

*Review*

# Risks of Climate Change on the Singapore-Malaysia High Speed Rail System

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**Abstract:** Warming of the climate system is unequivocal, and many of the observed changes are unprecedented over five decades to millennia. Globally the atmosphere and ocean is increasingly getting warmer, the amount of ice on the earth is decreasing over the oceans, and the sea level has risen. According to Intergovernmental Panel on Climate Change, the total increasing temperature globally averaged combined land and surface between the average of the 1850-1900 period and the 2003 to 2012 period is 0.78°C (0.72 to 0.85). But should we prepare for such the relatively small change? The importance is not the mean of the warming but the considerable likelihood of climate change that could trigger extreme natural hazards. The impact and the risk of climate change associated with railway infrastructure have not been fully addressed in the literature due to the difference in local environmental parameters. On the other hand, the current railway network in Malaysia, over the last decade, has been significantly affected by severe weather conditions such as rainfall, lightning, wind and very high temperatures. Our research findings point out the extremes that can lead to asset system failure, degraded operation and ultimately, delays to train services. During the period of flood, the embankment of the track can be swept away and bridge can be demolished, while during drought, the embankment of the track can suffer from soil desiccation and embankment deterioration, high temperature increases the risk of track buckling and high winds can result in vegetation or foreign object incursion on to the infrastructure as well as additional quasi-static burden exerted. This review is of significant importance for planning and design of the newly proposed high speed rail link between Malaysia and Singapore.

**Keywords:** railway infrastructure; high-speed rail; tracks; risk; management and monitoring; climate change; global warming; adaptation; operational readiness

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## 1. Introduction

In recent years, there has been increasing interest to the policy makers to build High Speed Rail (HSR) worldwide, including in Malaysia. In the creation of this new form of transportation, Malaysia needs to ensure that the new HSR will cope and adapt to the climate change. In addition, the complexities of climate change and predictions of climate model outputs have introduced an additional measure of uncertainty for railroad operators [1, 2]. Extreme weather has affected railway operations and safety, including fatalities, injuries and property damage. Despite climate change posing serious challenges to infrastructure projects, little research has been conducted in Malaysia into how vulnerable it will be especially to the transport infrastructure. It has been widely recognized that there is a need to integrate consideration of climate change and its impacts in development policies and projects [3]. 'Decisions made today—for example, in the creation of new

infrastructure or other assets-need to occur in a way which ensures that the outcomes of those decisions are robust enough to cope with, or adapt to, changing climatic conditions in the future’ [4]. Although climate change adaptation measures have been proposed to respond to extreme events at a higher level by many researchers [5-10], the infrastructure vulnerabilities and resilience-based design have not been addressed. For example, a reduced speed of train will apply when ambient temperature reaches a certain degree but the more effective rail stress management has not been discussed [10]. This has raised a research question and investigation to better understand the risks of climate change and corresponding infrastructure vulnerabilities to pertinent extreme conditions. The present risk concept does not provide any specific asset management to meaningfully repair, retrofit or replace any component effectively in a particular region, such as Malaysia [11]. As such, this paper serves to provide pathway to the detailed and tailored adaptation solutions.

High Speed Rail from Kuala Lumpur, Malaysia to Singapore (HSR), which is still in its planning stage (at the time of writing), would be the first of its kind in Malaysia. Prime Ministers of Malaysia and Singapore jointly announced the project of HSR on the 19th February 2013 and describe the HSR as a ‘Game Changer’. The projects target is to be fully operational by 2020. The key concept of the HSR derived by Malaysia Land Public Transport Commission (SPAD), will have 7 stations, 2 Terminus stations, which are in Kuala Lumpur and Singapore. 5 transit stations, each is in Negeri Sembilan, Malacca and 3 in Johor. The HSR will have 2 operation systems, which are express, non-stop journey from Kuala Lumpur to Singapore and estimated journey time is 90 minutes, while HSR Malaysia transit operation will have 7 stops including at terminus station will experience a 120 minutes journey time. This journey time does not include the waiting time and immigration process. The trains are expected to run at 300km/hour or faster however average speed will be lower due to the slower speed to approach the stations.

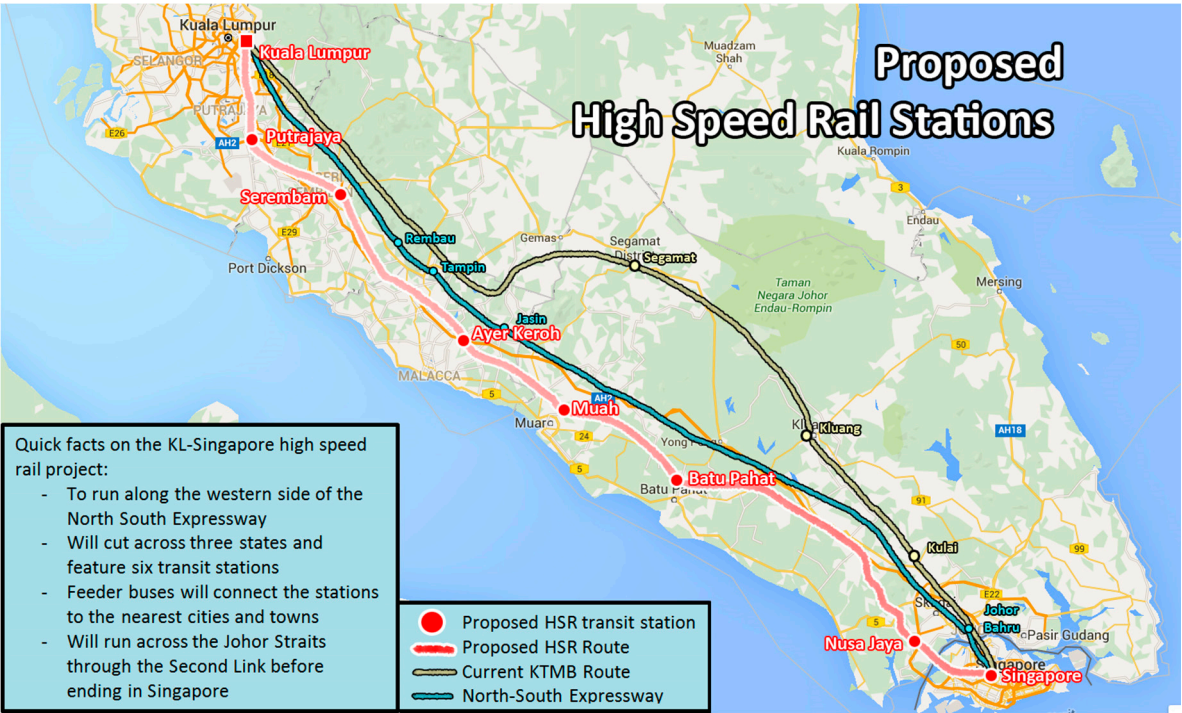
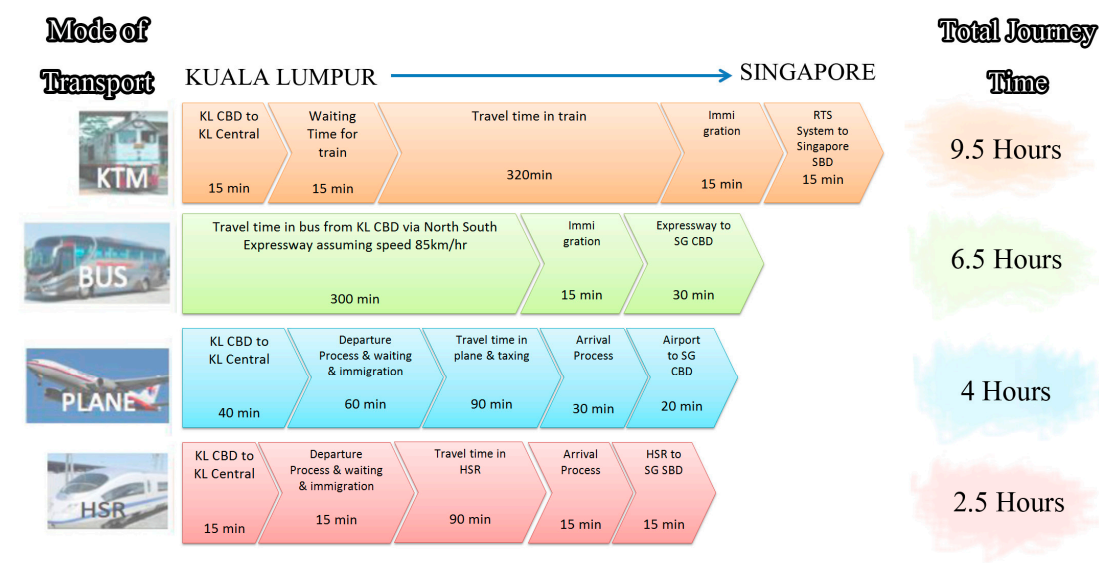


Figure 1. Proposed High Speed Rail Malaysia to Singapore (courtesy: SPAD).

Baseline alignment has been developed by SPAD as shown in Figure 1 below, but the detailed alignments remain confidential at this stage. The HSR will have a dedicated line, which is proposed to be a double track on a standard gauge. The HSR project is believed to impact the way of life for Malaysians and Singaporeans in terms on social, politics and economics. According to SPAD, the main objective of HSR is “to reduce travel time between Kuala Lumpur and Singapore to 90 minutes by strengthening the link between two of Southeast Asia’s most vibrant and fast-growing economic

engines compared to the 5 to 6 hours journey time by road or 8 hours by conventional train” [4]. Although plane travel time is 90 minutes similar to the propose HSR but the hassle of long hours waiting before and after departures will actually give total journey time of 4.0 hours by plane [11]. Contrary to the HSR, passenger still can board the HSR even arrive at the railway station 15 minutes before departure. CBD shown in Figure 2 is Central Business District. The introduction of HSR will increase the daily journey from KL to Singapore and vice versa and at the same time, life quality for both countries people will be improved as well as the economics of both countries will be stronger. The HSR, according to International Union of Railways [12-13], has a lower impact on climate and environment than all other compatible transport modes such as aviation and road transport, which are highly dependable on fossil fuels. Adoption of HSR might give a better solution in reducing the climate impact.



**Figure 2.** Travelling time from KL to Singapore comparison between KTM, Bus, Plane and HSR (courtesy: SPAD).

Although the HSR has been proposed by both Malaysian and Singaporean Governments, the lack of progress can be observed and has given a window of opportunity to include the climate change risks and adaptation strategy into the detailed design stage of the HSR system. Despite numerous climate change research around the world, its application to risk assessment for high speed rails in Asia is not thoroughly investigated. This is because georisk hazards and their sensitivity to climate change cannot be adequately assessed at a high-level or top-down analysis. As a result, there is a need to assess climate change risk to high speed rail infrastructure at the design and construction stages. The main objective is to identify the risks imposed on the high speed rail system caused by local conditions including topographical, geological and climate change of the proposed HSR route in Malaysia. The study also aims to evaluate how the infrastructure design can satisfy all the operational requirements given the climate impact issues. In carrying out this study, critical literature reviews were carried out. The data of Malaysia HSR are derived from SPAD, and the data of weather are supplied by Malaysian Meteorological Department in order to study the impact of climate change and operational requirement to the design of the infrastructure. We aims to investigate the undefined risks due to climate change for potential actions proposed to mitigate the impact. We have performed literature search on open databases with respect to Malaysian local climate incidents and analyzed them. The insight will help engineers to better design and construct the infrastructure critical to economic growth of cities and regions.



2. Climate, Geography and Lessons Learnt

Malaysia is divided into 2 parts, Peninsular Malaysia and East Malaysia (refer to Figure 3, which are separated by the South China Sea). Peninsular Malaysia however is alienated by 2 parts, west and east coasts by the Titiwangsa Mountains.

The climate in Malaysia is dominated by 2 monsoon regimes namely as northeast monsoon and southwest monsoon. The northeast monsoon circulates during the months of December, January and February, which is Malaysia’s wettest season and the period where the most flooding occurs. Meanwhile the southwest monsoon occurred between the months of May and September, the drier period for the whole country leading to droughts at this period. Being in the equatorial zone and tropical country, the average temperature throughout the year is constantly high (26°C) and has a very high humidity due to the high temperature. Malaysia also has very heavy rainfall which is more than 2500mm per year.

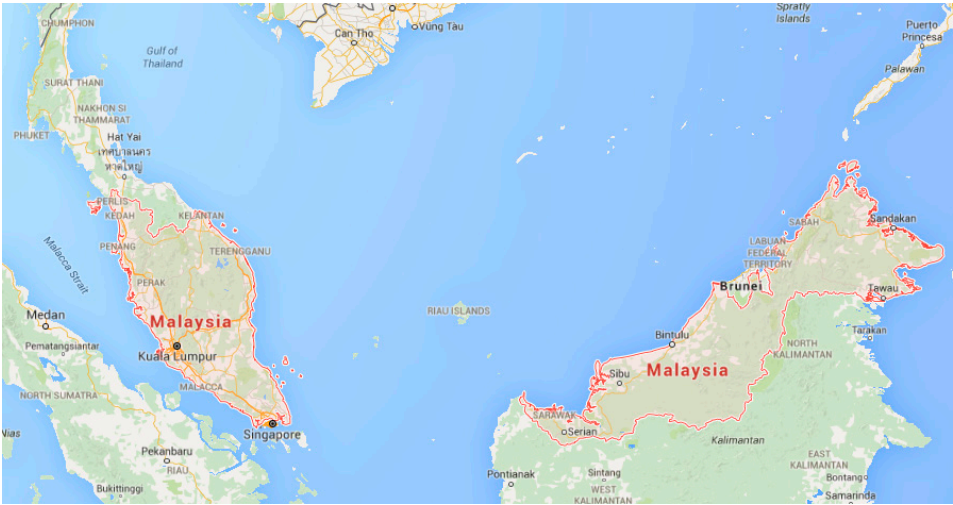


Figure 3. Malaysia Map from Google Maps.



Figure 4. Malaysia rail map (courtesy: SPAD).

“Warming of the climate system is unequivocal and since the 1950s, many of the observed changes are unprecedented over decades to millennia” [14-15]. According to Malaysia Meteorological Department [16], earth surface temperature records have clearly indicated that the climate of the earth is warming, with the rise being due to the increasing concentration of greenhouse gases (GHG) in the atmosphere. Thus in the next 50 year, Malaysia will experience higher temperatures, changing rainfall patterns, rising sea levels and more frequent extreme weather events ranging from drought to floods. The Malaysian famous rail jungle (east coast line) (refer to Figure 4), which is operated by National Malaysia Railway (KTM) was disrupted for almost 6 months due to the massive flood in December 2014. The damage included the railway quarters, signalling, tracks, locomotives, machinery and rolling stock. The disruption affected thousands of workers, traders and children going to school. There is still one stretch of line still not back in operation due to the railway bridge in Kemubu, Kelantan had completely collapsed as evidenced in Figure 5. Operation of the train service in the east coast is expected to be fully operational by February 2016 with the completion of the railway bridge in Kemubu. Construction of the new 250m long bridge across the Nenggiri River is expected to cost RM30 million or GBP4 million [17]. This incident should give a lesson to the railway industries and policy maker that extreme weather can have a severe impact to the transportation operations as well as to their infrastructure [18-23]. Rebuilding railway infrastructure is not easy and very costly thus to provide a reliable railway system into the future, studies of the impact of climate change is needed [24]. From these studies, the adaptation of railway infrastructures and rolling stock to the climate change could be established.



**Figure 5.** Malaysia East Coast Line railway bridge which cross Nenggiri River in Kemubu, Kelantan had totally lost due to massive flood in December 2014 (courtesy: Malaysia Department of Public Works).

### 3. Topographical and Geological Challenging Conditions to Malaysia

To thoroughly assess emerging risks, it is essential to understand conditions of the soils and potential foundation of rail infrastructure, which is highly sensitive to climate. It has been decided by SPAD, the HSR Malaysia route will be along the coastal area. Malaysia comprises of a wide range of rock types from the sands and silts of the coastal plains to the granite of the Main Range. Geologists, as shown in Figures 6 and 7, grouped the rocks according to their type, age and environmental deposition. The most widely unit for geology reference is based on their formation and giving each type their own geographical names. In Peninsular Malaysia, the geology range from Cambrian to the Quaternary, that is from 570 million years to about 10,000 years ago, are represented and are shown in Figure 6. Sedimentation was unremitting throughout the Palaeozoic

and Mesozoic eras and due to the basin instability, there were major faults within and between Palaeozoic, Mesozoic and Cenozoic group of rocks, which is grouped according to four types of belt namely as Western Belt, Bentong-Raub Suture, Central Belt and Eastern Belt zone. Thus Granitoids occupies nearly half of Peninsular Malaysia.

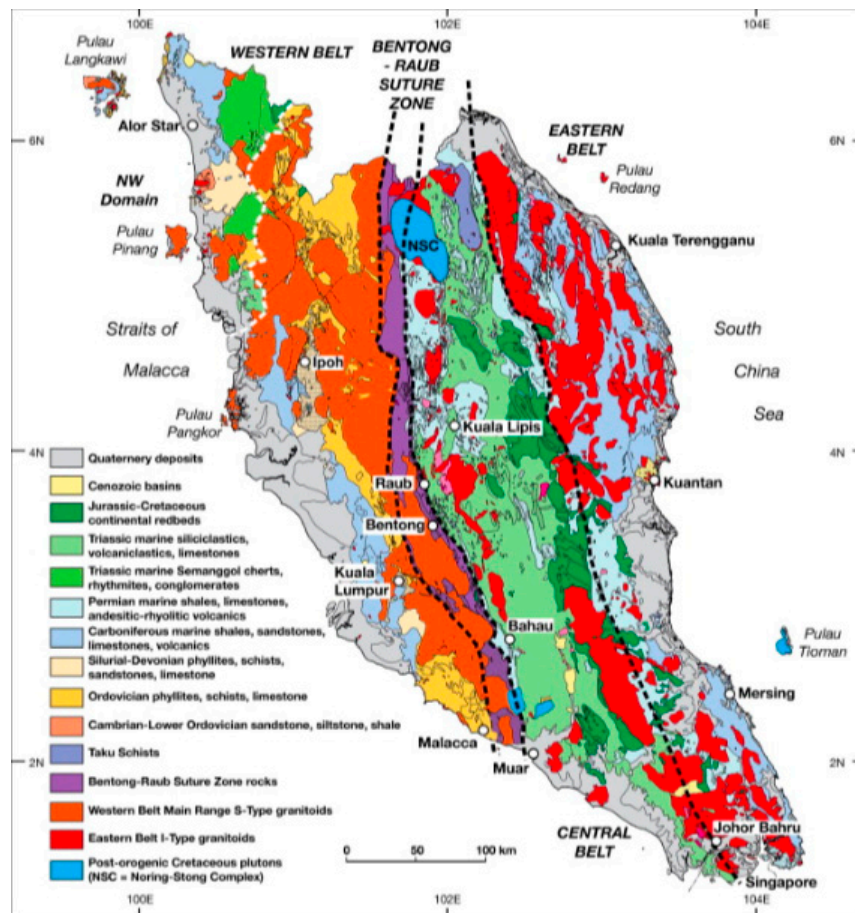


Figure 6. Geology Map of Peninsular Malaysia [25].

From Gunung Gagau in the north to Gunung Pantu in the south, which are located at the eastern Peninsular of Malaysia, contain the sedimentary basins. The sediments comprising of sandstone, conglomerate and shales with minor coal seams and volcanic, show fluvial, lacustrine and deltaic conditions of deposition. Geological Maps of Peninsular Malaysia in Figure 6 show that Malaysia's coastal area consists of mostly quaternary deposits [25-26]. Only in the straits of Malacca, the coastal geology is in the form of ordovician phyllites, schists and limestone. Kinta and Klang Valley contains valuable tin ore. Thus, made the Kuala Lumpur in Klang Valley as the capital city of Malaysia due to the rise of tin mining in the middle of the 19th century.

As shown in Figure 7, the proposed HSR route starting from Kuala Lumpur will pass through a carboniferous area, which prominently consists of limestone. The route then will cross granite in the Seremban area. Towards to the south, the alignment will pass through the limestone and sandstone area. In the south bound, the HSR route from Melaka to Nusajaya lies on the coastal area matching with the geology profile of marine and continental deposits. Mostly, the soil conditions are basically in the form of clay, silt and peat.

According to Bakshipouri et al. [27-28], approximately 40% (236.827 km<sup>2</sup>) of Kuala Lumpur area is underlain of unique limestone and karst, which are extensively developed and classified as extreme Karst class Kv (see Figure 8). The process of karst formation commences as rainfall (H<sub>2</sub>O) that passes from the atmosphere onto the top, where it then infiltrates the ground. Mixed with (CO<sub>2</sub>) gas from the air and soil, this water produces a weak carbonic acid (H<sub>2</sub>CO<sub>3</sub>), which seeps further into the ground and makes contact with the limestone (CaCO<sub>3</sub>) and/or dolomite (CaMg(CO<sub>3</sub>)<sub>2</sub>). Figure 8



shows typical morphological features ground conditions within five classes of the engineering classification of karst. These examples show horizontal bedding of the limestone; dipping bedding planes and inclined fractures add complexity to most of the features, and also create planar failures behind steep cliff faces. The dotted represents any type of clastic soil or surface sediment [29].

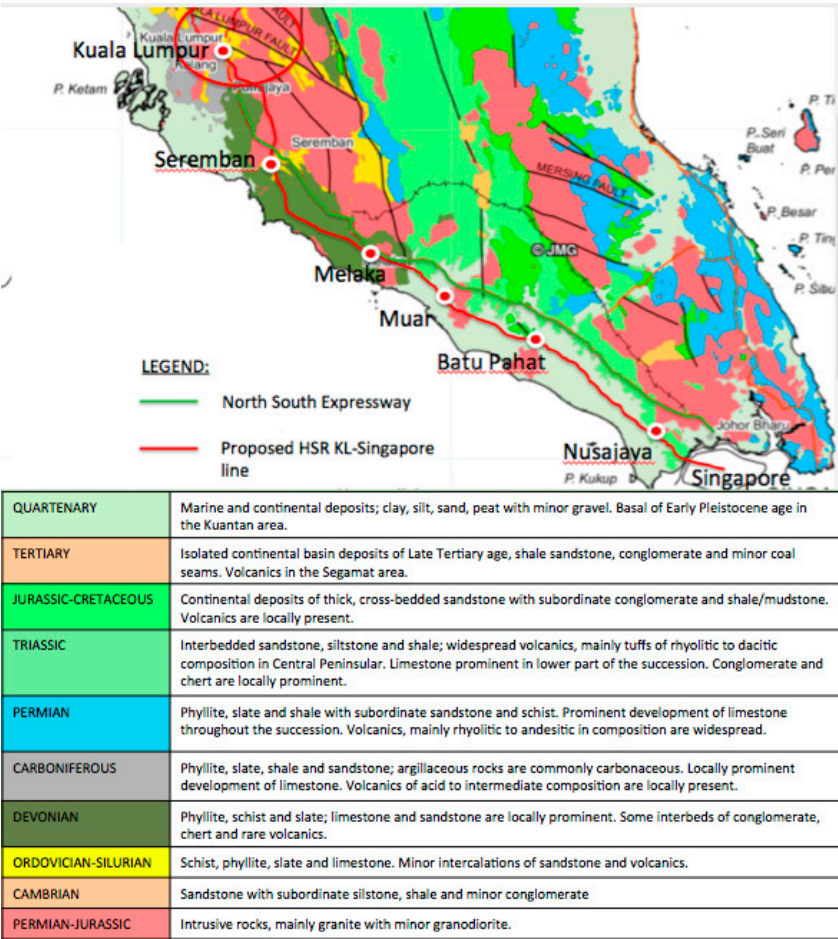


Figure 7. Geological Map at HSR Malaysia route [25].

4. Global and Malaysia Climate Change Predictions

4.1. Climate and Weather

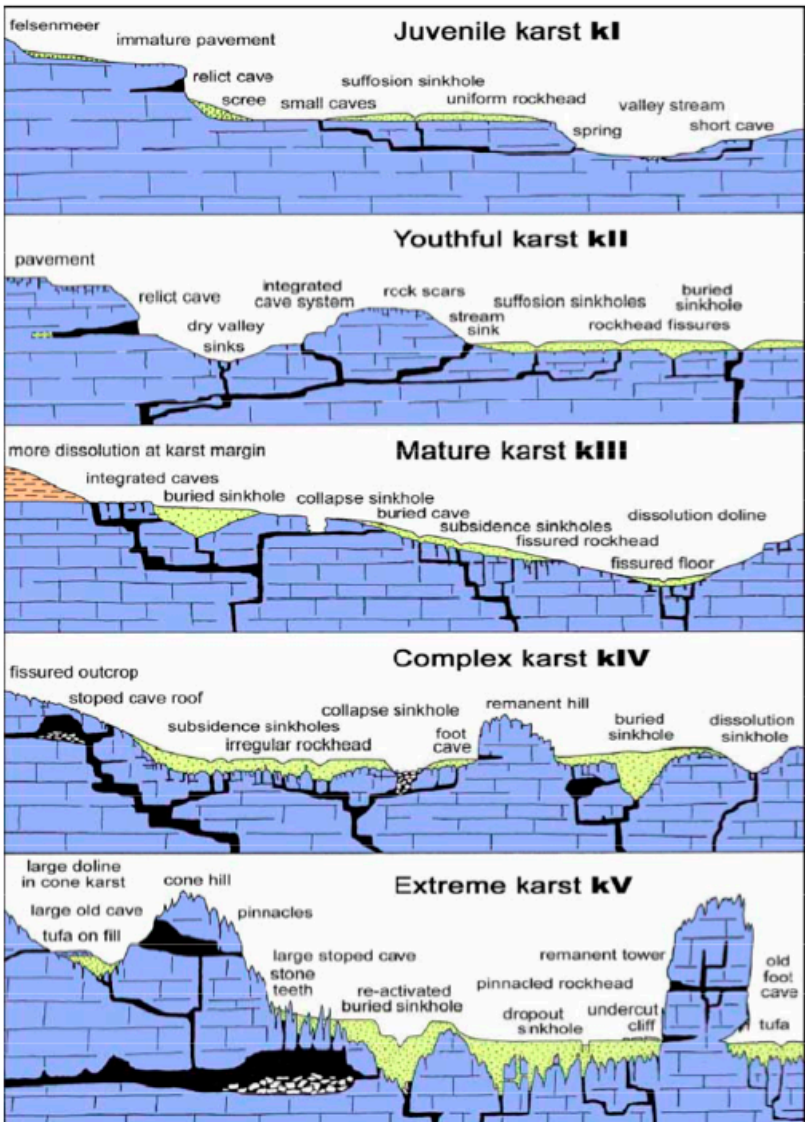
The American Meteorological Society defines climate as: “The slowly varying aspects of the atmosphere-hydrosphere-land surface system. It is typically characterised in terms of suitable averages of the climate system over periods of a month or more, taking into consideration the variability in time of these averaged quantities”. According to Dessler [30], weather refers to the actual state of the atmosphere at a particular time. For example weather in Birmingham on 26th July 2015 was sunny for the whole day without any precipitation with temperature of 19°C during the day and 10°C at night. Climate in contrast is used for a statistical description of the weather over a period of time usually a few decades. Climate is a record in which indicates the low and high temperatures at certain places for a period of time.

4.2. Global Climate Change

The American Meteorological Society defines the term climate change as follows [31]: “It is any systematic change in the long term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer.” In other words, if there is any change between statistic of weather for such a period A and period B, that is climate change. According to the observations of the IPCC Working Group 1 Summary for Policy makers (SPM) of the

Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report [32], the evidence for rapid climate change is compelling:

- i. Global temperature rise
- ii. Sea level rise
- iii. Warming oceans
- iv. Shrinking ice sheets
- v. Declining Arctic sea ice
- vi. Glacial retreat
- vii. Extreme events
- viii. Ocean acidification
- ix. Decreased snow cover



**Figure 8.** Typical morphological features of karstic ground conditions within five classes of the engineering classification of karst [29].

4.2.1. Global temperature rise

One of the parameters often associated with climate change is temperature. Since 1850, each of the last 3 decades, the Earth’s surface constantly experienced increasing warmer temperatures. The period from 1983 to 2012 was likely the warmest 30 year period of the last 1400 years in the Northern Hemisphere [32]. As shown in Figure 9 below, for the period of 1880 to 2012, there was a linear trend



warming of 0.85 (0.65 to 1.06)°C [2] for globally averaged combined land and ocean surface temperature data. The different colours in the graph line indicate different data sets. The ocean warming increased near to the surface, and the upper 75 m warmed by 0.11 (0.09 to 0.13)°C per decade over the period 1971 to 2010.

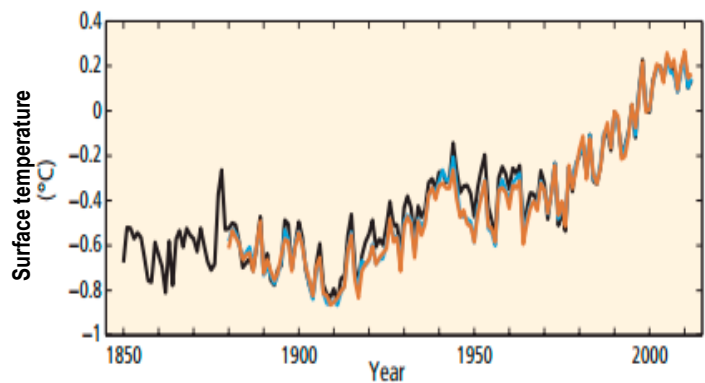


Figure 9. Globally averaged combined land and ocean surface temperature anomaly [29].

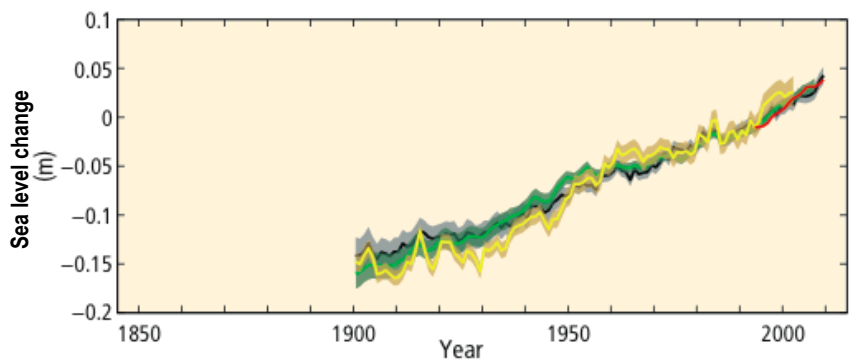


Figure 10. Globally averages sea level change [29].

4.2.2. Sea level rise

Sea level rise can be related to the climate change due to two reasons [30]: first as terrestrial ice melts, the melted water runs into the ocean, increasing the total amount of water in the ocean and therefore the sea level. Secondly water expands when it warms. Figure 10 shows the global mean sea level increased by 0.19m between 1901 and 2010. That is 1.7mm/yr in the year 1901 to 3.2mm/yr in 2010. Since the mid 19th Century, the rate of sea level rise has been greater than before. Colours indicate different data sets. All datasets are aligned to have the same value in 1993, the first year of satellite altimetry data (red). Where assessed, uncertainties are indicated by coloured shading.

4.2.3. Extreme events

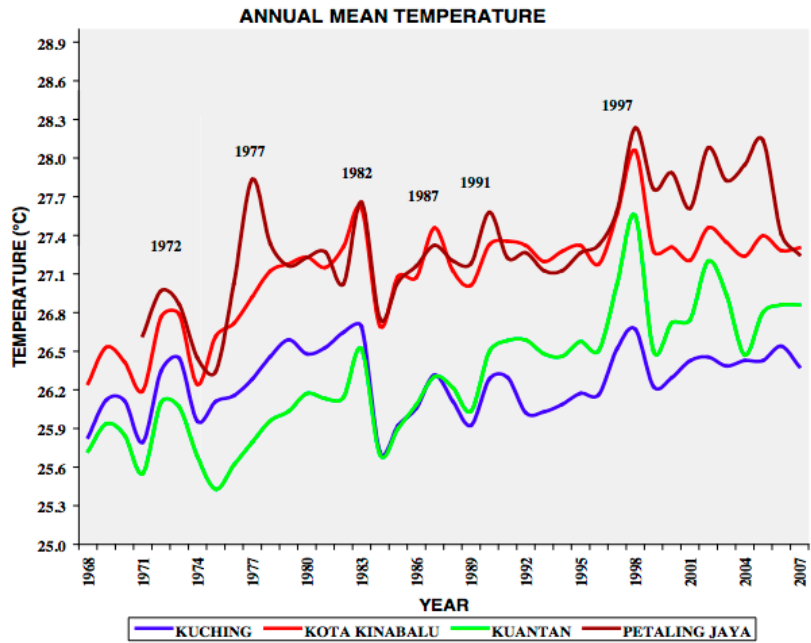
According to the IPCC [31], it is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale and it is likely that the frequency of heat waves has increased in large parts of Europe, Asia and Australia. Precipitation has also increased rather than decreased. In North America and Europe, the frequency and intensity of heavy precipitation events is likely greater than before.

4.3. Malaysia Climate Change

4.3.1. Past climate trends

Malaysia is located near to the equator thus characterised as a tropical country and monsoon climate, given the heavy and constant precipitation all year round. The weather is strongly

influenced by the topographical features such as the mountain and sea land configuration. Two monsoons which dominate the Malaysia climate according to Malaysia Metereological Department [16] are the summer Southwest Monsoon that influences the climate of the region from May to September, and the winter Northeast Monsoon from November to February. Tropical storms and depressions form in the South China Sea and the Indian Ocean sector.



**Figure 11.** Annual Mean Temperature Trend for 4 Meteorological Stations (Courtesy: Malaysia Meteorological Department).

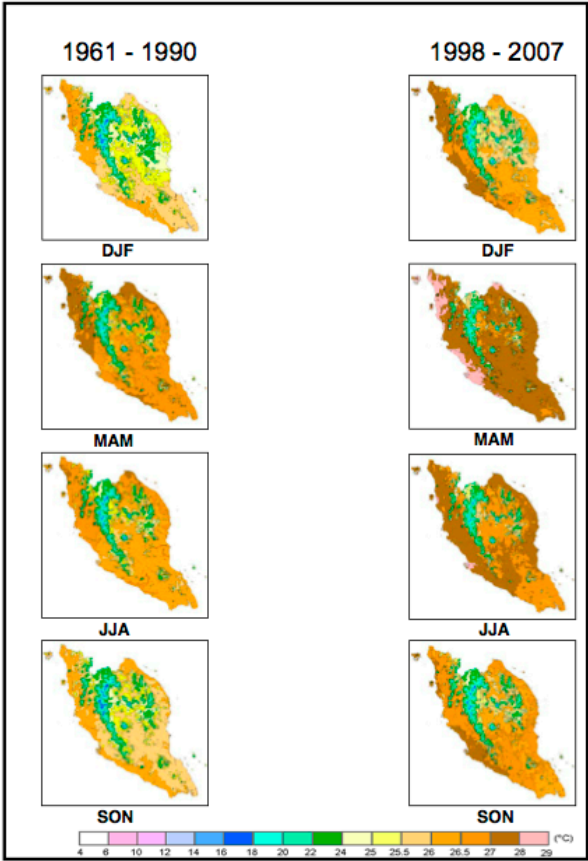
The obvious change in climate that Southeast Asia is currently experiencing is increasing surface air temperature. The El Nino-Southern Oscillation (ENSO), time scale based oscillation of the Indian Ocean Dipole (IOD) and the intraseasonal Madden Julian Oscillation(MJO) may influence extensively the observed interannual and intraseasonal rainfall distribution in Southeast Asia. There are several studies that demonstrate tropical cyclones originating in the Pacific have increased given major impact to the Philippines and Vietnam, including the Peninsular Malaysia southern bound massive flood in 2006 and 2007 [33]. The increasing temperature and decreasing rainfall, have both significantly increased the intensity and spread the forest fires in Southeast Asia. Fires in peat lands in Indonesia during El Nino dry season are now common every year and had caused haze to most ASEAN countries. The countries that are badly affected due to this haze are Indonesia, Malaysia and Singapore. In 2005, the Prime Minister of Malaysia declared a state of emergency in Port Klang, Selangor, 40km from Kuala Lumpur after the Air Pollution Index has reached 500- the emergency level [34].

a) Temperature

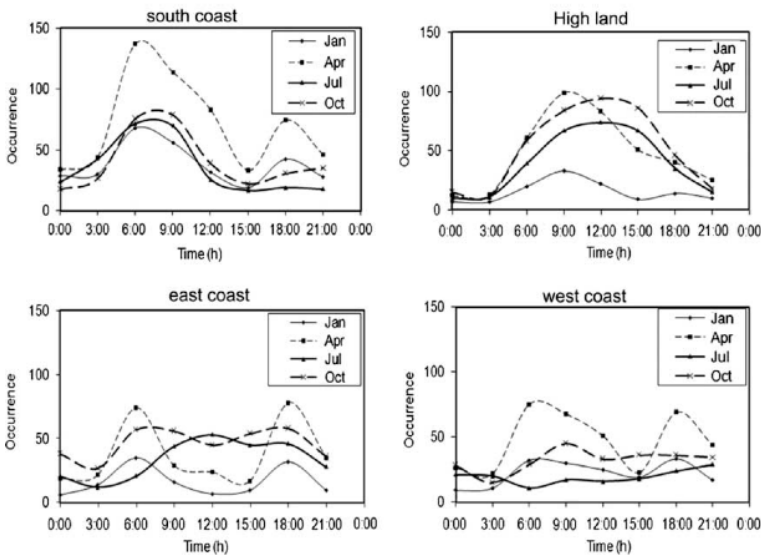
Malaysia Metereological Department [16] has selected Kuching, Kota Kinabalu, Kuantan and Petaling Jaya meteorological stations to represent West Malaysia and Peninsular Malaysia respectively to study the trend of both temperature and rainfall data over the last 40 years (1968-2007). Figure 11 shows increasing temperatures throughout the 40 years period for the four stations. Kuching shows the smallest increase of temperature, which may be due to the larger areas of forest cover in Sarawak and the least urbanisation compared to the other states in Malaysia. There was also evidence that strong El Nino events were recorded in 1972, 1982, 1987, 1991 and 1997 that has to do with the significant rise in temperature recorded shown in Figure 12.

Seasonal mean temperature for Peninsular Malaysia is shown in Figure 12 and categorised as 30 years (1961-1990) temperature and 10 years (1998-2007) temperature respectively. The analysis done by Malaysia Metereological Department [16] is divided into 4 seasons, December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON).

It is shown in Figure 12 that, despite 10 or 30 years duration, MAM and JJM are the warmest and coldest seasons in Malaysia respectively. Figure 12 also clearly shows that Malaysia is getting warmer. According to Malaysia Meteorological Department [16], an average temperature increase of 0.5°C to 1.5°C is recorded in Peninsular Malaysia and SON records the highest temperature increase followed by DJF.



**Figure 12.** Long Term Mean Temperature for West Malaysia. Colours indicate the temperature in degree Celsius. DJF-December, January, February. MAM-March, April, May. JJA-June, July, August. SON-September, October, November (Courtesy: Malaysia Meteorological Department).

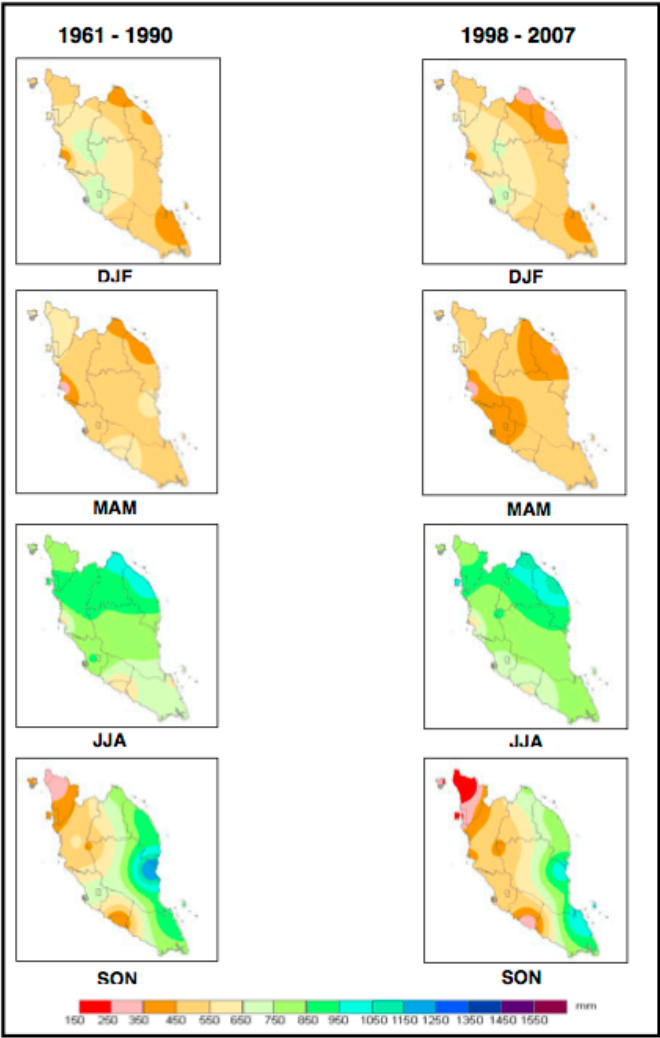


**Figure 13.** Occurrence of rainfall based on south coast, high land, east coast and west coast of Peninsular Malaysia (Courtesy: Malaysia Meteorological Department).



b) Rainfall analysis

Malaysian rainfall distribution patterns are determined by both seasonal wind flow patterns and local topographic features. The east coast of Peninsular Malaysia is likely to have more heavy rain as the area is more exposed to the South China Sea. However, the west coast area of Peninsular Malaysia is likely to be sheltered from heavy rains due to the topographical features. Thus, the east coast has experienced more flooding during the monsoon season compared to the west coast. Figure 13 shows the average occurrence of rainfall based on the south coast, high land, east coast and west coast of Peninsular Malaysia. Readings were recorded from 12am till 9pm. It is stated that the south coast will experience more rainfall during April, and east coast will get more rainfall on the same month due to the seasonal times. Figure 14 shows the Long Term Mean Rainfall for Peninsular Malaysia, the colours indicate the total rainfall in mm. DJF-December, January, February; MAM-March, April, May; JJA-June, July, August; SON-September, October, November [16]. Comparing actual records of rainfall quantity between 1961-1990 and 1998-2007, it is found that the Peninsular experienced more rainfall in the later period, demonstrating the solid evidence of climate change.



**Figure 14.** Long Term Mean Rainfall for Peninsular Malaysia Colours indicate the total rainfall in mm. DJF-December, January, February. MAM-March, April, May. JJA-June, July, August. SON-September, October, November (Courtesy: Malaysia Meteorological Department).

5. Climate Change on Extreme Weather and Their Effects to Railway Infrastructure

Extreme weather events have occurred frequently in Malaysia the past decade. The most devastating natural disasters experienced in Malaysia are floods and landslides.

### 5.1. Floods

The destructive flood in southern peninsular of Malaysia which occurred in two events back to back in December 2006 and January 2007 are known as Typhoon Utor. The massive flood in Kota Tinggi Johor started when the Northeast monsoon brought heavy rain through a series of storms. The series of floods were unusual as the 2006 average rainfall return period was 50 years, while 2007 had more than 100 years of return period. Local weather changes are among the natural causes that triggered the flash flood [35-36].

### 5.2. Landslide

Asia suffered more landslides compared to other world regions due to its climate nature. According to United Nations University [37], among natural disasters, landslides are the seventh ranked killer, after windstorms, floods, droughts, earthquakes, volcanos and extreme temperatures, in which an average of 940 people annually were killed by landslides in the decade 1993 to 2002, most of those victims from Asia. There are many factors which can trigger the landslides including changes of slope geometry, changes of water level, rainfall intensity, and changes in loading. However, the major cause of landslides in Malaysia is due to high precipitation.

As Figure 15 shows the traffic stuck due to the rock fall but can still swerve and go around the debris but it is different with trains. The trains do not have this option even if the smallest landslide occurs on the railway line. This brings greater risk to the trains and its passengers. It is important for the infrastructure manager to design the slope and track embankment with the consideration of extreme rainfall due to climate change.



**Figure 15.** The Bukit Lanjan rockfall along the New Klang Valley Expressway, in November 2003, resulted in a six month closure of that particular stretch (Courtesy: Malaysia Department of Public Works).

The wettest winter on record in England and Wales caused widespread and severe consequences including flooding and disruption to road transport in the Somerset Levels. It also caused the collapse of the iconic South Devon Railway sea wall at Dawlish (refer to Figure 16), undermining rail access to and from the county of Cornwall and Devon [38-40].

A rise in the sea level will automatically affect the reading of 100 years flood level in which Malaysian design standard normally adopt when designing the platform level bridge. There are many consequences to the railway infrastructure due to hot and dry weather and the obvious example is the risk of buckling. According to Network Rail, the definition of buckling is the extent of track deformation constituting a reportable buckle is that which would render the line unfit for the passage of trains at line speed and/or necessitates emergency remedial work to a running line under cover of either a temporary restriction of speed or closure of the line. Buckling is very treacherous as

it could cause derailment to the train and end up disruption of railway operation service. Figure 17 shows a Singapore bound train derailed on 26th of January 2013 due to rail buckling [11]. The wagons landed on their sides and trapped the worker and injuring five passengers. The train service to the southern part of Malaysia was disrupted for several days due to the difficulties of rescuers to reach the remote area where the incident happened.



**Figure 16.** The main railway line to Cornwall and Devon was demolished at Dawlish by storms which hit the UK in February 2014 [41-42].



**Figure 17.** KTMB train derailed due to rail buckling and had landed on its side, trapping the driver and injuring about five passengers just before the Kempas, Johor station southern part of Malaysia (Courtesy: Malaysia Department of Public Works).

In the United Kingdom, the Railway Safety and Standards Board (RSSB) with involvement of Met Office has assessed the risk of heat on railway assets and the railway operation. The findings included:

- An increase in the number of days required to monitor track buckling and an increase in the frequency of speed restriction as a result.
- Reduction in productivity of the workers caused by heat stress.
- Passengers experiencing more heat stress.



6. Responses to the Threat of Climate Change

Malaysia has conducted several studies on the climate change scenarios through Malaysian Meteorological Department and Ministry of Science, Technology and Innovation and several universities. However, there were only a few studies on the threat of climate change to the infrastructure particularly in the railway industry. Based on the expert interviews at KTMB and SPAD, the risks and vulnerable assets can be identified for Malaysian railway networks.

Table 1. Risks and vulnerable assets of high speed rail infrastructure in Malaysia.

Climate Impact Group	Vulnerable asset	Infrastructure Group	Ranking
Intense rainfall	Embankments	Geotechnical	1
	Rock cuttings		2
	Earth cuttings		3
	Drainage	Civil	4
	Culverts		5
Storms	Trains	Operation	6
	Signalling equipment	Signals	7
Flash flood	Trains	Operation	8
	Signalling equipment	Signals	9
	Embankments	Geotechnical	10
	Track circuits	Electrical	11
	Signalling equipment	Signals	12
Extreme heat	Mechanical equipment		13
	Complex junction	Track	14
	Overhead wire	Electrical	15
	Electrification	Electrical	16
Bush fire			
Intense rainfall	Trains	Operation	17
	Railway station		18
	Train function	Rolling stock	19
Extreme heat	Passenger comfort	Operation	20
	Train function	Rolling stock	21
Intense rainfall	Complex junction	Track	22
Storms	Overhead Wiring Regulator	Electrical	23
	Ballast washaway	Track	24
Sea level rise	Trains	Operation	25
	Stations / Platforms		26
	Tunnels	Civil	27
	Bridges and viaducts		28
Intense rainfall	Bridge scour	Civil	29
Extreme heat	Rail bunching and/or buckling on sharp curve or steep gradient	Track	30

**Table 2.** Proposed planning process for climate change adaption for HSR Malaysia.

No.	Planning Component	Purpose
1	Critical weather events	Knowledge and understanding of impact on HSR Malaysia
2	Critical components of HSR Malaysia	Knowledge and understanding of structural, systems and elemental response and vulnerability to critical weather events
3	Prediction of climate change impact	Methodology for predicting the impact of specific critical weather events on components of the HSR Malaysia
4	Development of adaptation options	Permits evaluation of different adaptation policies that are practical, cost-efficient and suitable to localised issues
5	Design standards	Identification of changes to design standards to mitigate the impact of climate change
6	Management policy	Identification of changes to management policy to mitigate the impacts of climate change

**Table 3.** Risks and adaptation measures for high speed rail in Malaysia.

Climate Impact Group	Risks	Safety Impact	Performance Impact	Likely Negative Impact from Climate Change	Long or Short Term	Adaptation Measures
Sea Level Rise	Increased flooding generally	Medium	High	High	Long	Platform level need to cater to sea level rise and drainage design must cater to Average Recurrence Interval (ARI) plus climate change projection.
Increased Rainfall	Landslide	High	High	High	Long	Drainage design must cater to Average Recurrence Interval (ARI) plus climate change projection
Increased Rainfall	Settlement	High	High	Low	Long	Need to monitor the ground movement and the relation with rainfall intensity especially at the karst area in Kuala Lumpur.
Heat	Track buckling	High	High	High	Long	Need to study on rail design resilient to high temperature or provide watchmen, condition monitoring and appropriate inspection strategies.

Research conducted by universities in Malaysia was more on the climate change impact on agriculture. It is thus important to first understand and be able to identify emerging risks to rail infrastructure at the design and construction stage. The insight into the risks and potential impact will enable better management of construction, better choice of materials, better planning for crisis and post-crisis management, and so on. Based on critical risk analysis, Table 1 portrays possible risks and the vulnerability of the high speed rail assets in Malaysia. The ranking was based on the analysis and expert interviews from Malaysian Department of Transport using previous experiences, soil and geological conditions, historical data of geo hazards and responses, and the data from SPAD on the track alignment and track structures. It is found that intense rainfall could trigger a number of emerging risks. In addition, because the neutral rail temperature has been designed at a higher degree in Asia, the risk ranking for rail buckling is not as high.

The Climate Change Act 2008 is an Act of the Parliament of the United Kingdom implemented a process by which statutory authorities, such as Network Rail, are required to comply with formal

reporting requirements in respect of climate change adaptation [43–44]. According to Lane and Dora [41], in order to undertake the required reporting process, it is firstly necessary to identify the key activities that are required, to develop a reliable method for the prediction of climate change impact as shown in Table 2.

In this case, Malaysia HSR could adopt this planning and perhaps this policy can be the guidance to the other rail operators such as KTM and Rapid KL [45]. The assessment on the risks and consequences of the critical weather events to HSR Malaysia and possible adaptation measures is thus shown in Table 3.

7. Conclusions

Global community has agreed recently in COP2016 in Paris that climate change is real and unequivocal. However, Malaysia is still far behind in terms of assessing the risks of climate change especially to its existing railway systems. Our critical review has found that there was a lack of studies on the effect of climate change to the Malaysian railway operation and as well to the railway infrastructures. In particular, the projected urban growth in Kuala Lumpur and Singapore has led to the necessity to establish improved transport links between the two cities, including road, aviation, ports and rail. Recently, a High Speed Rail (HSR) system has been jointly proposed by both Malaysian and Singaporean Governments. However, the existing railway network in the region has been affected significantly by severe weather conditions such as rainfall, lightning, wind and very high temperatures. Now that Malaysia is planning to design and build the new HSR, mitigation and adaption measures to the risk of climate change are a must to ensure that we together can achieve and deliver:

- A safe railway
- A high reliable railway
- Increased capacity
- Value for money
- A predict and prevent ethos

The risk, safety and performance impact from each climate impact group to the operation of HSR Malaysia has thus been evaluated and highlighted in this paper. Based on critical risk analysis and expert interview, the responses to the threat of climate change have been firstly proposed for Malaysia-Singapore HSR system. We found that the most critical risks involve with intense rainfall, which undermines embankments, rock cuttings, earth cuttings, and drainage and culvert systems in railway network. This is due to the fact that the geotechnical and geological conditions in the rail network are highly sensitive to moisture content and pore water pressure. On this ground, planning and design for HSR is required in order appropriately respond and adapt to climate change. By adopting adaptation measures, Malaysia can mitigate both performance and safety impacts from climate change over the long term.

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