tan *et al*., 2019). Any future changes such as water disputes between states, pollution, continued logging in river basins and catchment areas, and even a reduction in water resources from climate change and warming temperatures have the potential to greatly affect Penang's ability to acquire an adequate water supply for its residents. Penang also has the lowest domestic water tariff in the country with Malaysian water tariffs being some of the lowest in the world (Chan *et al*., 2016). Hence it is not surprising that the state also has the highest consumption rate of domestic water in Malaysia at 290 litres per capita per day (l/cap/d) (Rizaninam and Awaina, 2018). In comparison, Singapore's domestic water consumption was 141 l/cap/d in 2018 with a target of further reducing it to 130 l/cap/d by 2030 (PUB, 2020)

Adding to the pressure, Penang is undergoing rapid development and the state's population is expected to further increase (RSN, 2018). Major developments such as the Gurney Wharf and Penang South Islands (PSI) reclamation projects, and the Batu Kawan master plan will require significant water supplies and could be considered water-intensive projects (Davasagayam, 2019). Projections from the Penang Water Supply Corporation (Perbadanan Bekalan Air Pulau Pinang, PBAPP) show that by 2050 Penang's water demand will hit 1,884 million litres per day (MLD) (Fig. 23) (Jaseni, 2014; PBA, 2019). Implementation of the Sungai Perak Raw Water Transfer Scheme (SPRWTS), a potential secondary water source that could deliver an additional 1,000 MLD, has already been delayed seven years as of 2019 (Dermawan, 2019a).

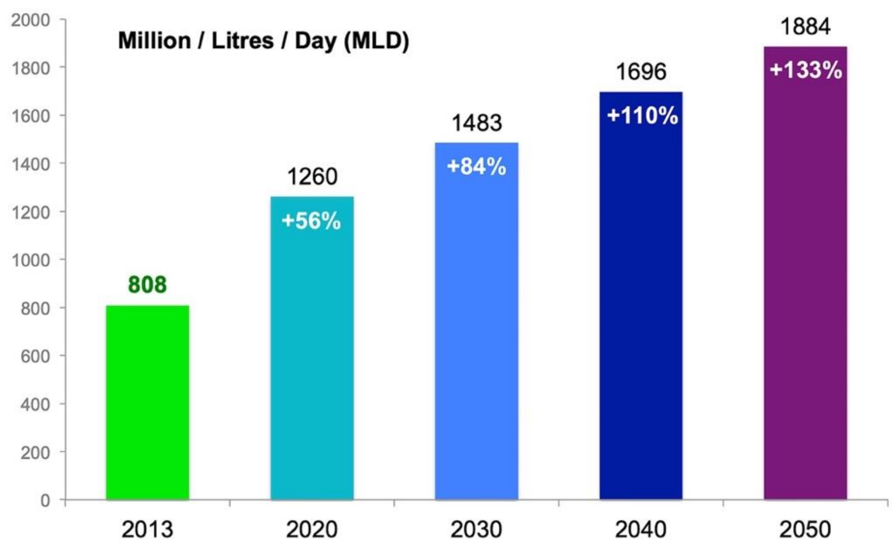

Fig. 23 Penang's projected water demand

Source: (Jaseni, 2014)

Climate change threatens Penang's water security in various ways. Droughts not only dry up water bodies like rivers, streams and lakes, but also significantly affect the quality of the remaining raw water due to factors such as increased salinisation, stratification and changes in nutrients and turbidity levels (Mosley, 2015). Conversely, during periods of high intensity rainfall and floods, storm water run-offs pick up nutrients, pollutants, sediments and waste before flowing into streams and rivers, causing water pollution (EPA, 2016; Koh *et al.*, 2017). Such extreme events could also disrupt the state's water supply by damaging water treatment plants and infrastructure that deliver water (Demuth, 2008).

Sea level rises would decrease adequate access to raw water as saltwater intrusions contaminate freshwater resources including groundwater reservoirs and aquifers (Ehsan *et al.*, 2019; Zwolsman *et al*., 2010). In addition, warmer temperatures and excessive nutrients in water bodies create the perfect conditions for algal blooms (EPA, 2013). A reduction in the quality of raw water will increase the cost of water treatment with more complications in disinfection processes, higher risks of overloading of treatment systems, increased operational costs and a greater likelihood of public health issues (Zwolsman *et al*., 2010), which will add to the financial stresses of PBAPP.

Water insecurity heightened by climate change will not only affect public health in Penang but also negatively impact its economic health—in particular, the electronic sector which relies heavily on a relatively cheap and safe water supply. An insecure water supply will also affect food security as rice production and other agricultural activities require large amount of water.

To increase the state's water security, PBAPP has taken initiatives to improve non-revenue water management and to intensify the implementation of water-saving devices (Chan *et al.*, 2016). PBAPP and Water Watch Penang (an NGO) have also carried out educational programmes and raised awareness about the need to reduce household water consumption. However, stronger measures are needed to shift consumption patterns, such as increasing water tariffs and making water a strategic commodity for the state. The low water tariffs currently in place not only discourage more sustainable water consumption but also disincentivise investments in water-saving technologies.

3.2 Food Security

Malaysia is a food-importing country and the major imports include rice, vegetables, fruits, dairy products, animal feed and processed food items. Therefore it is susceptible to climate change impacts on not only local food production systems but also those of the exporting countries. In Penang, although the agriculture sector contributes only 2.2 per cent to the state GDP, a stable growth from 2020 onwards is expected due to increasing local demand (Ong, 2020). Paddy production and fishery activities are the main contributors to this portion of the state GDP.

3.2.1 Paddy Cultivation

Rice production is highly dependent on several parameters, the most important of which are temperature, rainfall, atmospheric carbon dioxide content and solar radiation (Alam *et al.*, 2011; Dabi and Khanna, 2018). Changes in temperature will significantly affect crop phenology and the timing of physiological process such as germination and leaf expansion (Chamhuri and Alam, 2014). The paddy plant, essentially a water-intensive plant, is susceptible to changes in thse water cycle and, as a result, drought and flood events can be incredibly damaging (Huntington, 2010; Vaghefi *et al.*, 2013).

Malaysia, including Penang, is a net importer of rice, relying on countries like Thailand, Vietnam and Pakistan for 30–40 per cent of its rice imports (Firdaus *et al*., 2013; Omar *et al*., 2019; The Star, 2019a). Though Malaysia ranked high in 2017 in the Global Food Security Index compared to neighbouring countries, the country's research and development into climate change-resilient crops is lagging behind (Omar *et al*., 2019).

For text in box: (Omar *et al.*, 2019).

While the Malaysian Agricultural Research and Development Institute (MARDI) has introduced 49 paddy varieties, countries like Thailand, Vietnam and Indonesia have released 82, 96 and 183 varieties, respectively, as of 2018 (Omar *et al*., 2019).

Although Malaysia's current rice varieties are capable of producing high yields, many of these rice varieties have their limitations such as not being drought tolerant or resistant to common pests and diseases (Amri *et al.*, 2019; Ramli, 2019).

In Penang, as of 2016 there were approximately 12,782 ha of paddy fields, with the majority located in northern Seberang Perai (Fig. 24) (BPEN, 2017; RSN, 2018). Penang produced 148,297 metric tons of paddy in 2016 and had the second highest average yield in the country after Selangor (Kee, 2018). Yet Penang’s rice self-sufficiency level is estimated to be 63 per cent, while the remaining market demand is fulfilled by imports (Penang Institute, 2019). Presently, the paddy fields are at risk of being converted for urban development (Samat *et al*., 2014; Kee, 2018).

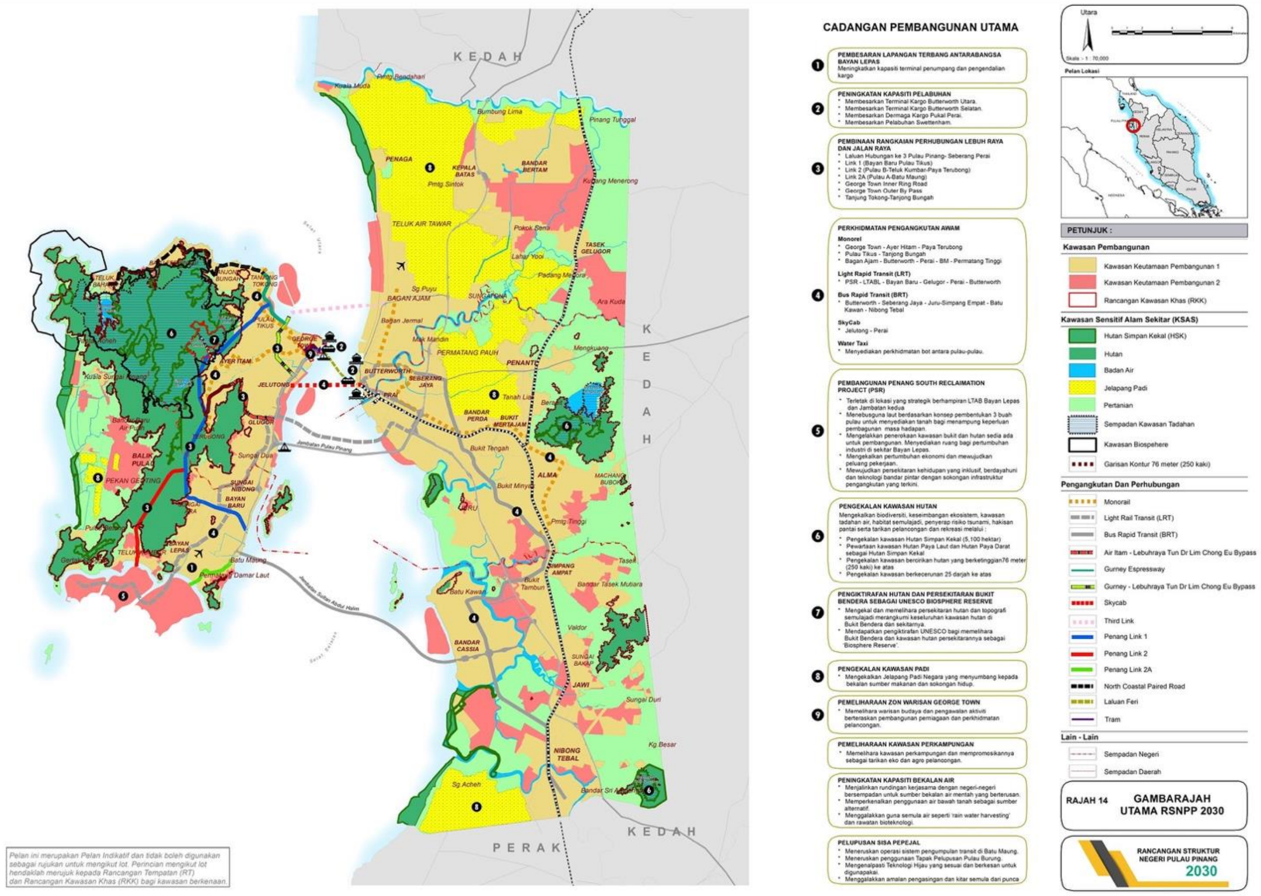

Fig. 24 Locations of paddy fields in Penang (in yellow)

Source: (RSN, 2018)

Penang has been hit by extreme weather events in recent years and paddy fields have not been spared (Tang, 2019). One of the worst events on record was in November 2017 where 9,680.82 ha of paddy fields (nearly 76 per cent of the total area) were destroyed in a 12-hour storm (The Sun Daily, 2017). On the other hand, paddy cultivation is also threatened by drought events. In the past, during sustained periods of drought when the water supply was insufficient, Penang had to stop irrigation for agriculture to prioritise water for household use instead (due to its ‘no water rationing policy’) (Afandi, 2016).

Climate change also increases the risks for agricultural diseases and pests (Chamhuri and Alam, 2014). Some common issues encountered in rice farming for Malaysia are the bacterial leaf and panicle blight, sheath blight and rice blast which are both caused by fungi, and infestations by brown and green plant hoppers and stem borers (Ramli, 2019). At present, no rice varieties are resistant to these pests and diseases, except for the new MR303 and MR307 varieties, which are only resistant to foliar and panicle blast (ibid.). Crops that are already experiencing abiotic stress (e.g. from external factors like high temperature and droughts) from climate change would be even more susceptible to diseases (Ahanger *et al.*, 2013). To exacerbate the problem, climate change provides an opportunity for bacterial and fungal pathogens to have longer periods available for reproduction, increased rates of reproduction and reduces the effect of seasonal patterns in naturally controlling these pathogens, thereby increasing the likelihood of spread to vulnerable hosts (Santini and Ghelardini, 2015; Sutherst *et al.*, 2011). Similarly, some species of insects that are crop pests will reproduce at a faster rate in warmer temperatures, have greater geographical ranges in terms of habitat and ‘longer growing seasons for warm climate pests’, hence jeopardising crop yields even more (Sutherst *et al.*, 2011).

Sea level rise also affects crops at low-lying coastal areas. As shown in Fig. 14, Seberang Perai, where the state’s intensive agriculture takes place (see also Fig. 24), faces a high risk of being inundated by seawater by the year 2050 during coastal flood events (Climate Central, 2020). This land would be contaminated with seawater and the increased soil salinity would reduce crop yields. Salt injury that eventually occurs in rice crops affects all stages of rice growth, and some examples of the symptoms include sterility, stunted growth, curling and drying of leaves and white tips (Meybeck *et al*., 2012).

It is expected that agricultural productivity and yields in Penang will decrease in the future. In a projection of future rice yields in 2030 of select areas of peninsular Malaysia, Penang may experience reduction in yield during both the main season and off season as a result of increased maximum and minimum temperatures during the period of rice growth (Vaghefi *et al.*, 2013). In the study, Penang was projected to have the greatest reduction in rice yield of the granary areas studied (ibid.). Based on climate scenarios generated using data from the MMD, farmers will see revenue losses of 67 per cent in 2020–2029, 88 per cent in 2050–2059, and 127 per cent in 2090–2099 as a result of warming (Firdaus *et al.*, 2013). Using a scenario with a temperature increase of 2°C and CO_2 concentration of 383 ppm, another simulation predicted that an annual loss of

RM162.531 million for the rice industry, with this figure increasing to RM299.145 million if the CO_2 concentration increases to 574 ppm (Vaghefi *et al.*, 2011).

3.2.2 Fisheries

Representing two-thirds of the Earth's surface, aquatic ecosystems such as marine, coastal, estuaries, rivers and lakes are susceptible to climate change (Barange *et al.*, 2018; Mohanty *et al*., 2010). The impacts of climate change on aquatic food production are complex and involve an interconnected system with various physical and chemical factors, such as temperature, dissolved oxygen content, salinity, pH, wind, vertical mixing and tidal patterns (Brander, 2010). Direct effects on marine organisms encompass impacts to life cycle, metabolism, behaviour and species survival; indirect effects are usually felt through ecosystem processes and changes in food webs (ibid.). In terms of capture fisheries and aquaculture, the former are closely linked to global ecosystem processes and therefore more prone to the effects of climate change (Mohanty *et al.*, 2010). The latter, which functions to complement and increase fish stocks in the supply chain, may also be affected via altered breeding cycles from higher temperatures and increased vulnerability to diseases (ibid.).

Malaysia is a large fish-consuming nation and also a net importer of fish (FAO, 2019). The value of the Malaysian fishery sector has almost doubled in the last decade and had a gross output of over RM14 billion in 2017, with the highest proportion attributed to marine fish catches, followed by aquaculture and inland fisheries (Ku Kassim, 2020; Afiq Aziz, 2018). However, Malaysian fishermen have been reporting lower fish catches, affecting their income (Mcintyre, 2019; Omar *et al.*, 2013). Fig. 25 shows the decline of demersal fish biomass throughout the years compared to its original biomass in the 1960s (Ku Kassim, 2020).

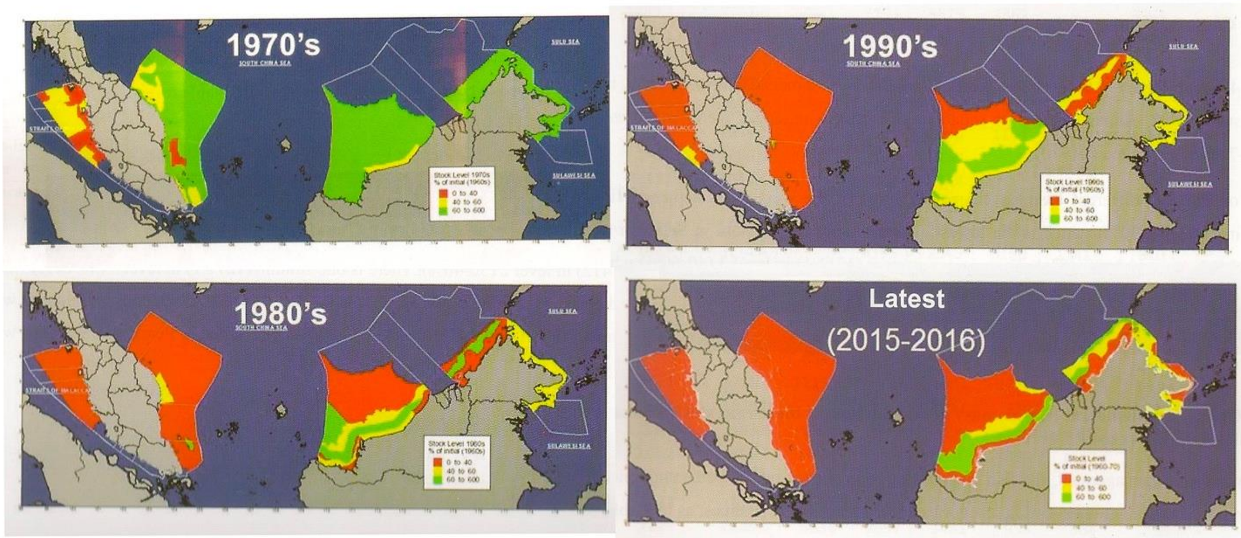

Fig. 25 Changes in demersal fish biomass as compared to the 1960s
Source: (Ku Kassim, 2020)

Penang's fishery industry plays a major role in ensuring the state's food security and also reducing poverty (Vaghefi, 2019). With a fish intake of almost 57 kg per capita per year, Malaysians are among the largest fish consumers in the world as this number is more than double the global average consumption of 20.3 kg per capita (Johnstone and Vaghefi, 2019; Ku Kassim, 2020). Marine capture fisheries, aquaculture fisheries and inland fisheries make up Penang's fishery sector and in 2016 contributed 65.3 per cent, 34.6 per cent and 0.05 per cent, respectively, to fish production in the state (DOF, 2017; Penang Institute, 2019).

Major changes like rising sea temperatures resulting from increased global temperature have a wide array of impacts on marine species and ecosystems. Fig. 26 shows how sea surface temperatures in Malaysia have risen from 1985 to 2014. The sea surface temperature in Penang has experienced an increase of approximately 1.1°C across this time period (Ku Kassim, 2020).

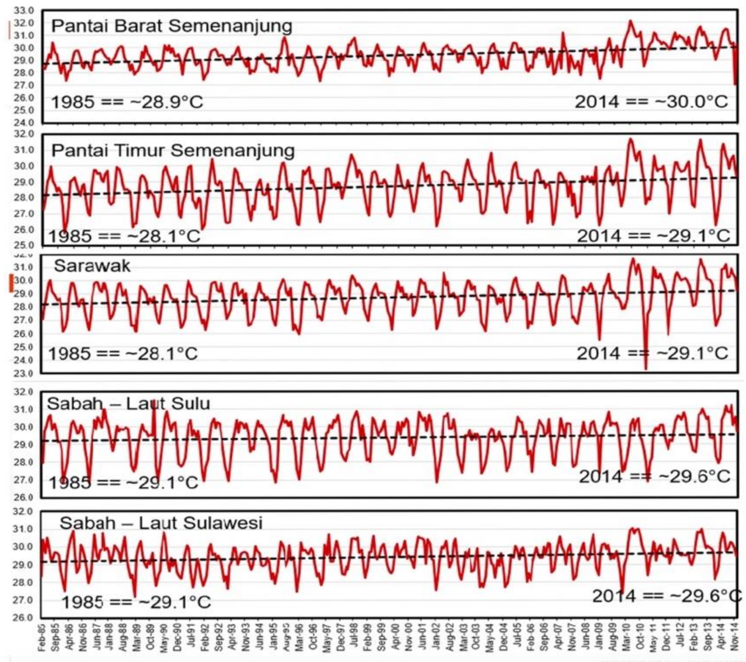

Fig. 26 Sea surface temperature recorded across Malaysia, 1985–2014

Source: (Ku Kassim, 2020)

The distribution of fish will be affected by the shifts and increases in sea temperature as they migrate in search of waters with more suitable temperatures or their numbers die out; hence some areas of Malaysia may experience a gain in fish stocks while significantly more other regions will face severe losses. The Indian mackerel (*Rastrelliger kanagurta*, known locally as *ikan kembung*) is an important fish that is widely consumed in Malaysia. However, the abundance and availability of this fish species is very likely to diminish under climate change. The projection in Fig. 27 indicates a poleward shift of the Indian mackerel away from the equator by 2050 (Ku Kassim, 2020). This is also highlighted in the examination of three different warming scenarios of sea surface temperature (Fig. 28). As the sea surface temperature increases along the east coast of peninsular Malaysia, suitable habitats for the Indian mackerel decrease, resulting in the decline of this species (Kaschner *et al*., 2016; Ku Kassim, 2020).

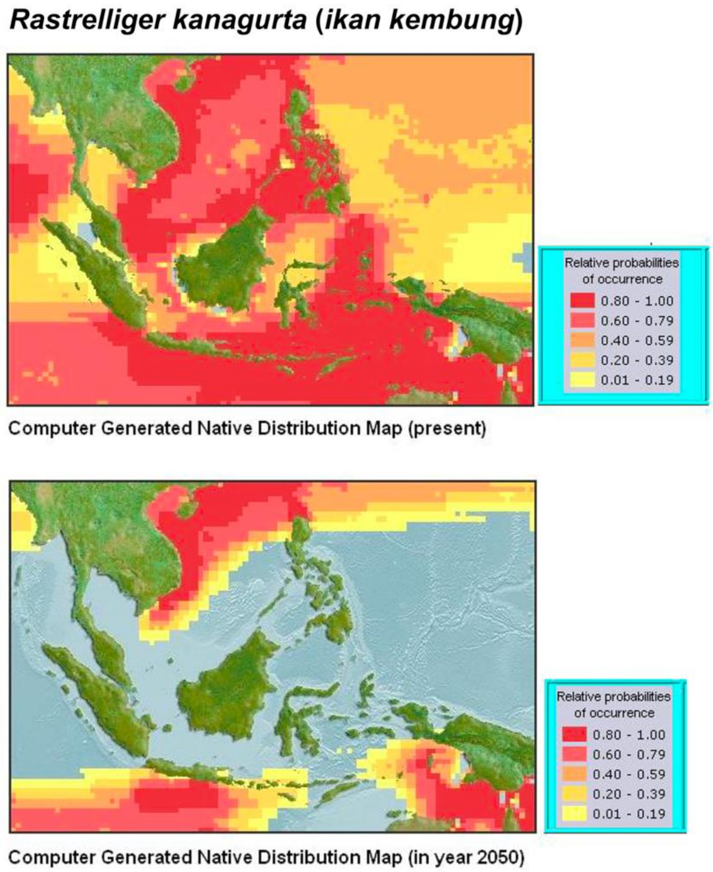

Fig. 27 Current distribution of the Indian mackerel and projected distribution in 2050

Source: (Kaschner *et al.*, 2016; Ku Kassim, 2020)

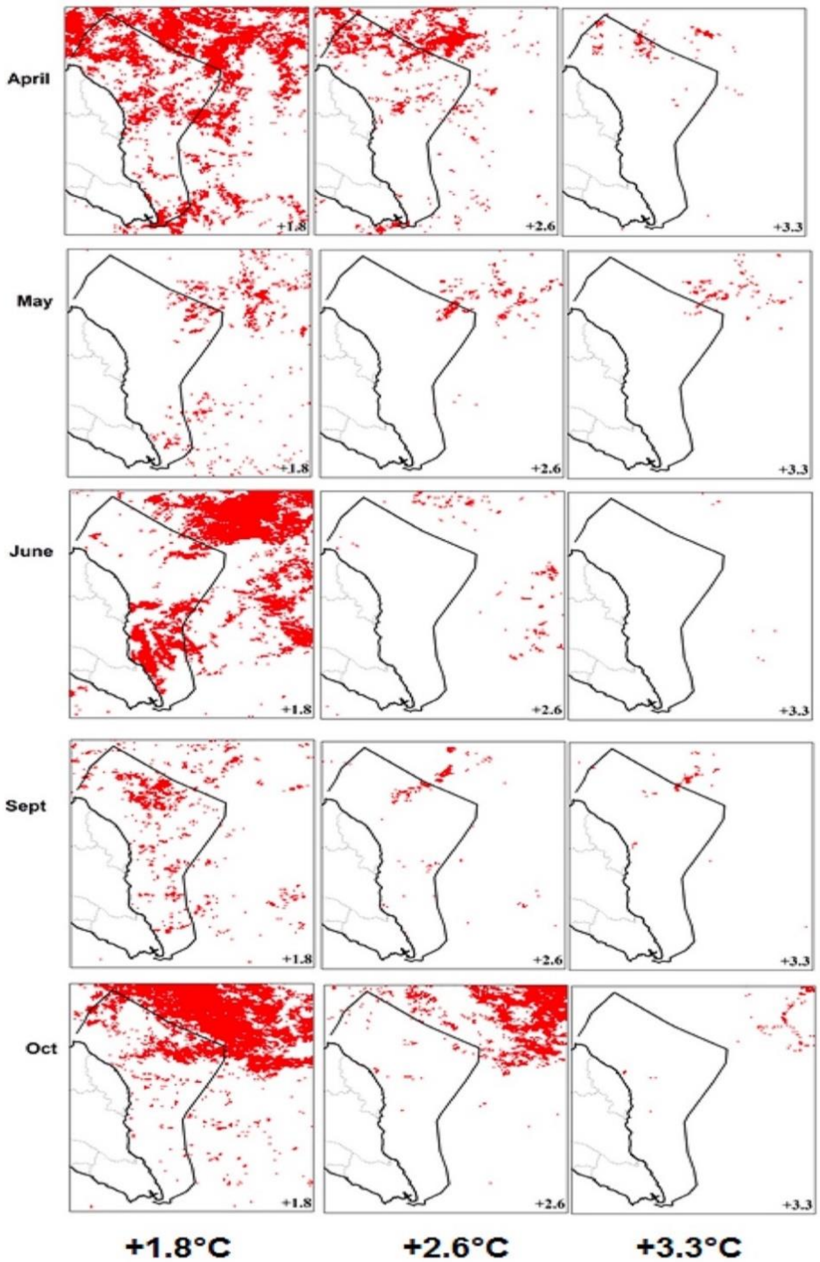

Fig. 28 Monthly distribution of the Indian mackerel off peninsular Malaysia's east coast under three warming scenarios

Source: (Ku Kassim, 2020)

Coral bleaching will also be an issue (Ku Kassim and Raja Bidin, n.d.). To the southwest of Penang Island lies Pulau Kendi, home to many coral reefs which are also fish breeding grounds . Warmer sea temperature leads to coral bleaching, thereby reducing fish production and catches (Muir and Allison, 2006). Increased water temperatures, coupled with excess nutrient pollution, promote frequent harmful algae blooms, causing oxygen depletion and the release of toxins, resulting in fish kills. In May 2020, a toxic algae bloom of *Cochlodinium* sp. triggered by run-off following rainfall events has led to massive fish death in the fish farms of Penang and Perak (Lo, 2020). Furthermore, high atmospheric carbon dioxide leads to ocean acidification via the increased uptake of carbon dioxide, preventing reef-building and other shellfish from building shells (Muir and Allison, 2006). Also, since temperature strongly influences disease transmission potential, disease outbreaks may become more frequent and intense (Barange *et al*. 2018; Mohanty *et al*., 2010).

In the case of aquaculture, pond aquaculture failure occurs as a result of changes in temperature and precipitation (Hamdan *et al*., 2015). In a 2015 El Niño event fluctuations in environmental conditions affected aquaculture productivity in Penang (Vaghefi, 2017). Shrimp farming, a major contributor to Penang’s aquaculture sector, can be particularly affected by water stratification (Hamdan *et al.*, 2015; Vaghefi, 2017). In addition, aquaculture operators may be reliant on captured fish as a food supply for certain cultured species. However, the future availability of these aquaculture feeds is also uncertain. In terms of water quality, salinisation due to sea level rises would cause adverse effects to freshwater aquaculture located in low-lying coastal areas as the fish would not be able to maintain their internal salt concentration (Victorian Fisheries Authority, 2018). All these impacts incur higher costs for infrastructure and operations for fisheries operators (Allison *et al*., 2009). Figure 29 below shows the aquaculture zones in Penang.

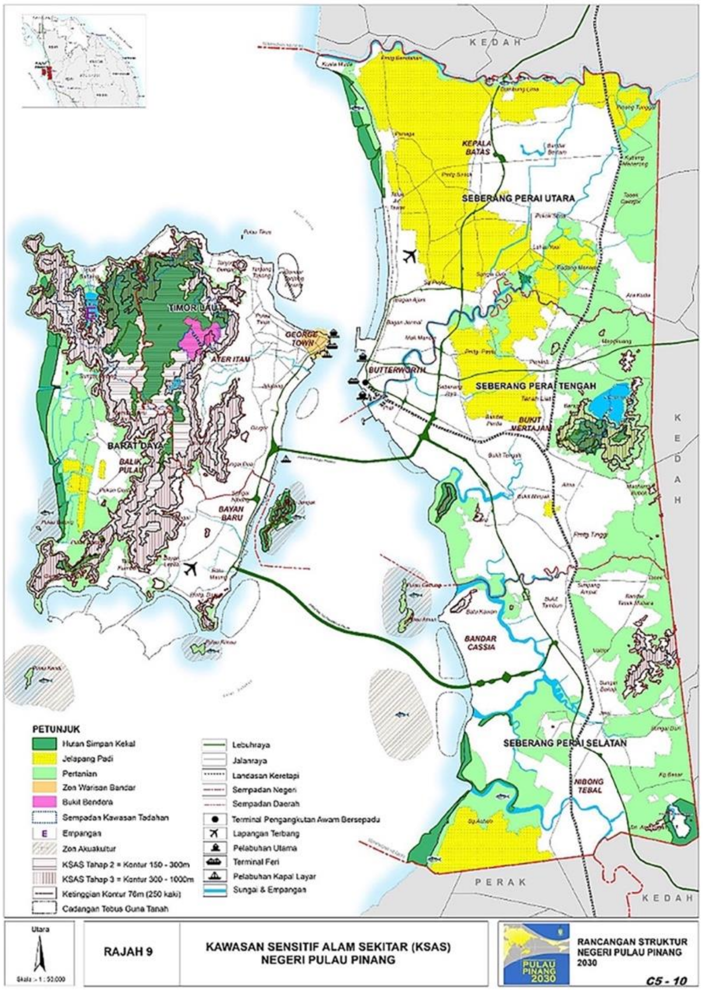

Fig. 29 Environmentally sensitive areas in Penang, including aquaculture zones

Source: (RSN, 2018)

Apart from the impacts on marine life, climate change also affects fishing operations (Ku Kassim and Raja Bidin, n.d.). Extreme weather conditions pose a great danger to fishermen (Abu Samah *et al.*, 2019). Small fishing vessels, which the majority of Penang's fishermen rely on, are not able to withstand strong winds and waves, hence affecting fishing operations and reducing catches (ibid.). For aquaculture farms located in coastal areas and offshore, rising sea levels and increasing storm surges expose farm infrastructure to a higher risk of being damaged (Allison *et al.*, 2009). The impacts of climate change on fisheries should not be underestimated. The decline in fish stocks along with the dangers and financial losses faced by the fishing and aquaculture industry will no doubt affect fish consumption and trade (Barange *et al.*, 2018).

3.2.3 Livestock

Livestock operations are affected by numerous factors arising from climate change. The key factors include quality and quantity of feeds, heat stress, freshwater availability, livestock diseases, and genetic capabilities and biodiversity (Rojas-Downing *et al*., 2017; Thornton *et al*., 2009). In terms of livestock feeds, poultry and pork production in Malaysia is highly dependent on imported corn and soybeans (Moktir and Wai, 2017). Should any global conflicts or supply issues arise, the country's deliveries of livestock feed could be disrupted. As there are large-scale shifts towards biofuels in many countries, it is a matter of time before these feeds are diverted to energy generation instead of being exported as feeds in light of the global 'food: feed: fuel conflict' (ibid.).

Livestock production is a resource-intensive activity. Although in Penang this industry is not as strong as compared to crop and fishery production (BPEN, 2017), it is still an important source of food and protein. Penang's most self-sufficient livestock production in recent years has been chicken and pork, with self-sufficiency levels (SSL) of 118.9 per cent for chicken and 265.8 per cent for pork (Penang Institute, 2019). In 2019, the poultry and pork industries contributed 82.77 per cent of the state's overall RM1.1 billion livestock output (Sekaran, 2020). Similar to the crop and fishery industries, livestock production could also be adversely affected by climate change. In 2017, 40 livestock breeders suffered an estimated loss of RM404,500 during the massive flood triggered by torrential rains (The Sun Daily, 2017).

Livestock, like humans, can experience heat stress. Pigs and poultry are mostly confined in conventional production housing systems, which are usually made of insulated building materials with mechanical ventilation systems (Schauberger *et al*., 2019). As the world warms and temperatures soar in the tropics, these densely populated buildings further increase the risk of heat stress, hence affecting animal production and wellbeing. Ultimately, even meat and egg quality could be affected, with chickens exposed to heat stress being lower in protein and higher in fat content (Bhadauria *et al.*, 2014).

These unhealthy environmental conditions reduce animal immunity and increase the prevalence of harmful pathogens, resulting in the spread of infectious diseases (Escarcha *et al.*, 2018). In addition, the living conditions of livestock would be worsened with the depletion of freshwater resources. With 1.5ºC of warming there will be widespread biodiversity loss (Buis,

2019) and livestock populations may be no exception to this. The shrinking of genetic diversity in native breeds prevents the ability to develop desirable genetic traits that allow for better adaptation, and will leave the remaining livestock population vulnerable to further changes (Gewin, 2011).

The loss of livestock would inevitably have a huge economic impact on the state and also raises serious concerns and questions about animal welfare and Penang's food security. Going forward, modernisation and diversification of agriculture play a crucial role in enhancing food security and sustainability in this sector.

3.3 Loss of Biodiversity

Apart from water and food security, climate change will also negatively impact on Penang's 'biodiversity security'. Malaysia, with its rich flora and fauna, is ranked twelfth in the world in terms of biodiversity and is considered to be a 'megadiverse' country (CBD, n.d.). The country has at least 15,000 species of vascular plants and 185,000 species of animals (NRE 2006, 2016). More importantly, biodiversity delivers ecosystem services that are essential for human survival and wellbeing. Ecosystem services include provisioning services such as food and water; supporting services such as nutrient cycling and soil formation; regulating services such as flood control and carbon sequestration; and cultural services such as cultural heritage, outdoor recreation and spiritual enrichment (SfEP, 2015). Unfortunately, habitat fragmentation and destruction, pollution, invasive species, poaching and wildlife trade put pressure on biodiversity in Malaysia NRE, 2016). These threats, coupled with climate change, would inflict further negative impacts on biodiversity, and subsequently threaten human health and livelihoods.

The mangrove forests in Penang are an important habitat that is potentially under threat, mainly from development projects as well as climate change (Fig. 30). Although the mangrove forests are renowned for being good coastal defences against floods and coastal erosion, storm surges and extreme sea levels could inflict significant damage on them (Blankespoor *et al.*, 2017). Their survival is determined by their ability to adapt. Penang's mangrove forests would need to migrate landwards to survive rising sea levels, while depending on factors such as the availability of space, topography and a continuous supply of nutrients and sediments transported by freshwater (ibid.). Failing this, mangrove forest will cover less area and will eventually perish.

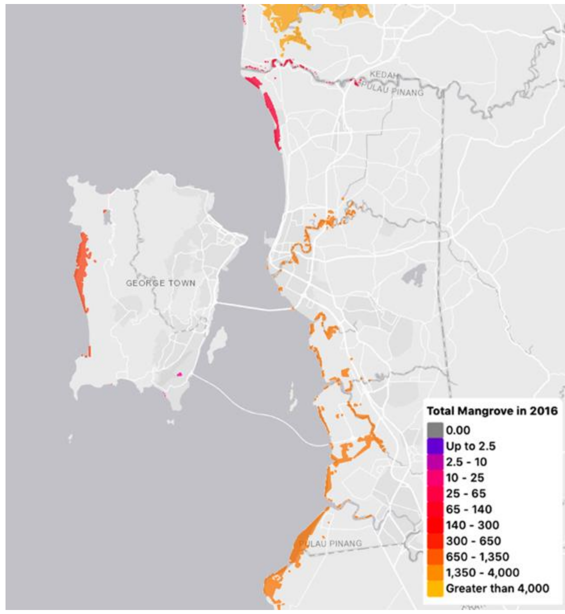

Fig. 30 Location of mangroves and their estimated area (ha) in Penang in 2016

Source: (The Nature Conservancy, 2018)

The decline of mangrove forests would also lead to the loss of important 'breeding grounds and nursery sites for a variety of terrestrial and marine organisms', affecting capture fishery production (Carugati *et al.*, 2018). Inhabiting Penang's mangrove forests are several species of mackerel, grouper, prawn, threadfin, snapper and silver or white pomfret, all of which are listed as high commercial value organisms (Nordhaus *et al.*, 2019). Mud crabs, sea snails (*balitong*), catfish species and baitworms are also found in and near the mangroves (ibid). Referring to the areas of land projected to be below annual flood levels in 2050 (see Fig. 14), and also in light of the 0.52 m sea level rise scenario projected for the west coast of peninsular Malaysia, it is very likely for the coastal mangroves in Penang to be inundated in the future by rising sea levels.

One of the most noticeable impacts so far is the gradual loss of molluscs, which also inhabit the intertidal zone. The mollusc population plays several integral ecological and socioeconomic functions, forming an important part of the food chain and is also a valuable fishery resource (Abdul Halim *et al.*, 2019). Closer to everyday life, the blood cockle (a type of mollusc) is disappearing from the favourite local dish, *char kuey teow*, due to increasing prices from a lack of supply (Sim, 2019). This has been associated with pollution from human activities and also climate change (Omar *et al.*, 2011). Studies have demonstrated that ocean warming and acidification are capable of influencing shell properties of molluscs; warming reduces shell strength while acidification reduces shell flex (Mackenzie *et al.*, 2014). In this case, bivalves with jeopardised shell function will be exposed to greater threats from their physical environment and predators. To address these environmental issues, Universiti Sains Malaysia's Centre for Marine and Coastal Studies (CEMACS) has placed data loggers at the Teluk Bahang intertidal zone to monitor marine pollution and observe global warming patterns by measuring water temperatures over the long term (The Star, 2019b).

4 Impacts on Public Health

Human health is closely dependent on the health of the environment, that is the biophysical and ecological systems of the Earth. Climate change causes biodiversity losses, stress on terrestrial and marine food-producing systems, depletion of freshwater supplies and a greater occurrence of natural disasters. The warming of global temperatures will also alter and expand the geographical range and seasonality of certain infectious diseases. All these events have huge negative implications for the health of human beings. Public health is strongly impacted indirectly from climate change, mainly due to water (drinking and sanitation) and food scarcity, infectious diseases, mental health wellbeing and climate refugees.

4.1 Water and Food Scarcity

Since climate change exacerbates water scarcity, reduced access to potable water will affect human health as well as productivity. A lack of access to clean water will also give rise to sanitation issues that can create public health emergencies (water-borne diseases are discussed in more detail in Section 4.2)

As discussed in Section 3.2 on food security, climate change threatens Penang's food security. As food prices spike, access to affordable and healthy food would become a real challenge for low-income households or individuals (Ivers, 2015). Food insecurity causes these vulnerable groups to consume more cheap calorie-rich foods (Myers, 2020), and decreases their intake of nutrient-rich foods such as fruits and vegetables (Meybeck *et al*., 2018). This can trigger both obesity as well as a malnutrition epidemic. The affected populations will face higher risks of chronic diseases such as heart disease, strokes, cancers and diabetes (Ratini, 2018).

According an analysis conducted by a researcher called Wan Muda in 2019 based on current data on nutrition in Malaysia and Southeast Asia, there has been an increased rate of childhood stunting cases for almost every state from 2006 to 2016 (Wan Muda *et al*., 2019); Penang had the highest increase in childhood stunting, more than doubling from 9.8 per to 20.3 per cent (ibid.). In terms of underweight cases, Penang has also recorded an increase from 9.0 per cent to 16.7 per cent within the past 10 years (ibid.). Furthermore, the prevalence of child obesity in Penang was the fourth highest rate in the country at 13.3 per cent, exceeding the national average of 11.9 per cent in 2015 (IPH, 2015). In fact, the WHO stated in 2019 that Malaysia has the highest obesity and overweight rate in Asia, with 64 per cent of men and 65 per cent of women falling into either the overweight or obese categories (WHO, 2019). The high consumption of sugary drinks is responsible for the country also having the second highest child obesity rate in Southeast Asia (Clark-Hattingh, 2019).

4.2 Infectious Diseases

With the onset of climate change, the incidence and distribution of infectious diseases are an emerging public health threat (Žegarac, 2017). With changes in temperature and rainfall, transmission patterns of infectious disease are also likely to change and that certain vector-borne and water-borne diseases like malaria may spread faster as environmental conditions may be more favourable under climate change (WHO, n.d.).

4.2.1 Vector-borne Diseases

The WHO defines vector-borne diseases as ‘human illnesses caused by parasites, viruses and bacteria that are transmitted by vectors’, such as mosquitoes and ticks (WHO, 2020). In March 2020, the WHO noted that vector-borne diseases made up more than 17 per cent of infectious diseases and contribute to over 700,000 deaths annually (ibid.). It has also been stated that transmission of vector-borne diseases has been low in countries with cooler temperatures and developed economies (Jordan, 2019). However, as these regions warm, there is a concern that even developed nations like the United States might not remain immune for long (ibid.).

Fig. 31 demonstrates how climate change influences the reproduction, distribution and viability of pathogens (McMichael and Lindgren, 2011). Mosquito-borne diseases like dengue, malaria and chikungunya are associated with warm and humid environments. Climate change creates favourable conditions for the maturation of the disease-causing pathogens as well as increased mosquito breeding, thereby increasing potential transmission of mosquito-borne diseases. In addition, as flood events become more common, other disease vectors like rodents would emerge, carrying diseases like leptospirosis and hantavirus (WHO, n.d.). Previous spikes in leptospirosis cases have been recorded after floods in the Philippines and India as flood victims have had to navigate through contaminated waters (Amilasan *et al.*, 2012; Thomas, 2018).

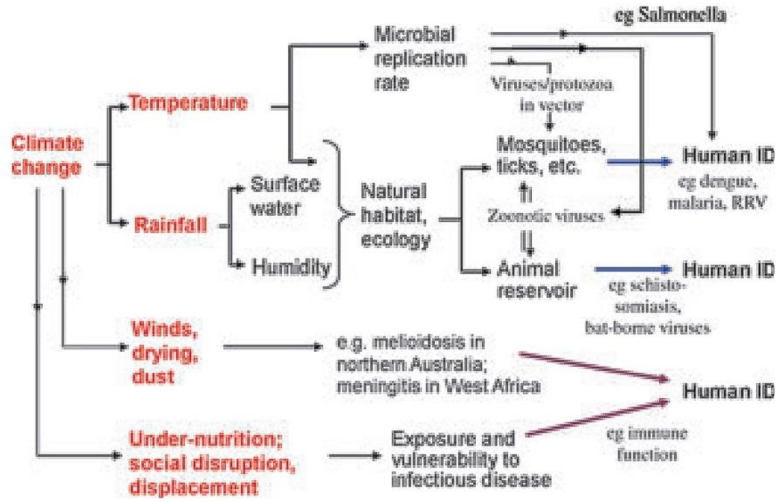

Fig. 31 The influence of various climate conditions on the spread of infectious diseases in humans

Source: (McMichael and Lindgren, 2011)

Malaysia is a dengue-endemic country. The country has generally seen an upward trend in dengue cases over the past 20 years (Fig. 32) (Hashim *et al.*, 2019). One systematic review of the current literature has noted that research on the effect of climate change on dengue in Malaysia is relatively limited and existing findings are rather inconsistent (Hii *et al.*, 2016). Nevertheless, it did caution that based on climate change projections for Malaysia there will be increased risk of dengue outbreaks (ibid.). Similarly, it is likely that Penang will see a surge in cases. Table 2 shows different cases of vector-borne diseases in Penang from 2009 to 2017 with dengue and malaria both being transmitted by mosquitoes and leptospirosis.

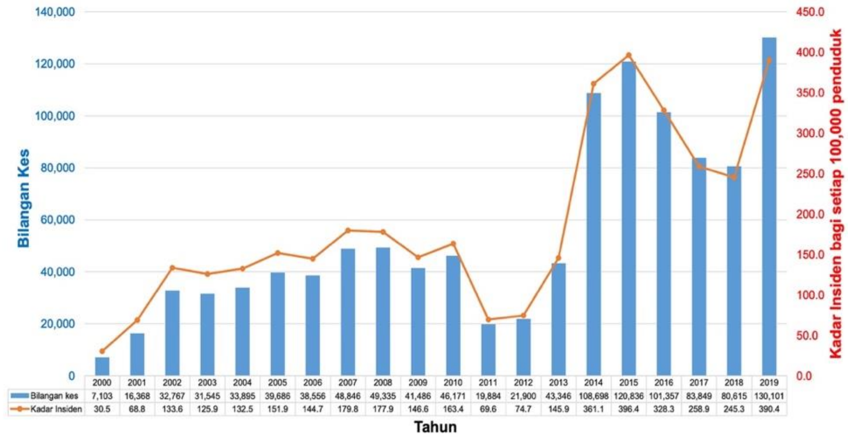

Fig. 32 Number of dengue cases and incidence rate from 2000 to 2019 in Malaysia

Source: (KKM, 2020)

Table 2 Dengue, malaria and leptospirosis cases reported in Penang from 2009 to 2019

Disease	Year										
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Dengue fever/ Dengue haemorrhagic fever	2,444	1,834	1,579	791	1,053	3,141	5,830	2,756	2,681	6,071	4,119
Malaria	86	111	88	37	39	37	17	3	9	7	6
Leptospirosis	–	14	33	128	98	192	140	43	80	97	54

Source: (Jabatan Kesihatan Negeri Pulau Pinang, 2017)

Infectious diseases can spread easily and rapidly in impoverished communities due to overcrowding, malnutrition, inadequate ventilation and sanitation, and lack of security and social protection (Campbell-Lendrum *et al.*, 2015). Furthermore, improper waste management and sources of standing water in these areas contribute to the abundance of mosquitoes. It has also been identified that densely populated low-cost housing are breeding hotspots for mosquitoes (Ying, 2020). Along with the other impacts of climate change, these communities would suffer from increased exposure to infectious diseases and become more vulnerable to diseases. For example, the data in Fig. 33 estimates that approximately 43 million Malaysian citizens will be at risk of being infected with malaria by 2070 (WHO, 2015).

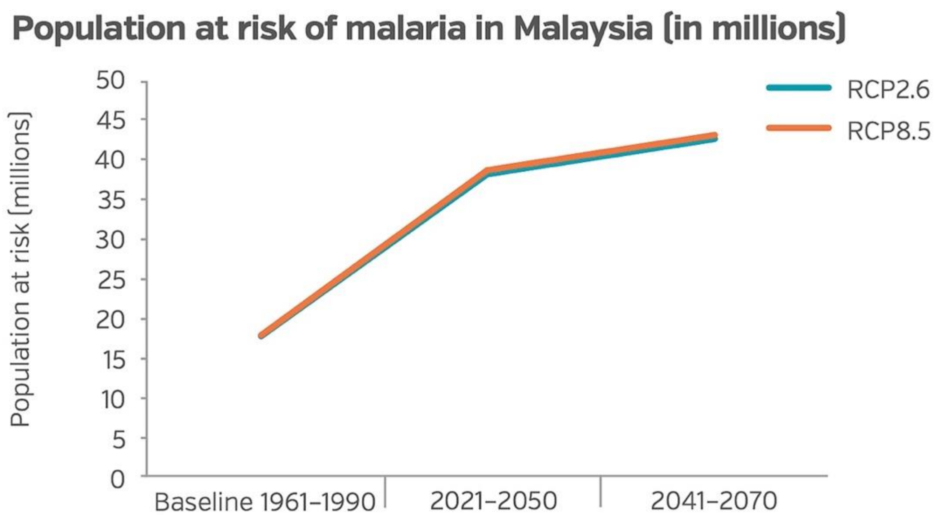

Fig. 33 Population at risk of malaria in Malaysia (in millions)

Note: RCP: Representative concentration pathway of carbon dioxide (CO_2) concentrations

Source: (WHO, 2015)

4.2.2 Water-borne Diseases

Water-borne diseases are caused by microorganisms in water, primarily faecal pathogens. The majority of infections in humans occur via consumption or exposure to contaminated water and often result in gastrointestinal distress and diarrheal diseases. Some commonly known water-borne diseases are cholera and typhoid fever, which can cause gastroenteritis that is responsible for 'up to 25% of deaths in young children in Africa and south-east Asia' (Amicizia *et al*., 2019). In developing countries, a lack of proper sanitation facilities is the main contributor resulting from faulty sewer systems or issues relating to purification facilities (Hawthorne, 2018). Outbreaks also occur after periods of rainfall (Portier *et al*., 2010) and during the monsoon seasons. As climate change alters temperature and rainfall patterns, changes in the incidence of water-borne diseases should also be expected (Ministry of Science, Technology and the Environment, 2000).

Water-borne diseases are still a public health concern in Malaysia. In Penang, cases of typhoid fever and cholera remain low (Jabatan Kesihatan Negeri Pulau Pinang, 2017). Water-borne diseases are transmitted via floods after continuous downpours and overflows of water bodies like rivers and drains (Javaid *et al*., 2012). Floodwaters mixed with various pollutants such as human or animal faeces and hazardous substances pollute land and waterways. As flood victims become displaced and exposed to contaminated water they risk contracting infectious diseases (Syah Mallow, 2017). Although water-borne diseases are not currently a major concern in Penang, they might see resurgence in the future should extreme flood events render clean water and sanitation facilities unavailable.

4.3 Mental Health

Apart from physical health, environmental changes as a result of climate change impose a great strain on mental health. Mental health consists of three key dimensions that are interconnected: emotional, psychological and social wellbeing (Galderisi *et al*., 2015). Fig. 34 shows that direct and indirect exposure to climate change-related disasters can affect mental health. Disaster-stricken communities with deteriorating physical health conditions are a recipe for mental health issues.

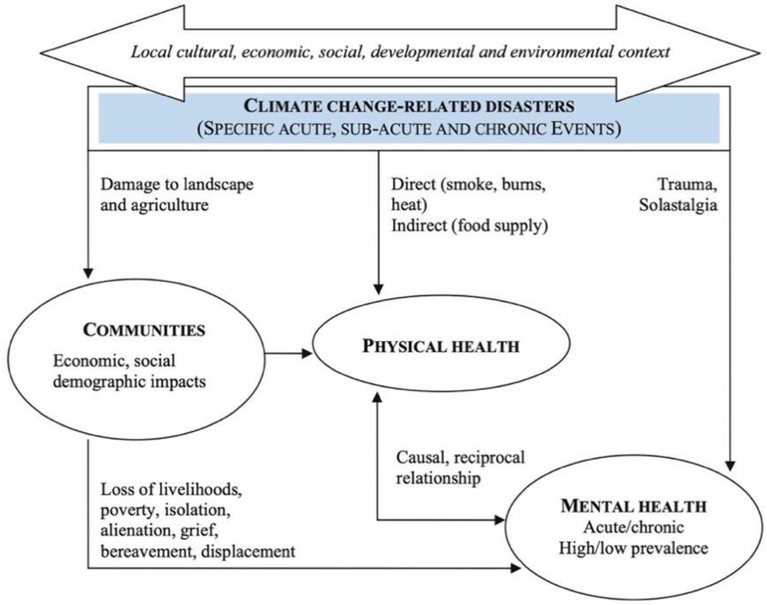

Fig. 34 The relationships between climate change-related disasters and mental health
Source: (Berry *et al*., 2010)

In 2019, the Australian Medical Association (AMA) declared climate change a health emergency (Murphy, 2019). The loss of homes, land and livelihoods from floods, fires and droughts has an emotional toll on rural communities (Charlson, 2019). In Australia, farmers are particularly affected and the suicide rate of farming men is twice that of the general male population (Bryant, 2018).

It was observed that prolonged dry seasons, heatwaves and increasing global temperatures were responsible for increases in mental illness and psychological distress such as aggression, depression and adjustment disorders and leads to suicides among farmers if these issues are not addressed (Padhy *et al*., 2015).

The WHO has stated that mild and moderate mental disorders in the general population would rise from 10 per cent to 20 per cent after a disaster event while more severe forms of disorders such as psychosis and severe depression would increase from 2–3 per cent to 3–4 per cent (Ashraf, 2005). In the aftermath of the 2004 Indian Ocean earthquake and tsunami, the WHO urged countries to provide mental health care services to the affected communities for the short and long term (ibid.).

There is also a correlation between hot working temperatures and mental health (Mullins and White, 2019). Another study explained that mental health deteriorates when one is exposed to occupational heat stress (Tawatsupa *et al*., 2010), which is of serious concern to tropical countries like Malaysia. Another study examined data from 2002–2012 and indicated that along with hotter temperatures, a greater number of rainfall days, 'short-term exposure to more extreme weather, multiyear warming', and disasters also relate to the worsening of mental health (Obradovich *et al*., 2018).

The extent to which climate change could impact the mental health of human beings is a somewhat subjective matter, especially when the impacts are more indirect than direct and are thus harder to measure. The impacts of climate change on each individual's mental stability is multifaceted, and range from jobs losses, displacement and associated social stresses to physical health. In The Employment Impact of Climate Change Adaptation report by the International Labour Organisation (ILO) in 2018, it was noted that disasters 'overwhelm and local risk management capacity', wipe out careers, push people to migrate and 'slow down economic activity' (ILO, 2018). Although there is currently no data showing the impact of climate change on the mental wellbeing of Penangites, it is safe to suggest that the disruptions caused by the effects of climate change will create stresses at the individual, household and societal levels.

4.4 Climate Displacement

It has been predicted that approximately 200 million people worldwide will be displaced due to climate change by 2050 (Jakobeit and Methmann, 2012; Merone and Tait, 2018). The International Organisation for Migration (IOM) have produced regional maps that display the geographic distribution of the various risks and impacts of climate change, along with population density (IOM, 2015). Fig. 35 shows that Malaysia's densely populated neighbouring countries are threatened by the depletion of fisheries, extreme monsoon precipitation, sea level rises and an increasing number of bushfires. It has been predicted that many regions in East and Southeast Asia will be very prone to forced mass migration due to the fact that most Asian megacities such as Dhaka, Manila, Bangkok and Jakarta are located in low-lying regions and are therefore more vulnerable to sea level rises (ibid.). Malaysia's geographical proximity and economic viability make it likely that the country could become a preferred destination for climate refugees in the future.

Fig. 35 Climate change impact map of Asia

Source: (IOM, 2015)

In addition, Malaysia will also face greater internal migration pressure as projected by Dr Renard Siew, the Malaysian head of the Climate Reality Project. He estimated that there is a possibility that a quarter of Malaysia's population might be displaced by 2030 due to climate change as the country is being threatened by severe floods, sea level rise and temperature rise (Norshidi, 2018).

Refugees are more likely to be already suffering from severe malnutrition problems (Spiegel *et al*., 2008). Food and water insecurity caused by climate change may lead to an overall reduction in food consumption and greater malnutrition and dehydration problems among refugees (Devlin and Grey, 2020). Apart from malnutrition issues, refugees (especially children, the elderly and pregnant women) are at a higher risk of contracting both infectious diseases and noncommunicable diseases either on their journey or simply by being housed in substandard refugee or migrant camps (ibid.; WHO, 2017). Looking after these refugees or migrants will require more investments in public health services.

Mass migration not only negatively impacts on the health of the displaced population but will also affect the health of the local community in the host country. In a situation of poorly managed migration, outbreaks of new diseases or diseases that had been under control in the host country such as polio or measles can affect the local population.

5 Socioeconomic Impacts

Apart from the impacts discussed above, climate change also exerts huge stresses on Penang's economic and social systems. Due to the lack of comprehensive and up-to-date studies on these issues, this report briefly outlines the additional challenges that Penang will face, or is indeed already facing, using the existing studies available.

5.1 Economic Dimensions

5.1.1 Financial Costs of Disasters

When a disaster strikes, the state government and local institutions have to bear the immediate economic impacts. Apart from the direct financial costs incurred, there is also the need to take into account victim-related compensation such as deaths, work injuries and long-term health care costs. This has yet to include disaster recovery and mitigation costs (Doerr and Santin, 2017). For example, damage caused by natural disasters from 1998 to 2018 cost Malaysia about RM8 billion (CFE-DM, 2019). In Penang, important tourist sites in low-lying areas such as the George Town UNESCO World Heritage Site could be significantly affected in future extreme flood events and this would be a severe blow to the local economy (The Sun Daily, 2018a).

5.1.2 Unemployment

Climate change destroys work opportunities. Environmental degradation negatively affects employment across different sectors as certain jobs greatly depend on ecosystem services such as the agriculture sector (ILO, 2018). Erratic weather patterns and continued decreases in arable land will limit work opportunity in these sectors, leaving vulnerable communities more exposed to future threats including those in already marginalised communities .

Climate change-induced disasters will also negatively impact economic activities, leading to more retrenchments and layoffs. The Covid-19 pandemic has already demonstrated the nation's lack of resilience, especially from an economic standpoint (Kaur, 2020). If no further measures are taken to strengthen economic and social resilience the nation may plunge into a similar state of shock following future events.

5.1.3 Inflation and Recession

Climate change is associated with rising inflation due to decreased outputs, consequently affecting businesses and consumers (Wade and Jennings, 2015). With drops in food production following low agricultural productivity and crop failures, food prices are expected to increase drastically. In Malaysia and Penang by extension, B40 (bottom 40 per cent of income) households would be most susceptible to these changes (Devaraj, 2018).

This applies similarly to land. As the sea level rises, land will become scarce and space will become a precious and priced commodity (Wade and Jennings, 2015). A high proportion of B40 household lives in flood-prone areas (e.g. Seberang Perai Utara and Seberang Perai Tengah) (Penang Institute, 2019). These communities will not have the financial means to permanently shift to residences on higher ground if the frequency and intensity of flooding increase (Devaraj, 2018).

GDP growth is also affected by climate change. A study by Burke *et al*. (2015a) has shed light on the impact of climate change on global GDPs per capita. It has been estimated that by 2100 Malaysia would experience a 87 per cent drop in GDP per capita (Fig. 36) (Burke *et al*., 2015b).

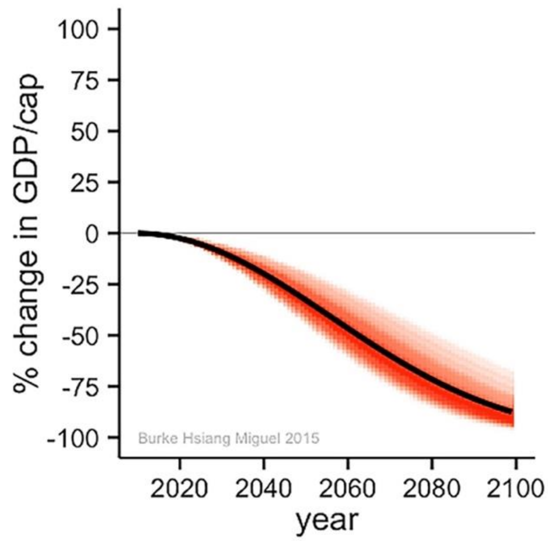

Fig. 36 Projected change in Malaysian GDP per capita due to climate change impacts
Note: The black line in the figure represents the 'best estimate' of the projected change and the areas in red represent uncertainties in the estimation.
Source: (Burke *et al*., 2015b)

5.2 Social Dimensions

5.2.1 Crime and Conflict

Climate change is capable of driving societies to the brink. Desperation incites violence and conflicts at different levels, such as social conflict between communities, interstate conflicts and civil wars (Agnew, 2012). The main reasons are: 1) competition for resources; 2) conflict from migration; 3) weak or poor governance; and 4) poverty.

Water wars or water conflicts are not a new phenomenon with over 900 cases of conflict involving water being recorded globally in the course of human civilisation, including ancient history (Pacific Institute, 2018). There have been 15 water-related conflicts in Southeast Asia since the 1960s with water being either used as a weapon, triggering disputes, or becoming a 'casualty' of war where civilians were left without adequate water resources (ibid.). Projections highlight the possibility of Malaysia facing increased hydro-political conflict over water as water resources become scarcer due to climate change (Fig. 37) (Farinosi *et al*., 2018). If Penang's water consumption and water sources are not properly managed, future water crises are likely.

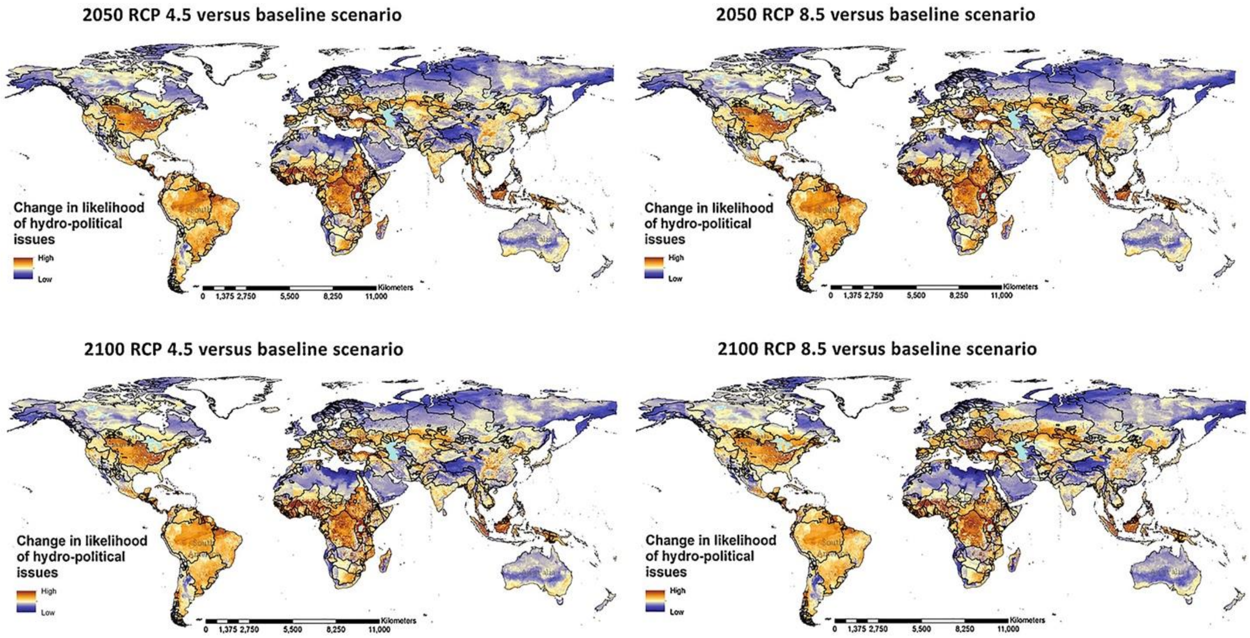

Fig. 37 Projections of two future climate change and population scenarios in 2050 and 2100 in relation to hydro-political issues
Source: (Farinosi *et al*., 2018)

It has long been understood that a hotter temperature increases the likelihood of aggression. A Malaysian study indicated that weather conditions, especially temperature, had a positive correlation with criminal activity, especially property crimes (Muzafar, 2017).

5.2.2 Labour Productivity

A hot working environment increases the risks of heat-related illnesses, thus reducing work capacity and labour productivity (UNDP, 2016). Certain groups working in the primary sectors run a higher risk of being exposed to heat stress, with the affected industries in Penang being agriculture, forestry and fishing, manufacturing, construction, utilities, transport and public services (DOSH, 2016). More working hours will be lost in 2030, particularly in the agricultural and construction sectors (Fig. 38) (ILO, 2019)

Country	1995						2030					
	Agriculture (in shade) (%)	Industry (%)	Construction (in shade) (%)	Services (%)	Total (%)	Total (thousand full-time jobs)	Agriculture (in shade) (%)	Industry (%)	Construction (in shade) (%)	Services (%)	Total (%)	Total (thousand full-time jobs)
Brunei Darussalam	1.64	0.27	1.64	0.01	**0.27**	**0**	4.27	0.88	4.27	0.03	**0.45**	**1**
Cambodia	9.05	3.99	9.05	0.67	**7.53**	**394**	14.52	7.80	14.52	1.70	**7.83**	**769**
Indonesia	4.00	1.03	4.00	0.03	**2.14**	**1885**	7.68	2.80	7.68	0.17	**2.97**	**4018**
Lao People's Dem. Rep.	3.18	1.28	3.18	0.21	**2.80**	**52**	5.71	2.66	5.71	0.49	**4.51**	**158**
Malaysia	3.09	0.71	3.09	0.04	**1.05**	**83**	6.18	1.91	6.18	0.12	**1.51**	**246**
Myanmar	5.21	2.09	5.21	0.30	**3.21**	**720**	8.71	4.12	8.71	0.67	**2.65**	**855**
Philippines	3.20	0.89	3.20	0.06	**1.62**	**426**	6.50	2.35	6.50	0.23	**2.33**	**1217**
Singapore	4.33	0.80	4.33	0.01	**0.50**	**8**	9.30	2.52	9.30	0.07	**0.84**	**33**
Thailand	8.10	3.76	8.10	0.71	**5.34**	**1695**	13.03	7.08	13.03	1.63	**6.39**	**2637**
Timor-Leste	0.16	0.01	0.16	0	**0.08**	**0**	0.70	0.09	0.70	0	**0.36**	**2**
Viet Nam	5.71	2.38	5.71	0.35	**4.40**	**1650**	9.71	4.96	9.71	1.03	**5.14**	**3062**
South-East Asia	**5.20**	**1.68**	**5.20**	**0.19**	**3.10**	**6913**	**8.87**	**3.89**	**8.87**	**0.54**	**3.66**	**12999**

Note: The table shows the percentage of working hours lost to heat stress (and the associated health, well-being and productivity effects) in each sector and in the economy as a whole. It also shows the equivalent loss in terms of full-time jobs for the economy as a whole. Work in agriculture and construction is assumed to be carried out in the shade. The heat stress index for work in the sun in the afternoon adds around 2–3°C to the in-shade WBGT (see Appendix II for further details). The data are based on historical observations and on estimates obtained using the RCP2.6 climate change pathway, which envisages a global average temperature rise of 1.5°C by the end of the century.

Source: ILO estimates based on data from the ILOSTAT database and the HadGEM2 and GFDL-ESM2M climate models.

Fig. 38 Projection of working hours lost due to heat stress by sector and country in 1995 and 2030

Source: (ILO, 2019)

5.2.3 Human Migration and Displacement

Migration to 'greener pastures' will become an increasingly common trend in the future. Farmers and herders, displaced coastal inhabitants and communities facing climate social conflicts or extreme weather events induced by climate change will be forced to move, with many moving to megacities in developing nations that are already overpopulated, polluted and lack basic infrastructure (Agnew, 2012).

Penang currently has the third highest number of refugees in the country after Selangor and Kuala Lumpur with 18,660 people (UNHCR, 2020); this figure is projected to be even higher if undocumented migrants are taken into account as illegal migration has become a ubiquitous phenomenon in Malaysia. In 2019, a community engagement consultation survey was done in

Penang for Think City by a group of professionals on the Butterworth Outer Ring Road (BORR). The survey identified several issues within the communities and immigration issues have been highlighted as one of the concerns. Some local communities perceived that illegal immigrants who set up businesses had competed with local businesses and disrupted the local economy. Some also voiced concerns that illegal immigrants tended to take religious matters and decision-making into their own hands, which had fostered a sense of dissatisfaction among local communities (Mohd *et al*., 2019).

6 Summary

This report sheds light on the possible future trajectories that Penang will likely face in the context of significant climate change. Many of the analyses suggest grim predictions of the physical and social disruptions that await the state if proper preventative and adaptive measures are not taken. This report presents the outcomes of many scientific and social science studies and acknowledges that the results offer predictions and not certainties. Nevertheless, it is indisputable that climate change will amplify the vulnerabilities Penang already faces at present, such as flooding, water and food insecurity, biodiversity loss and environmental pollution, with climate change threatening the very ecosystems that Penangites rely on for survival. The multiple physical and social disruptions outlined in this report will in turn bring about economic instability and a lowering of the standard of living.

The purpose of this report is not to create unreasonable panic or undue concern among the general public. Rather, it is written on the basis that policymakers as well as citizens need to face the truth about the climate change-related challenges Penang will encounter in the future in order to make informed decisions regarding what kind of development pathway the state should pursue. The report also raises questions about the gaps in knowledge and hopes to spur further research into the site-specific challenges and solutions Penang needs.

It is true that climate change is a global issue and it is not possible for Penang to neutralise the many effects of climate change single-handedly. Nevertheless, there are many steps the state can take to safeguard its people, places and prosperity. For example, Penang can look to accelerating its transition to a low-carbon economy. It can also promote sustainable consumption, production and development while prioritising the protection of its carbon sinks (e.g. forest and mangroves) within the state.

Most importantly, Penang needs to take climate adaptation seriously. This entails the state helping to make its residents, infrastructure and government institutions more resilient and better prepared to deal with the impacts of climate change, including at the grassroots and local levels. At the operational level, this means all future projects need to be assessed on the basis of how much they reduce or enhance Penang's ability to deal with climate-related disasters. Penang also needs to strengthen its social security and safety nets to make sure that communities most affected by climate change can rebound relatively quickly and easily. Ultimately, it is in everyone's interest that Penang starts to take the threats of climate change seriously and work with relevant stakeholders to come up with both immediate and long-term solutions.

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