Literature review of studies related to climate change impacts in the Philippines

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1 Table of Contents

2 Table of Figures and Tables

Abbreviations

ADB	Asian Development Bank	LDS	Length of dryspell
CMIP5	Coupled Model Intercomparison Project Phase 5	LN	La Niña event
		NOD	November, October, December
EPI	Extreme precipitation index	PDO	Pacific decadal oscillation
EN	El Niño event	RCPs	Representative Concentration Pathways
ENSO	El Niño Southern Oscillation		
EWEs	Extreme weather events	SEA	Southeast Asia
GCM	General Circulation Modell	SLR	Sea level rise
GDP	Gross domestic product	SRES	Special Report on Emissions Scenarios
IPCC	Intergovernmental Panel on Climate Change		
		SST	Sea surface temperature
JAS	July, August, September	TC	Tropical Cyclone
JFM	January, February, March	UHI	Urban heat island

3 Executive Summary

This report gives an overview of the existing literature on climate change impacts in the Philippines. The country is one of the most vulnerable regions in the world in terms of weather-related hazards. This applies to the past and – exacerbated by anthropogenic climate change – will continue to be applicable in the future. The extreme vulnerability of the archipelagic nation is demonstrated within the vast amount of literature that currently exists covering the exposure to, and the change in, occurrence rates of various types of weather-related threats (e.g. typhoons, floods, droughts…) and the sensitivity and the adaptation options of the different sectors in the country.

We compiled the literature and distilled the main outcomes for the slow-onset changes in temperature, precipitation, and sea level rise and the changes in weather extremes (i.e. heavy rain events, storms, heat waves…). The literature gives a consistent picture of the changes in temperature, extreme precipitation, and droughts. For these variables, increases are already detectable for the past and will persist in the future. For the past and future changes in storm frequency and intensity, there is a clear assumption on the global basis – lower frequency but increasing intensity – but the regional characteristics are not fully explored. The same is true for sea level rise, which is affecting the regional characteristics of storm patterns. For precipitation, the heterogeneous patterns in the country and varying approaches in literature means the results are unclear and precipitation remains the biggest challenge.

We also compiled literature concerned with the impacts of the changing climate on the sectors of human livelihood (comprised of urban and rural livelihoods, health, gender and infrastructures), agriculture, and aquaculture, as well as coastal areas.

For human livelihood, we identified multiple interrelations with changing climate in the literature. Taking into account the ever-growing population living in urban agglomerations, it is very important to highlight the impacts in these areas. The ADB (2012) assumes a growth in urban population at risk of multiple hazards in the Philippines of 350% between 2000 and 2050. Non-climatic problems, i.e. inadequate housing conditions and lack of economic and political participation will combine with and compound the intensifying threat of typhoons, floods, urban heat stress and SLR. For areas with high population density, another important issue is infectious diseases. The literature gives initial indications that the occurrence of e.g. dengue could be affected adversely by the changing climate. Adequate water infrastructure is a necessary precondition to prevent the spreading of such infectious diseases.

Fresh water availability is at risk of saltwater intrusion due to sea level rise. Besides the hydro-meteorological burdens, the coastal areas of the country will suffer, in particular, from deterioration of natural resources (e.g. decline of coral reefs and mangroves). In coastal areas, the stress induced by a changing climate adds to the already existing pressure of destructive human activities (e.g. pollution, unsustainable fishing practices, etc.). The biggest climate-induced stress factor in the agricultural sector will be heat, which will affect the growth of the plants and change the occurrence rates of droughts.

4 Introduction

The burning of fossil fuels and large scale land use changes in the last 150 years are majorly responsible for emitting large amounts of greenhouse gases. The resulting change in the composition of the atmosphere has had a strong influence on the climate system. Since the beginning of industrialization (e.g. IPCC, 2013), carbon dioxide has increased from 270 parts per million (ppm) to 396 ppm (2013) – a level that is unprecedented for at least the last 800.000 years (IPCC, 2013). The intensified greenhouse effect traps more energy in earth's atmosphere, which, beside other effects, leads to global warming. The observed warming in the climate system is unequivocal (IPCC, 2013) and so far the global mean of Earth's atmospheric near surface temperature has warmed up by roughly 0.8 degrees. The year 2016 was reported to be the warmest year in reported weather records since 1880 (NOAA, NASA, 2016).

Besides a further temperature increase, the scientific community expects an ongoing increase in sea level rise (SLR), changes in precipitation (both in amounts and patterns) and changes in occurrence rates of extreme weather events (EWEs) (e.g. heat waves, heavy rain events, tropical storms…). A challenge in understanding climate change and measuring the ongoing changes in climate variables (e.g. temperature and precipitation) is the awareness of natural climate variability and how it affects natural weather events.

It is important to take into account that climate change and the corresponding natural and socioeconomic impacts will not happen homogeneously in the different regions of the world. Some regions may face an increase in precipitation (i.e. higher northern latitudes). For others, scientists anticipate a decrease (southern Europe, Middle East). As already ongoing climate change becomes more obvious, discussions about the issue will increase as it saturates into institutions, society and efforts to tackle the problems. Besides trying to mitigate (lower carbon emissions to decrease upcoming climate change), there is recognition that adaptation to climate change is also necessary.

One central aim of climate science is the provision of information regarding the climate of the future. To obtain this information, so-called General Circulation Models (GCMs) are used. GCMs are numerical models, which aim to represent the physical processes in the atmosphere, ocean, cryosphere and land surface. They are used to simulate the response of the climate system to growing concentrations of greenhouse gases in the atmosphere. To model the future climate, the input of the greenhouse gas concentrations of the future is necessary. But these concentrations completely depend on human behavior, technical advancements, and political decisions in the near future. Since this is not possible to forecast, climate science uses so-called scenarios for greenhouse gas concentration in the atmosphere of the future. These scenarios are indirect scenarios for the development of human society.

In the third and fourth assessment report of the IPCC, so-called SRES scenarios (Special Report on Emissions Scenarios) of future emissions and concentrations of greenhouse gases (GHG) in the atmosphere were used as a basis for global climate models. In the latest report (AR5), this changed to the Representative Concentration Pathways (RCPs), which directly are keyed to a range of trajectories of GHG concentrations and climate forcing. They are labeled by their approximate radiative forcing that is reached during or near the end of the 21st century (RCP2.6, RCP4.5, RCP6.0, and RCP8.5) (Burkett, 2014). The RCP2.6 scenario represents a very optimistic scenario with low greenhouse gas emissions, which is only possible to meet with stringent climate policies to limit actual emissions. In contradiction, RCP8.5 represents a future with very high GHG emissions as a result of a non-climate policy scenario (Vuuren, 2011). RCP6.0 and RCP4.5 are so-called stabilization scenarios and are situated between the two extreme scenarios, in terms of their radiative forcing but also mean global surface temperature change until the end of the century. The mentioned SRES scenarios can be related to the new RCPs in a way that A2 corresponds to RCP8.5, A1B lies in between RCP8.5 and RCP6.0 and B1 is related to RCP4.5. The optimistic RCP2.6 scenario has no comparable SRES scenario. We will further refer to the different pathways by using the abbreviation, e.g. RCP8.5. In some literature, these RCP8.5 projections are also called the 4°C world, as the global mean temperature increase until 2100 will roughly be 4°C (e.g. World Bank, 2013a).

This report is a literature review for climate change impacts in the Philippines. As described in the next chapters, the Philippines is one of the most threatened regions in terms of natural (in particular weather related) disasters. Climate change and the challenges of socio-economic development are making the situation even worse. All in all, the scientific field of climate impacts in the region is a strongly growing one. There are many research groups worldwide contributing to an increasing understanding of the interrelations between global changing climate: its local characteristics and the resulting environmental and socio-economic consequences.

Of great importance as a source of knowledge are the reports of the IPCC – the Intergovernmental Panel on Climate Change – which was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP). Its reports support the prevention of anthropogenic climate change and compile the work of thousands of scientists in related fields worldwide. We refer here a lot to that work as it is internationally accepted as an authority on climate change. In 2007, the organization was awarded with the Nobel Peace Prize. At the end of each chapter, we will specify the publications that we believe are the most important. This was assessed by the scientific interrelation, i.e. citation in the IPCC reports and/ or general frequency of citations.

Study limitations

Given the time limitation and the sheer amount of scientific papers that have been published relating to this topic, this study only considered the most recent scientific publications. However, this study tried to fill the vulnerability-matrix (and the reference list) with the relevant publications. We mostly rejected older literature, as we believed the scientific insights are, if relevant, entailed in more recent publications.

In the field of climate science, the Reports of the IPCC are of great importance as they entail the combined, reviewed and most recent knowledge of the worldwide scientific community. We use the reports not only as a source of information, but also to gain an insight into the reliability of a publication within a short time. Many publications encompassed in the literature review are cited in the IPCC reports, which require a certain reflection in the scientific community. Further, we added the frequency of citations to the overview-matrix. But it is very crucial to state at this point – not being cited in the IPCC or having low frequency of citations, does NOT mean the publication is invalid for insights of climate change impacts in the Philippines.

5 Climate Change in the Philippines

5.1 Background Philippines

As an archipelagic nation, the Philippines is under severe threat of climate change. The inhabitants, nature, and infrastructure of the country make it one of the most vulnerable to the impacts of the changing climate and associated weather extremes (e.g. tropical cyclones) and other natural hazards (Emanuel, 2005; Ueda and Hori, 2006; Meheux et al., 2007, Yusuf and Francisco, 2009).

The Philippines is situated in Southeast Asia (SEA) between the South China Sea and the Philippine Sea. The archipelago consists of more than 7000 islands, with a total size of roughly 300.000 km² and a combined coastline of more than 36.000 km making it the country with the longest coastline in the world (Jabines and Inventor, 2007). The country is characterized by the biggest island (Luzon) in the north, Mindanao in the South and a group of islands (Visayas) in the center.

The population size amounts to 108 million people (2014) and is strongly increasing with a growth rate of 1.81% (2014). The share of the urban population accounts for 49% (2011) with an urbanization rate of more than 2% (2010-15). The largest urban agglomerations are the capital Manila and Davao with 11.9 million and 1.6 million inhabitants respectively (2011). The Gross Domestic Product (GDP) is the 32th largest of the countries of the world with roughly $270 billion (2013) and a growth rate of 6.8% (2013). The composition of GDP by sector is 11.2% agriculture, 31.6% industry, and 57.2% services (The World Factbook, 2015). Like many regions of the developing world, the differences between the urban and rural areas are large. The capital Manila contributes nearly half of total national economic production (World Bank, 2013b; Yusuf and Francisco 2009) and 97% of the total GDP in the Philippines is controlled by 15% of the population.

Due to its location in the tropics, the yearly mean temperature of about 27°C in the Philippines shows only small variability within the year (DENR, 1999). The temporal distribution of rainfall in the Philippines shows a strong seasonality, which is caused mainly by surface winds brought by the monsoons and topographic effects (Chang et al., 2005). The range of annual intensity is between 1000 and 5000 mm (DENR, 1999).

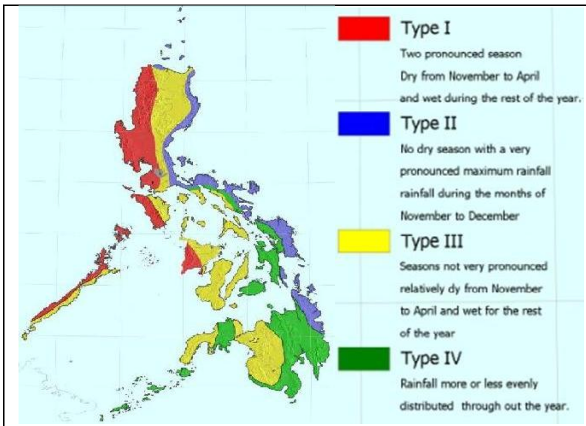

Figure 1: Precipitation pattern of the Philippines (source: PAGASA, 2015)

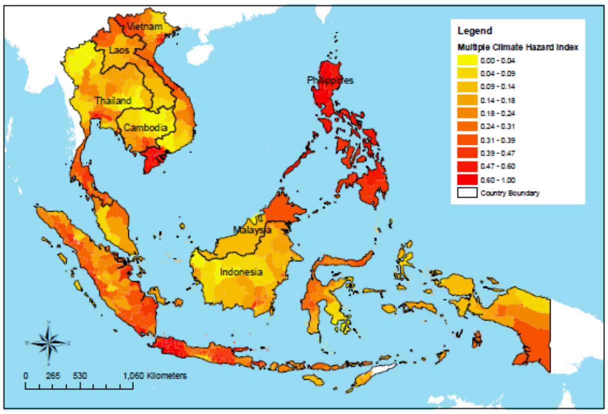

Figure 2: Multi-hazard Vulnerability Map of Southeast Asia (Source: Yusuf and Francisco, 2009)

Figure 1 shows the spatial heterogeneity of the yearly precipitation patterns in the country. The northwest is characterized by a pronounced wet (May to October) and a dry season (November to April), whereas a centered band from the north to the south shows only weakly pronounced seasonality. The eastern coast does not have a clear season in the year with low rains and shows very strong precipitation events in the months November and December. In a band of the inner south, the rain is nearly evenly distributed over the year. These partly spatially contrasting features are due to the north-south orientation of the mountainous regions in the archipelago (Villafuerte et al., 2014a). Although not reflective of the full complexity, we will later refer to the seasons in precipitation with the description of dry season mainly in January to March (JFM) and wet season in July to September (JAS). Yao et al. (2009) provides seasonal maps of the precipitation distribution for whole SEA.

When the western North Pacific subtropical high moves northeastward it enables the southwesterly winds from the Asian summer monsoon to extend over the Philippines. This brings the beginning of the rainy season around mid-May (Akasaka, 2010). The East Asian winter monsoon brings northeasterly surface winds in November that lead to wet conditions on the windward east coasts and dry conditions on the leeside west coast of the country (Chang et al., 2005).

As the country is situated in the so-called "typhoon belt", it is exposed to multiple hydro-meteorological hazards, e.g. tropical cyclones, flooding but also droughts. On average, the country is hit by 20 typhoons per year (ADB, 2009). Five to seven of them can be destructive. In particular, the eastern coast of the country is highly exposed to typhoons with wind speeds of 200 kilometers per hour. One quarter of the worldwide number of these strong typhoons occur in the Philippine Area of Responsibility (Uy et al., 2011). In many risk or vulnerability assessments, the Philippines are among the most affected countries in terms of climate change impacts and EWEs (Brooks and Adger, 2003; UNU-EHS, 2011; Kreft, 2015). Others also argue that the Philippines are one of the most disaster-prone countries in the world (Porio, 2011; Yumul et al., 2011). Yusuf and Francisco (2009) conducted a vulnerability mapping of 530 subnational areas in SEA. By overlaying maps for exposure to hazards, sensitivity and adaptive capacity they gained a vulnerability map of SEA with the Philippines exhibiting the highest levels (Figure 2).

Yumul et al. (2010) argues that the country has to spend a substantial portion of the annual budget to repair and rehabilitate devastated communities. The World Bank (2010) stated that, annually, the country has to spend 0.5% of its GDP for natural hazards. Between 1998 and 2009, the Philippines had to deal with costs of up to US$24.3 billion (23.9% of GDP) due to storms, exposing 12.1 million people (IPCC, 2014).

Yumul et al. (2010) further draw attention to the fact that the resilience of the communities and individuals can be seen as relatively high, due to adapting to past experiences, but hazards can exceed such coping capacities. Gaillard et al. (2007) raised the points that the impact of the 2004 tropical depressions and typhoons on the Philippines' eastern coast was so devastating not due to the actual hazards, but rather was rooted in the underlying social, political, and economic conditions that further contributed to people's vulnerability.

In 2013, the super typhoon Haiyan gave evidence to the exposure and vulnerability of the country to these kinds of extreme events. Despite forecasts and warnings provided days in advance, the typhoon killed more than 6,000 persons, affected millions of others and devastated areas in central

Leyte. It is said to be the strongest cyclone to make landfall in the Philippines, which also holds true for the storm surge it induced (WMO, 2013).

According to the World Bank (2010), looking at the EMDAT disaster data base (Guha-Sapir et al., 2009) leads to the insight that, in the years 2000 to 2008, weather-related disasters accounted for 98% of all the people affected and 78% of all the people that died due to disasters in the Philippines.

Much literature exists covering the issue of climate change and extreme weather related deaths (other regions or globally). We refer to the IPCC – Fourth Assessment Report, which clearly states with very high confidence that climate change currently contributes to the global burden of diseases and premature deaths. Further, they determine an increased number of people suffering from death, disease and injury due to heatwaves, floods, storms and droughts with high confidence (Confalonieri et al., 2007; more also in IPCC, 2014).

5.2 Impacts of Climate Change in the Philippines

As we have shown above, the country has an outstanding exposure towards weather and weather extremes due to its location and shape. To show the importance of the specific threats, we look at past patterns and features of weather and weather extremes. To prepare for the threat of weather and weather extremes for each sector in the country, we assess how far within the scientific literature changes in the climate could be detected and what are the future projections discussed in the literature for the Philippines. After looking at the climate variables, we analyzed the literature for the impacts of climate change on the different sectors. As the inter-annual variability plays a very large role in the local climate, in each of the sub-topics, we refer to the large-scale effects of ENSO (El Niño Southern Oscillation) and PDO (Pacific decadal oscillation).

5.2.1 Slow-onset changes

Slow-onset changes in the past

Various research is available that deals with the question, of whether or not a change in weather and climate indices is already observable. The **observed temperature** in SEA is increasing with a rate of 0.27-0.4°C per decade since the 1960s, which is double the rate of the global average with only 0.13°C per decade in 1956-2005 (Tangang et al., 2006). Chooprateep and McNeil (2014) studied the monthly surface temperature in SEA and found a temperature increase of 0.174 (±0.025) °C per decade for the region of the Philippines (for the period 1973 to 2008). Cruz et al. (2007) referred to an increase in mean annual, maximum and minimum temperatures for the Philippines of 0.14°C from 1971 to 2000 (assumed: change per decade – although not mentioned in the report). Cinco et al. (2014) applied a trend analysis on observed data from 34 weather stations in the Philippines and found warming trends in mean, minimum and to a lesser extent in maximum temperatures. Most of the stations showed an increasing trend for the numbers of hot days.

For the **observed precipitation** in the country, the weak increasing trend observed by Caesar et al. (2011) was not significant. Cruz et al. (2007) referred to an increasing trend in annual mean rainfall since 1980s and in the number of rainy days since 1990s. Further, they stated that mean annual precipitation is decreasing on the western Coast of the Philippines. Villafuerte et al. (2014a) referred to contradictory results for precipitation in the North West of the country. Jose et al. (1996) showed an increasing trend in both seasonal and annual total rainfall during 1951–1992, whereas Cruz et al. (2012), who used rainfall data from 1961–2010, showed a drying trend over the same region, but as already stated in Cruz et al. (2012), the results were achieved using different data sets. As later mentioned, the ENSO phenomenon has a strong impact on precipitation patterns. Lyon and Camargo (2008) showed an above (below) average rainfall typically occurring in this area in boreal Summer of El Niño (La Niña) events. In the subsequent fall, rainfall anomalies of the opposite sign develop across the country.

Endo et al. (2009) made a comprehensive study on the entire network of weather stations in SEA. For the average values of precipitation, they found the number of wet days (days with precipitation ≥ 1 mm) decreasing in SEA, while the average intensity per wet day increases (Figure 3, left). Figure 3 (right) and further graphs in Endo and Matsumoto (2010) confirm a comparable development for the Philippines - less wet days, mostly higher intensities and changes in extreme precipitation (we will refer to later). Another comprehensive study was done by Yao et al. (2009). They used gridded observational data from 1978 to 2006. By analyzing the seasonal trends for total precipitation, they found for most areas of the Philippines an increase, although clear statements for significance could not be found.

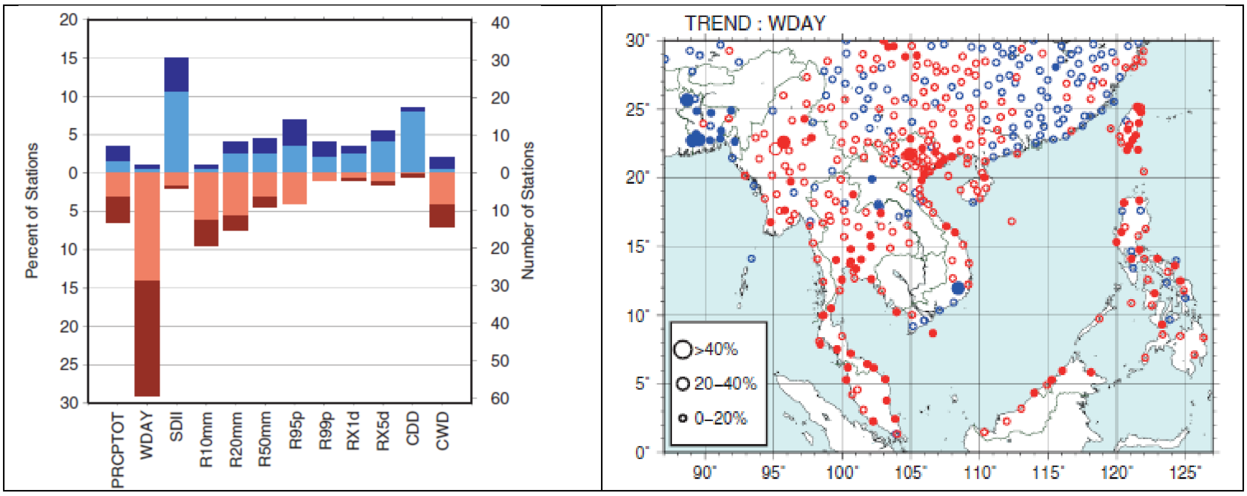

Figure 3: Fraction of weather stations with a significant trend over SEA (left) and the stations in SEA and their type of trend for number of wet days (right). (Red and blue bars indicate decreasing respective increasing trends (stronger color means higher significance); red (blue) circles indicate increasing (decreasing) trends).

To the influence of the **ENSO mechanism**, which is in detail described in Warren (2013), Villafuerte et al. (2014) delivered the insight that the seasonal total precipitation in the Philippines is influenced in the following way. The wet season JAS tends to be wetter during an El Niño event and drier during a La Niña event, while an exactly opposite behavior occurs during OND (Lyon et al., 2006). The acronym ENSO refers to El Niño Southern Oscillation and is a phenomenon originated in the Pacific Ocean. The two states El Niño and La Niña describe patterns of above and below SSTs in the central and eastern Pacific. The whole phenomenon is the most important source of rainfall variability in the Philippines (all from Hilario et al., 2009).

Slow-onset changes in the future

Temperature projections calculated with CMIP5 (Coupled Model Intercomparison Project Phase 5) models show for the summer season in South East Asia (SEA) an increase by 4.5°C (model range 3.5°C to 6°C) with the RCP8.5 GHG-pathways. This is lower than the global-mean warming as the region is strongly influenced by **sea surface temperatures (SST)**, which increases with a smaller rate (World Bank, 2013a). However, in comparison to the local year-to-year natural variability, the assumed temperature increase is very large. So for most land areas in South East Asia (SEA), monthly shift in temperature taken from the RCP8.5 scenarios is more than six standard deviations of the past temperature distribution (World Bank, 2013a).

Projecting future precipitation is a challenge, as the monsoon in SEA is affected by the Asian and the Australian summer monsoon (Hung et al., 2004) and the GCMs manage to reproduce the precipitation pattern, but the differences between the models are large (World Bank, 2013a). Jourdain et al. (2013) used CMIP5 model projections, which could reproduce the present day patterns, but also showed no multi model agreement over SEA. The projected monsoon rainfall for SEA ranged from 5% decrease up to 10% increase in the RCP8.5 scenarios. Annual mean precipitation is projected to slightly increase (+20% in the dry period DJF) by the CMIP5 models for the Philippines (RCP8.5) (World Bank, 2013a). The Department of Environment and Natural Resources (DENR, 1999) published numbers of an increase in precipitation in the Central Visayas and Southern Tagalog provinces, including Metro Manila, with values of 60 to 100% increase. In general, the statement often can be found that the dry period gets drier and the wet period of the year wetter (e.g. World Bank, 2010; Cinco et al., 2013).

The World Bank (2013a) stated that the **local SLR** (SLR is not distributed evenly across the globe; more in Perrette et al., 2013) will be 10-15% greater in the study region compared to global mean by the end of the 21st century. It is projected to reach 100 cm under a strong 4°C warming (resp. 75 cm under a weaker 2°C warming scenario) by 2090 (World Bank, 2013a). Of great importance in the discussion about rising sea level is the possibility of local **land subsidence**, which could happen due to human activities or natural factors and could very much increase the burden of SLR. A natural factor could be that, in deltaic regions, weight is accumulated, which can lead to land subsidence. Anthropogenic factors that contribute to land subsidence are drainage and **groundwater extraction** (Ferguson and Gleeson, 2012). Groundwater extraction itself is strongly connected to the problem of **saltwater intrusion**. Changes in precipitation and temperature, together with land use change, can alter the groundwater recharge rate and increase saltwater intrusion into freshwater aquifers. Ranjan et al. (2009) analyzed groundwater recharge and classified the Philippines as a region with increase in recharge rate and an overall less to moderate vulnerability to coastal fresh groundwater. The result is weakened by the fact that they only used a SLR of 40cm above 2000 until 2100, which is far below the above mentioned actual predictions (World Bank, 2013). On a local scale, Insigne and Kim (2010) analyzed the issue of saltwater intrusion due to groundwater extraction in the region of Manila. They stated that areas that extract a large volume of groundwater will be severely affected by saltwater intrusion.

According to the IPCC (2014), there is a high confidence that the ENSO phenomenon will remain important for inter-annual variability in the region in the future. It is assumed that ENSO related precipitation variability will intensify. The overall confidence in projected changes in ENSO in the 21st century remains low.

5.2.2 Change in weather extremes

As the country is one of the regions of the world most prone to EWEs, how much these events have already changed in terms of their occurrence rate and/or strength and how they will change in the future is of great interest.

EWEs changes in the past

The major burden for the archipelago in particular under future SLR is that of **Tropical cyclones (TC)** (World Bank, 2013a; Nicholls et al., 2008). They influence and will further influence every sector of human livelihood - i.e. infrastructures, agriculture, and ecosystems - due to heavy precipitation, storms and landslides (Peduzzi et al., 2012). There are various publications dealing with extreme precipitation, monsoon, TCs, the ENSO effect and so forth – but not necessarily in connection to a changing climate (e.g. Cayanan et al., 2011). Also Yumul et al. (2010) gives an example of the possible impacts of an EWE without a deeper discussion about the relationship to a changing climate. However, they describe in detail the impacts of a series of extreme weather events in the years 2005 to 2007. Starting with a La Niña event with very wet conditions, disastrous flooding and landslides, the country's resilience was tested by several typhoons before the series passed over into El Niño mode. That was accompanied by the strong drought of 2007, which affected almost all sectors, mostly in Luzon.

It is critical to distinguish between changes in frequency and changes in the intensity of TCs. Some use the term 'increase in threat' or 'increasing impact' of TCs, but do not necessarily mean frequency and intensity, but rather the impact in terms of monetary or health impact. This could be independent from changes in the patterns of TCs, as these increases can mostly be traced back to the enormous growth in coastal populations, installed infrastructures, and economic values that could be affected in the region (Cruz et al., 2007; Knutson et al., 2010; Mendelsohn et al., 2012; Peduzzi et al., 2012).

The whole issue of **past trends in TCs** is controversial. Various sources discuss a change in the cyclone activity in the 20th century (IPCC, 2007; Geng and Sugi, 2001; we do not refer to extra-tropical cyclones). Peduzzi et al. (2012) was seeking clear signs of a change in occurrence rate of TCs in a data set of 1970 to 2004 – but could not prove any trends – either on a global or individual basis. The only exception was made by Knutson et al. (2010), who showed an increasing trend for the North Atlantic, although they could not determine how far this was based on multi-decadal variability or greenhouse-forced warming. Only a positive correlation of Atlantic TC frequency to SST could be shown.

On the other side, looking at the trends of strong cyclones (category 4 and 5) in different regions of the world, Webster et al. (2008) found significant signals for an increase. However, there was no significant trend in the total number of cyclones. Elsner et al. (2008) and Knutson et al. (2010) stated an increase for the upper limit of the distribution of TC intensities in the past – this means stronger storms become even stronger. Elsner et al. (2008) analyzed the period 1981 to 2006 and found significant upward trends for intensity on a global basis, but also for the western North Pacific.

Further studies on TCs for the region of SEA and the Philippines follow.

Chan and Xu (2009) analyzed the numbers of land-falling TCs in some regions in SEA and found that, for the region Vietnam and Philippines, there was no significant trend in the 20th century. They concluded that global warming has not led to higher frequencies of landfalling TCs. The same was found by Kubota and Chan (2009), who based their analysis on a data set from 1902 to 2005. They further stated that the landfalling TCs are related to ENSO and PDO and an oscillation of 10-22 years is apparent in their occurrence rate since 1945.

The cyclones that effect SEA, especially the Philippines, originate in the northwestern Pacific, which has the highest frequency of TCs in the world – only some cyclones come from the west – the Bay of Bengal. There is a strong correlation between the intensity of TCs and the ocean temperature (Park et al., 2014). Park et al. (2014) revealed that the warming trend in **<u>SSTs</u>** is much stronger in the western tropical Pacific than the central or eastern Pacific. They further stated that the threat of intense TCs to East Asia has increased in the last decade. But this could mostly be shown for the northern part of East Asia. For southern parts, the trends have mostly been negative. Further, they stated that there is an enhancement of the **<u>Walker circulation</u>** evident (it is unclear if this is multi-decadal variation or global warming signal), that leads to atmospheric changes that have suppressed the TC development in this region, despite the general SST warming in the eastern Philippine Sea (Park et al., 2014).

The very recent study of Villafuerte et al. (2014a) looked for **<u>past trends in extreme precipitation</u>** indices (EPIs) (e.g. maximum 5-day rainfall or number of consecutive dry days) by analyzing a 60-year dataset (1951-2010) of observed weather in the Philippines. They found a tendency towards dryer conditions for the dry season (JFM) (i.e. increasing trends in maximum length of dry spells [LDS]), which they attributed to the weakening of the East Asian winter monsoon. In opposite to that finding, they show that in the wet season (JAS), the LDS is decreasing and maximum 5-day rainfall is increasing, so the conditions are becoming wetter (particularly in the Northwest and central Philippines). Chang (2011) also analyzed **<u>past extreme precipitation</u>** for the whole region of SEA and reported increases in frequency and intensity. Endo et al. (2009) and Yao et al. (2009) applied a detailed analysis of trends in precipitation patterns of SEA using weather station respective gridded precipitation data. Both found increasing trends for the extreme precipitation indices - Endo et al. (2009) for yearly mean values and Yao et al. (2009) for seasonal data. Cinco et al. (2014) found some weather stations (Cotabato, Iloilo, Laoag and Tacloban) that showed significant increasing trends both for frequency and intensity of extreme daily rainfall events.

As mentioned above, the **<u>ENSO phenomenon</u>** is of great importance for weather related events in the region. Kubota and Chan (2009) verified a correlation between cyclone activity and the ENSO phenomenon, which could probably be traced back to correlation of both effects with the sea-surface temperature (Emanuel, 2007). The IPCC (2007) summarizes that, during an EN year, less TCs hit the country, while during a LN year, more TCs occur (in the JAS season this affect is reversed). The allocation of "EN – less TCs" and "LN – more TCs" is even exacerbated in a low phase of the Pacific Decadal Oscillation (PDO). The seasonal forecast is best for October to March.

The ENSO phenomenon also affects the internal variations in the EPIs in the study region. It leads to drier conditions with droughts in the case of an El Niño event (EN) (Jaranilla-Sanchez et al., 2011; Jose and Cruz, 1999) and to significant wetter conditions with excessive rains in case of a La Nina event (LN) (Hilario et al., 2009; Yumul et al., 2008). But the allocation between ENSO and weather conditions is not always easy. The strong drought of 2007 described above, happened unexpectedly in a very strong LN year (Yumul et al., 2010), which even exacerbated the devastation of the event. Lyon et al. (2006) analyzed this connection between rainfall and ENSO by looking at rainfall data from 40 observing stations across the Philippines and showed that the seasonal rainfall response to ENSO reverses between boreal summer (July–September) and fall (October–December) for both El Niño and La Niña. On a seasonal basis, Villafuerte II et al. (2014b) found in another publication that ENSO is correlated to the precipitation in OND (October to December) in the way that El Niño leads to dryer and La Niña to wetter conditions. In contrast, the season JAS is more influenced by the **monsoonal activity**, in particular in the western part of the country.

The trends in **extreme heat events**, e.g. in hot days and warm nights, have been analyzed by Manton et al. (2001), who showed significant increases and further a decrease in cool days and cold nights in the period 1961 to 1998.

Projected changes of the EWEs

To analyze the **future changes in drought occurrence**, Dai (2012) used global models, but could not find clear significant results for SEA. In contrast to that, Taylor et al. (2012) found a consistent increase in drought risk in a global assessment, which he indicates with the Palmer Drought Index (PDSI). Sillmann et al. (2013) showed that **heavy precipitation** events in SEA will increase in magnitude and frequency in the future. The share of heavy precipitation on the total amount of precipitation could increase to more than 50% in RCP8.5. They also found signs for a stronger drought risk as they showed that the maximum number of consecutive dry days is increasing.

Looking at the superregional level of SEA, the strongest increases for frequency and intensity of temperature extremes are found to be in Indonesia and southern Philippines by the World Bank (2013). Sillmann et al. (2013) found similar results and further argued that SEA is one of the two regions in the world that face strong increases in heat extremes even under a low-emissions scenario. In the RCP8.5 scenario, today's warm spells (above the 90th percentile of the base time period) would occur at most times of the year (~300 days) and today's warm nights (above the 90th percentile of the base time period) would occur in 95% of all nights in the future (Sillmann et al., 2013)

For the projected changes in TCs, one has to look separately for the frequency and the intensity of the storm events. As the World Bank (2013a) stated, there are no studies dealing with projections for a temperature change of only 2°C – so they all analyze future projections of TCs for a 4°c warmer world (RCP8.5). Atmospheric model results show an overall decrease in frequency in the area of the Philippines – with some exceptions (Sugi et al., 2009; Knutson et al., 2010; Held and Zhao, 2011; Murakami et al., 2012). Sugi et al. (2009) used a mesh AGCM (Atmospheric General Circulation Model) and showed also robust decreases in global TC frequency due to climate change. However, they stated that the regional characteristics can be different as they depend strongly on the SST projections used.

Other working groups (Caron and Jones, 2007; Emanual et al., 2008) analyzed the likelihood of a TC to develop – which is called cyclogenesis and can be used as an indicator for frequency (World Bank, 2013a) – and found increasing trends. In contradiction, Zhao and Held (2011) proved that the relationship between cyclogenesis and the frequency of TCs does not hold for the western North Pacific (WNP).

Knutson et al. (2010) summarized the findings of the changes in TCs: globally averaged intensity of TCs is shifted towards **stronger storms** (2-11% to 2100); in the global average we see a **decreasing frequency** of TCs (6-34%), but in contradiction high resolution models show for the most **intense TCs a small increase** and ~20% increase in precipitation in their vicinity due to SST rise. This was confirmed in a regional study by Murakami et al. (2012), who showed that the number of category 5 cyclones is increasing in western North Pacific and the mean maximum surface wind speed is increasing by 7% (3.5°C warming). In another publication, Murakami et al. (2011) stated a growth in average instantaneous maximum wind speed of 9% and a decrease in frequency of 10% in TCs making landfall in the Philippines. The **increase in storm-centered rainfall** was confirmed for the region of western North Pacific by Emanuel et al. (2008).

The IPCC (2013) stated that the projections of the 21st century show that it is likely that the global frequency of TCs will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean TC maximum wind speed and rain rates. However, the confidence in region-specific projections is still relatively low. The frequency of the most intense storms will more likely than not increase in some basins. More extreme precipitation near the centers of TCs making landfall is projected among other regions also for Southeast with medium confidence.

> There are a large number of publications dealing with the changes in slow-onset variables and EWEs because they are also relevant for the Philippines even when not directly dealing with the country, e.g. publications about sea level rise or ENSO. For the general overview, the summarizing publications of the World Bank and Asian Development Bank are very useful.
>
> Many publications referred to in that chapter are included in the IPCC (2013) report: Jourdain et al. (2013), Knutson et al. (2010), Peduzzi et al. (2012), Elsner et al. (2008), Kubota and Chan (2009), Emanuel (2007), Emanuel et al. (2008), Sugi et al. (2009), Murakami et al. (2011/2012), and Sillmann et al. (2013). R.V. Cruz was leading author of a chapter in IPCC (2007). Cruz et al. (2006), Lasco and Boer (2006) and another publication of PAGASA have been cited in that report. We, in particular, recommend these publications.

5.2.3 Impact on human livelihood

This section will look at the impacts of climate change in terms of **rural and urban livelihood** and the impacts on the sector **health and infrastructure**. The impacts in agriculture will be treated in another section.

The changing climate and the corresponding changes in the extreme events occurring in the country will have large impacts on the livelihoods of the population. In 2009, 18% of the country’s population was living in the **low-elevation coastal zone** and, therefore, suffer from already existing burdens and are further prone to upcoming climate change related threats, e.g. changes in storm surges and SLR (ADB, 2012).

The World Bank (2013) analyzed the impacts on the **rural livelihoods in deltaic and coastal regions** and argued that these regions are already very vulnerable to coastal flooding and TCs. This will be exacerbated by saltwater intrusion and coastal erosion, in particular, as the rural population is strongly dependent on agriculture and aquaculture, which will be affected by the changing climate.

Other publications focus more on the impact of climate change in the **urban environment**, the regions that already have to deal with manifold non-climate related pressures. In general, the level of urbanization in the Philippines is strongly increasing. Tran et al. (2012) published the following urbanization rates for the country: 27% in 1950, 33% in 1970, 43% in 1990, 51% in 2000 and a projected level of 66% for 2025. The share of population living in the urban areas is strongly growing. For Manila, the UN assumes a population growth from 11.6 million (2010) to 14 million in 2025 (World Bank, 2013a). This growth is partly internal population increase, but also due to **migration** from the rural areas – that is also true for the whole region of SEA. The Asian Development Bank (2012) wrote that the population in urban areas increased in the Philippines by 90% between 1990 and 2007, whereas the number of people living in rural areas was constant in the same time period. This can be traced back to the migration of people. When it comes to the vulnerability of urban areas to climate change, the topic of migration is of great importance and should be treated as a possible human response to areas and societies that face a multitude of risk factors (World Bank, 2013a).

If the growth in population cannot be absorbed by adequate housing policy, urban settlements are expanding in **informal settlements.** The share of these areas in the Philippines was 44% (UN-Habitat, 2003) in 2001 for the city of Manila the Rockefeller Foundations (2015) published a share of 20 to 35% of informal settlement. The burden for the population living in informal settlements is increased due to a lack of sanitation, lack of access to water and non-durable housing structures (World Bank, 2013a), which makes them highly vulnerable to climate change. The lack of sufficient adequate housing is also exacerbating the burden of urban heat.

Balica et al. (2011) constructed a vulnerability index for 9 major coastal cities worldwide. The index was built upon indicators based on hydro-geological, social, economic and administrative components. Due to its exposure to TCs and flooding, Manila was rated vulnerable in particular on the hydro-geological component. Recent storms illustrated this exposure of Manila: In the year 2009, Typhoon Ketsana induced flood waters that reached nearly 7 m above sea level in some city areas resulting in hundreds of deaths (Balica et al., 2011; WWF, 2009). In a comparison study of the WWF (2009) for Asian mega cities, Manila even reached the highest ranking in terms of vulnerability. For the economic component of the ranking, the capital had the highest vulnerability to coastal floods (Balica et al., 2011). They further stated that the economy of Manila will recover very slow mainly due to the high number of days needed to recover after a flood event in the past and the small length of the drainage system. In total, the city was ranked on the fourth place for today's vulnerability and could move to the third in the future depending on the scenario used. Regarding Manila, we also want to refer to the work of Bankoff (2003), who analyzed the complex mechanism that leads to the vulnerability of a region. He argues that this is more than the pure exposure to threats. Besides climatic change and rising sea levels, the effects of more localized human activities (i.e. land use practices, ground water extraction, living standards, population growth, and policy responses) also play a role in creating vulnerability.

The study of Brecht et al. (2012) also analyzed the vulnerability of cities in SEA, entailing several urban areas of the Philippines (Butuan, Cotabato, Manila, Taguig, and Kalookan). In general, they argued for a strong impact on urban agglomerations in SEA, as they are affected by increased TC intensity, SLR, and coastal flooding. Hanson et al. (2011) execute a ranking of the Port Cities in terms of exposure and vulnerability to climate extremes (they implement only the two Philippine cities Manila and Davao). They further checked for population and assets that are exposed to a certain SLR. Muto et al. (2010) conducted a study specifically on the study region Metro Manila focusing on the impacts of climate-induced **floods** and the influence of precipitation, sea-level rise and increased storminess on these floods. Working with the SRES scenarios B1 and A1F1 (extreme scenario), they found a SLR of 19 resp. 29 cm and a rainfall increase of 9.4 resp. 14.4% for the region that leads to storm surge height increases of up to 100 cm in both scenarios. In case of a 100-year-return-period flood in 2050, 24% of Manila's GDP could be affected.

Another major issue for urban agglomerations is the so-called **Urban Heat Island Effect (UHI).** Here, various literatures exists for many regions and cities worldwide (e.g. Oke, 1982; Arnfield, 2003). For the Philippines, e.g. Tiangco et al. (2008) analyzed the UHI for the city of Manila and found a temperature difference between rural and urban area of up to 3°C by applying remote sensing data.

The **economic power** in SEA is concentrated in the urban agglomerations – Manila's GDP accounts for roughly half of the country's GDP (World Bank, 2103a). Both economic power and, as mentioned earlier, population are strongly increasing. Lack of adequate infrastructures and adaptation measures lead to an increase in vulnerability (Dodman, 2009). The strong typhoons of recent years show major impacts in particular on the water and sanitation supply system – after cyclone Ondoy in 2009, 100,000 people in central Luzon province were without piped water supply (GDFRR, 2009; World Bank, 2013a).

Impacts on Health

There are many ways in which climate change can affect the health and well being of the population. As already mentioned above, the EWEs, i.e. typhoons, have large impacts on the **water and sanitation system** of a region. Lack of clean water and appropriate sanitation could lead to serious diseases, such as diarrhea and cholera (World Bank, 2013a; Dolhun, 2013). Droughts could also be a reason for shortcomings in water and sanitation and therefore influence the transmission of diarrheal diseases in the area of SEA (ADB, 2011). Yumul et al. (2010), for example, stated that water consumption in the drought of 2007 had to be constrained to save water. The authorities attempted to deal with the shortage by giving domestic use priority over industrial and agricultural demand. Further Yumul et al. (2010) specifies that health concerns due drought not only involve humans (e.g. viral conjunctivitis), but also animals (e.g. hog cholera).

Other diseases like malaria and dengue could increase due to **flooding** (ADB, 2011). A growing health burden is dengue fever transmitted by mosquitos. Due to climate conditions, the vector can survive year round and the recent development of rapid urbanization, environmental degradation, lack of a reliable water supply, and improper management and disposal of solid waste lead to a further propagation of the virus (Bravo et al., 2014). To what extent the occurrence of dengue is affected by weather and changing climate is widely discussed in the literature. Some literature analyze the effect even on a very local scale. Edillo and Madarieta (2012) analyzed recent trends in dengue incidence in Cebu province. They mostly related the dengue problem, like Bravo et al. (2014), to growing urbanization and population, inadequate public health infrastructure, poor solid waste management and lack of an effective mosquito surveillance system. However, they stated a relationship between the rainy season and the dengue cases, which was also exposed by Su (2008). She analyzed the correlation between Dengue and the temperature and precipitation patterns in Manila and found the latter to be of relevance for the occurrence rates of the illness. Dulay et al. (2013) made a statistical analysis of dengue cases in Iligan City, Lanao del Norte, Philippines on monthly basis and found temperature and humidity to be more important than rainfall. For the region of Central Visayas, Picardal and Elnar (2012) also studied the relationship between temperature and rainfall on dengue incidence, but found no significant correlation. As rainfall showed significant correlations in other studies, this shows that the local conditions, both climatological and socio-economic, are of great importance for the surveyed relationship. In the case of the region of Central Visayas it is very interesting that, despite scarce precipitation occurring in that region over the study period, many cases of dengue fever were still observed. Buczak et al. (2014) built a prediction model for dengue in Philippines by applying socio-economic and meteorological variables. Opena & Teves (2011) and Pasay et al. (2013) analyzing Iligan City and Ozamiz City, respectively, but the publications were found to be not fully reliable statistically.

Besides studies directly related to the Philippines, there are is wide range of literature dealing with other regions. Here, we refer to the following as they could be of relevance for the Philippines. Tseng et al. (2009) analyzed the impact of climate change on the prevalence of dengue fever for the region of Taiwan and found by doing an empirical estimation that climate conditions have an increasingly significant impact on the probability of people being infected by dengue fever. They assumed a climate change induced temperature increase will therefore exacerbate the risk of that disease. Hii et al. (2009) used a higher temporal resolution by using weekly data in Singapore and found mean temperature and precipitation had an impact on dengue incidence rate with a time lag of several weeks. They also assume a potential increase caused by the ongoing change in climate. Khasnis and Nettleman (2005) executed a general survey of infectious diseases and global warming and made some general statements that could here be used as a quintessence. They clearly state that global warming will change the epidemiology of infectious diseases, but also other effects play an important role, i.e. human migration, resistance of population, scarce potable water, insufficient health infrastructure, and others.

Further, many publications argue that the field of influence of environmental factors on dengue is under-studied (e.g. Picardal and Elnar, 2012; Bravo et al., 2014).

On a spatially broader view, the ADB (2011) wrote a report on the relationship between health and changing climate. On a very local level, Palacio & Palacio (2014) analyzed the authority's perception of climate change to assess the health system preparedness in the province of Albay. They conducted a survey on health system staff and found that the respondents perceived climate change to be a relevant threat for health. The publication further suggests certain policy measures to deal with the issue.

Another subject for health is **saltwater intrusion** into coastal aquifers, which provide on a global basis, drinking water to more than a billion people living in coastal areas (World Bank, 2013a). This is particularly relevant for small islands, as freshwater here can only be trapped in small and highly permeable layers (Praveena et al., 2012). The salinity and nutritional intake can affect coastal populations, especially maternal and child health (Khan et al., 2011). They further mentioned that exposure to salinity can be a reason for increased diarrheal diseases, hypertension, premature delivery, skin diseases, and acute respiratory infection in coastal populations. The World Bank (2013a) also stated that saltwater intrusion can have many health impacts. The Food and Agriculture Organization (FAO) limits the allowable part of salinity in drinking water to <0.5 parts per thousand and Khan et al. (2011) stated that, in some regions of Bangladesh, the value was above 15. This saltwater intrusion puts additional pressure on the per capita availability and quality of fresh water in some regions.

Saltwater intrusion can be increased by groundwater extraction from coastal wells (World Bank, 2013). This extraction of groundwater could also lead to **human-induced subsidence**, which could exacerbate many of the aforementioned stressors (Brecht et al., 2012). We refer here to an interesting publication related to these issues: Rodolfo and Siringan (2006) strongly argue that SLR is a problem for coastal areas, but they show that anthropogenic induced subsidence due to excessive groundwater extraction is much worse but, at the same time, not recognized by the authorities. As the publication is from 2006, we assume that there have been further activities related to that issue.

Bankoff (2003) raised the point that there have always been EWEs and, while accepting the relationship between global changes in climate to these events, one has to admit that **human activities** (i.e. land use practices, living standards and policy responses) also strongly affect the frequency and strength of natural hazards such as floods. One human activity that could interfere with disasters and is discussed in literature is **mining**. Holden (2012) wrote that mining can interfere with groundwater resources and therefore aggravate an El Niño induced drought. It deprives the rural poor of needed water and could, thus cause a disaster when a natural hazard impacts a vulnerable population (Holden, 2012).

As mentioned earlier, the issue of **migration** also plays a role in the Philippines. 7 million Filipinos live as migrants outside the country (ADB, 2012) – mostly due to economic reasons – but even these could be related to climate change. Others clearly have been forced to migrate due to disasters, e.g. the 400,000 people that were displaced by the typhoon Sendong (or Washi) that made landfall in Mindanao in 2011 (IDMC, 2013). The combination of a changing climate and climate-induced migration can lead to large impacts on people's health. Mosuela and Margaret (2014) further added to this topic that a priori migration (discussed for Haiyan) could even be a support in cases of a disaster, as familial affiliation could be used as a response option.

A detailed overview of the impact of changing climate on health for the Philippines can be found in Lorenzo et al. (2011) (e.g. time series analysis of several Infectious Diseases).

Interaction with Gender

Peralta (2009) comments that the impacts of climate change are not only unevenly distributed among countries, but different social groups or parts of the society will be hit in different ways. There is a demand for research on the link between climate change and gender, not only because women comprise one of the most vulnerable groups, but also because women play a pivotal role in mitigating and adapting to climate change (Peralta, 2009). The changing climate will have a more severe effect on women due to gendered norms that determine socio-economic roles and a weaker socio-economic status to women (Brody et al., 2008; Peralta, 2009). Brody et al. (2008) gave an overview on the various interrelations between climate change and gender. Tatlonghari and Paris (2013) show gendered adaptation to flooding in rice farming communities in Nueva, Ecija, Philippines.

Tanner (2010) published a work about children's response to climate, arguing that the general perception that children and young people are only victims of climate change impacts is wrong. He presents examples from the Philippines and El Salvador to show how young people can play a crucial role in adaptation.

Impacts on Infrastructures

Infrastructure here refers to hard Infrastructure (e.g. energy systems, transportation systems or water supply system) and soft infrastructure (e.g. schools, hospitals and other social institutions). In urban centers, the density of infrastructures is mostly higher than in rural areas, which is part of their attractiveness. Infrastructure can be affected by climate change in a many ways. In general, many impacts on infrastructures are described in Rosenzweig et al. (2011) and Wilbanks et al. (2012).

Below, we give some examples of impacts for the electricity infrastructure. Water and sanitation have partly been mentioned earlier. Transport is missing, but we assume a strong dependency on storm and flood events.

The production of electricity via hydropower plays a large role in the country. In a publication of the Department of Energy (2012), the share of installed generating capacity is for oil, natural gas and coal roughly 70%, for hydropower 21% and for geothermal power 11%.

Villafuerte et al. (2014a) refers to a time when hydroelectric power in Mindanao played an even bigger role with 90% of electricity production compared to today (54 %; Department of Energy, 2012). During an El Niño event, the drought conditions resulted in suspension of production by the hydroelectric plant and severely increased the economic vulnerability of the region. Although the contribution of hydropower is smaller today, the impacts of drought on this source of energy still remain. Besides the exposure to weather extremes, the issue of maintenance and reliability could play an important role – although we did not look for literature on that topic. The often-occurring storms in the country could have an impact on the electricity transmission network (Rosenzweig et al. 2011).

> Many relevant publications or the corresponding authors in this chapter show a significant reflection in the scientific literature. For example, Bankoff (2003), Rodolfo and Siringan (2006), Su (2008), Tseng et al. (2008), Rosenzweig et al. (2011) and Wilbanks et al. (2012) can be found in the IPCC reports and Arnfield (2003) and Oke (1982) show further a high citation frequency (table 1). As a very rough measure, we refer to the citation frequency as one source of knowledge about reliability.

5.2.4 Impact on agriculture and aquaculture

The two sectors of agriculture and aquaculture can be seen as the two main components of rural livelihood in SEA river deltas and coastal areas (World Bank, 2013a). To analyze the impacts of climate change, we have to distinguish again between the impacts of EWEs or the slow-onset impacts, like a change in the mean temperature.

In the Philippines, about 13 million hectares of **agricultural** area produce a wide variety of fruits, grains and vegetables (PAGASA, 2014). More than half of the agricultural area is used to grow rice and corn, which is the staple food of the Philippines. On the one hand, agriculture in Philippines contributes only about 4% to the national GDP but more than 72% of the population are engaged in agriculture and the sector provides 1/3 of the country's total employment (World Bank, 2010). **Aquaculture and fisheries** are of great importance for the coastal areas – they deliver according to FAO (2010) 36% of dietary animal protein in SEA. The World Bank (2013a) denotes a strong increase in the importance of this affordable source of food in SEA.

Agricultural production is under pressure from climate change for many reasons, i.e. salinity intrusion, inundation, SLR, TCs, or temperature increase during the growing phase (Dawe et al., 2008; Wassmann et al., 2009). Khan et al. (2011) mentioned that **saltwater intrusion** due to flooding by TCs can decrease agricultural yield, which they analyzed for Bangladesh (1/5 of the total area of the country is affected by salinity).

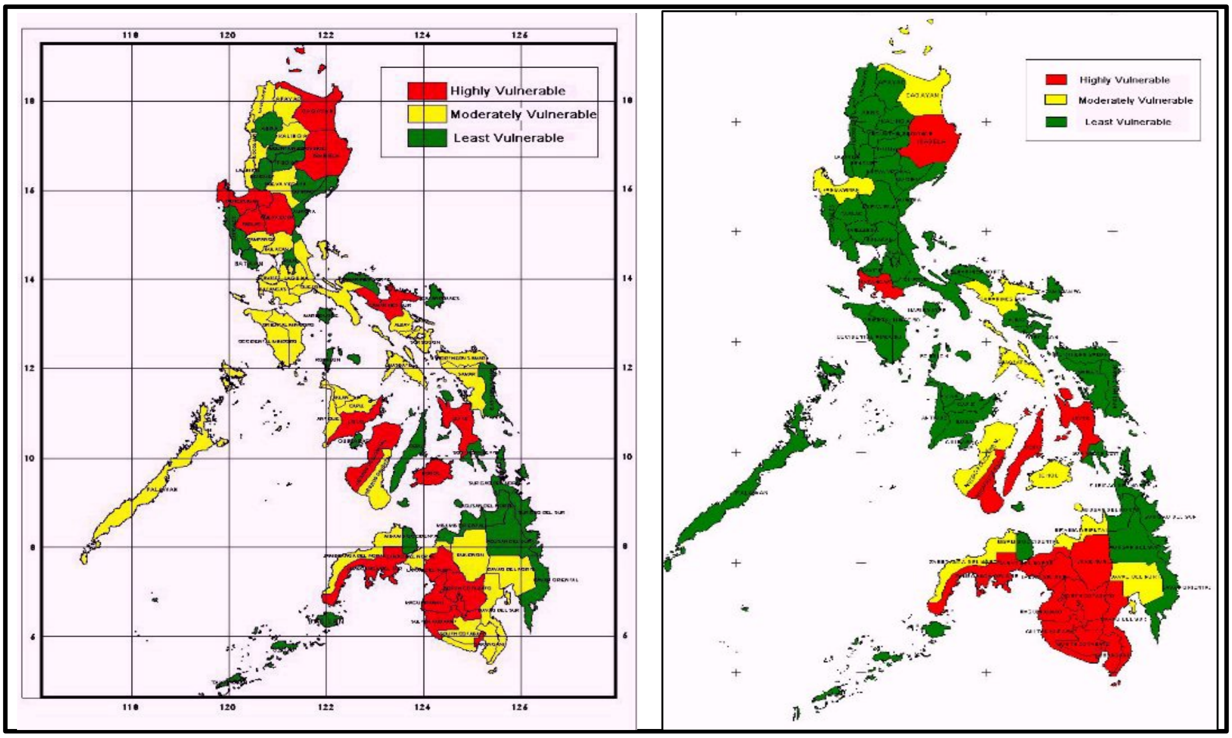

Figure 4: Vulnerability maps of rice (left) and corn (right) producing areas in the Philippines (PAGASA, 2014).

As agriculture strongly depends on the patterns of precipitation (mostly the rainfall of the southwest monsoon (JAS); Villafuerte et al., 2014b) many researchers have analyzed this relationship. E.g. Warren (2013) analyzed the vulnerability of the agricultural sector to **droughts**. Villafuerte et al. (2014a) also argues that heavy rain or drought conditions are directly affecting the agricultural sectors of the country – and therefore the **economy** of the Philippines. Warren (2013) analyzed the historical burden of ENSO induced drought and the corresponding famine due to impacts on agricultural yields in the Philippines. As stated above, El Niño events influence rainfall distribution, possibly resulting in severe droughts in certain regions (Villafuerte et al., 2014a; Lyon et al., 2009; etc.). According to Warren (2013), there has been an increase in the frequency of major food shortage and famine events in the last half of the twentieth century, which could be associated in part with an increase in severe El Niño-related drought events. He argues that this is the most important disaster type in the upland and semi-arid areas of the archipelago (Warren, 2013). Areas he mentioned to be often hit by severe drought in the past are parts of Luzon, the Visayas and Mindanao (especially General Santos City). The El Niño in 1998 caused a drought, affecting 90% of area of the Philippines with a reduction in rainfall of 50%. 50,000 ha of agriculture land dried up and two million people were affected in Mindanao, which forced the government to import rice (Warren, 2013). He further stated that due to the strong population increase the impacts of El Niño events could become even worse in the future. The massive loss of agricultural production in the country due to a drought was also analyzed by Yumul et al. (2010) for the 2007 drought. A more recent paper dealing with the relationships between food supply and disaster is Gibb and Veuthey (2011). These relationships can be multiple - for example the floodwater devastated road interrupts food transport, storms prevent fishers from fishing and many others maybe not as obvious examples.

On the webpage of PAGASA (2014), Vulnerability Maps for an El Niño event for the crops rice and corn can be found. The maps have been calculated by taking data from recent **El Niño drought events** and the corresponding effect on the specific area (PAGASA, 2014).

Other working groups even publish a quantitative statement. For example, Lansigan et al. (2000) found that typhoons, floods, and droughts caused 82.4% of the total Philippine **rice losses** from 1970 to 1990. While looking at the socio-economic impacts of Typhoon Harurot (Imbudo), Huigen and Jens (2006) found a relative loss for corn of 64%. Buan et al. (1996) also analyzed the impact of climate change on rice and corn production in the Philippines. We do not refer to the quantitative numbers as the models applied are nearly 20 years old, but they state a crucial point that a decrease in rainfall in some regions by 10% is not as bad because enough water available, but in other region, an increase by 10% could lead to more damage as floods affect the plants strongly.

In more spatial detail, Lansigan and Salvacio (2007) analyzed the effect of climate change on yields of rice and corn in selected areas in the Philippines by using 10 different climate change scenarios in three selected provinces, namely: Ilagan, Isabela; Los Baños, Laguna; and Malaybalay, Bukidnon.

Besides EWEs and their climate change induced changes in occurrence rates, the agriculture of the country is also influenced by slow-onset changes, e.g. of temperature, precipitation and SLR. Lasco et al. (2011) also stated the impact on yields due to changes in, e.g. mean **nighttime temperature** or changing rainfall patterns. This effect of declining rice yield with rising night temperatures was already described in general by Peng et al. (2004). Lasco et al. (2011) further mentioned indirect effects on the plants, like **fungal diseases** or increased pressure form **insects** (e.g. corn stem borer) due to changing temperature or moisture conditions.

The World Bank (2013a) stated that agricultural production is less effected by SLR than other SEA-countries, as agriculture in the Philippines does not take place in the coastal or low-lying areas. The bigger burden is created by TCs.

Another not yet mentioned major issue for agriculture in the Philippines is **land degradation**. The topic is covered in Fuentes & Concepcion (2007). They argue that people have always had to deal with climate variability in the country and developed appropriate coping mechanisms but, with the combined pressures of economic development, population growth and urbanization, these could be overextended.

Adaptation in the agricultural sector

Recommendations for adaptation measures can be found in many publications. According to Khan et al. (2011), the issue of SLR and saltwater intrusion could be treated by:

1. Strengthening early warning systems
2. Providing safe facilities to vulnerable populations and livestock
3. Readjusting embankment systems including embankment height and drainage openings
4. Coastal forestation as a green belt to reduce risk from sea-level rise and cyclone surge.
5. Conducting appropriate epidemiological studies for climate change impact on health

Yumul et al. (2010) listed the reactive measures that have been applied in the 2007 drought, as an upcoming drop in agricultural yields was obvious:

1. Fertilizers were provided to ensure bigger harvest
2. Repair of irrigation systems to safe water
3. Small water impounding projects were supported
4. Provision of farm equipment to ensure efficient planting operations.

Warren (2013) summarized his main shortcomings in terms of agricultural sensitivity:

1. Some rules lack strict enforcement
2. The budget is not large enough, there are too few resources
3. Not enough qualified personnel
4. Government agencies that lack cooperation.

For more information, the publication of the DENR (1999) can be used. It gives information about adaptation in many sectors. Wassmann and Dobermann (2007) focus directly on adaptation in the agriculture sector. The IPCC (2014) stated that farmers have been adapting to climate risks for generations and developed local adaptation strategies that have been documented for SEA (e.g. Peras et al., 2008; Lasco et al., 2010, 2011). This indigenous knowledge could be used as a basis for future climate change adaptation (IPCC, 2014). Lasco and Boer (2006) analyzed the vulnerability of watersheds in the Philippines and also offer adaptation methods for droughts and floods. Also widely discussed in the literature is the method of Community-Based Disaster Preparedness (CBDP), which could be used as an instrument for local coping and adaptation strategies and be further combined with development strategies (Allen, 2006). In the case study list (Table 2), more studies that deal with adaptation are listed.

In Indonesia, the WMO (2014) installed a so-called Climate Field School to bring climate information into the field, where also people from the Philippines participate.

Regarding the topics of this chapter, a lot can be found in the report of the IPCC (2014). Many researchers from the Philippines contributed to the report and are also cited in this report: R. Wassmann, R.D. Lasco, M.L. Perez and F.P. Lansigan. In IPCC (2007) J. Pulhin contributed as leading author to one chapter. Further publications of Allen (2006), Peras et al. (2008), Huigen and Jens (2006), Dawe et al. (2009), Peng et al. (2004) and reports of the Asian Development Bank can be found in the reports (IPCC, 2014; IPCC, 2007). We recommend these publications.

5.2.5 Impact on coastal areas

This chapter deals with the following issues: **coral reefs** and **mangroves** and the corresponding impacts of climate change, **coastal erosion** due to SLR and the following **land losses**, **saltwater intrusions** as result of SLR and/or anthropogenic engagement, **coastal wetlands** and the impact on **economics** and **tourism**, as well as some facts for **adaptation**, which are taking place or could be an option in coastal regions.

One important feature of the coastline of the Philippines is the abundance of **coral reefs**. The Philippines have 26,000 km² of coral reefs, which is a large share of the coral reef area of the coral triangle (96,000 km²). Rising levels of carbon dioxide and the resulting changes in climate present a large burden for the corals with impacts like ocean acidification and, increasing frequency and duration of ocean temperature anomalies. Additionally, the corals are stressed by **destructive human activities** (e.g. fishing and coastal development) (Burke et al., 2011). In view of the several major ecosystem services the coral reefs provide for the Philippines, this is large problem. They serve as a source of food, medicine and tourism revenues and they reduce wave energy and can therefore represent a natural protection of the coasts (Burke et al., 2011). Although only occupying a small share of world's oceans, they provide habitat for a very large biodiversity leading to high productivity in a relatively low nutrient water region.

Populations living along reef coastlines depend heavily on these coral services, i.e. the Philippines has 1 million-reef fishers (without aquaculture) (Burke et al., 2011). The corals as a source of food will be affected, in the way the species distribution will change. Cheung et al. (2010) analyzed the projected changes in catch potential out of 2055 and found for the area north of the Philippines a slightly increasing trend and for the south a stronger decreasing. The method was applied on a global scale and it is therefore hard to interpret the results on such a local scale. The World Bank (2013a) added also criticized the failure to include hypoxia and acidification which would lower the catch potentials. In the fourth report of the IPCC (2007), they added among other points the fact that the SLR occurring at a temperature increase of 1-3°C leads to increased bleaching events and coral mortality. In World Bank (2013a), various studies can be found that discuss the impacts on corals for different levels of CO_2 in the atmosphere and the importance of warming water. So for example, McLeod et al. (2010) analyzed the impact of SSTs in the coral triangle and found that the Philippines are the most threatened in that region. Arceo et al. (2001) analyzed the correlation between coral bleaching in the Philippines and SST anomalies that occur in the waters around the islands. Penaflor et al. (2009)

found an average increase of SSTs in the coral triangle of 0.2°C/decade, with the regions in the north and the east warming fastest.

The above mentioned coral ecosystem service of shore protection is analyzed in more detail by Villanoy et al. (2012). By modeling the waves at a reef in the Philippines, they show their importance for dissipating the wave energy. Their argumentation is that, as the corals are already under pressure due to impacts of climate change, one should protect them from further damage like pollution or destructive forms of fishing (more see also Newton et al., 2007). Villanoy et al. (2012) further state that the ability to protect the coasts depends on SLR and they claim that some reefs may grow fast enough to keep pace with rising level of the water. That point was criticized by the World Bank (2013a), arguing that the assumptions of Villanoy et al. (2012) may be too optimistic. Other literature shows, that even under less warming, most reefs would show **severe bleaching** in 2050 (Meissner et al., 2012).

By analyzing the stability of the Great Barrier Reef, De'ath et al. (2012) found that these three stressors of the ecosystem (TCs, **crown-of-thorns-starfish** (Acanthaster planci) and coral bleaching) lead to a mortality rate of 3.4% per year. As the surveyed decline in reef cover is roughly 0.5% each year, they assume that, in the absence of these threats, the estimated growth rate of the reef amounts to a yearly rate of nearly 2.9%, showing that there is a substantial capacity for recovery. They argued that, in the absence of the starfish, a small increase in growth (~0.9%/year) is possible but only if the other pressures, in particular those related to climate change, are kept low. The Coral Cay Conservation (2013) presents a monitoring report for the region of Napantao, San Francisco, Southern Leyte.

Another very important part of the Philippine coast is the **mangrove forest**, also providing a multitude of ecosystem functions. Their size amounts to 263,000 ha in the Philippines (Giri et al., 2011). SLR will lead to a loss of these ecosystems in the region, which itself could intensify the erosion occurring at the Philippine coast (Gedan et al., 2011; Giri et al., 2011; World Bank, 2013a). Valiela et al. (2001) specified a strong decrease (4500 km² in 1920 to 1325 km² in 1990) in Mangrove size in the Philippines due to climate change. Brander et al. (2012) analyzed the future changes in mangrove cover and claims that the losses in mangrove area in the Philippines up to 2050 is relatively low (less than 10%) compared to other regions in SEA. They started with a mangrove area of 1020 km² in the year 2000, which corresponds with the former publication. Obviously, the rate of decline became smaller as most of the mangroves have already been lost. The non-climate related pressure on the mangroves is described in Walters (2003).

The Philippines is further highly vulnerable to climate change induced **coastal erosion**, that can lead to **land loss** and is highly related to wind stress and loss of vegetation (World Bank, 2013a). The problem of land loss and coastal erosion is also valid for the beaches. Zhang et al. (2004) presented empirical results that beach erosion is much faster that actual SLR – which even increases the impact of SLR. For the San Fernando Bay area in the Philippines, Bayani-Arias at al. (2012) projected a beach loss of more than 120.000 m² (which further leads to a loss of more than 280.000 m² of land loss) under the assumption of an increase in seal level of 100 cm.

By applying the DIVA model, McLeod et al. (2010) analyzed the impacts of SLR on the region and showed for some provinces of the Philippines under the RCP8.5 scenario a projected decrease of **coastal wetlands** from 109,000 to 76,000 km² until 2100 (whole area). Looking at the coral triangle, they further showed that the damage costs in the Philippines could be highest in comparison to the other countries of the Coral Triangle (US $6.5 billion/year until 2100 without adaptation) – the coastal wetlands of the Philippines are projected to amount to around 50% by 2100 (all for 100 cm SLR). Blankespoor et al. (2012) also applied the model DIVA and found that a SLR of 100 cm will affect 100% of the coastal wetlands in the Philippines.

Saltwater intrusion could be a big burden for the health of people living near the coast and was already mentioned in chapter 5.2.3.

To assess the overall **vulnerability of coastal communities** under the above-mentioned threats, Orencio and Fujii (2013) invented the so-called coastal community vulnerability index (CCVI). They applied the method to the municipality of Baler, Aurora, Philippines. The index consists of seven factors namely geographical, economic and livelihood, food security, environmental, policy and institutional, demographic, and capital good. They found the region most vulnerable with the highest population density of resource-dependent individuals, but only connection to a small shoreline to fulfill their demand. As a possible adaptation measure, they argued for an early warning system to account for the potential risks from impending natural hazards. Other adaptation measures for coastal areas to tackle the burden of changing climate can be found in Sales (2009).

A recent assessment on the vulnerability of coastal areas towards storm surges was done by Lapidez et al. (2014). They simulated storm surges induced by Typhoon Haiyan-like storms using the tracks of historical typhoons of the years 1948 to 2013. As a result of the study, the research group of the Nationwide Operational Assessment of Hazards (NOAH; disaster mitigation program of the Department of Science and Technology, Government of the Philippines) provides a list of the most vulnerable coastal regions (in terms of storm surges) of the Philippines.

There are publications available that account for the **economic value** of coastal and marine resources. For example, Samonte-Tan et al. (2007) analyze that for the Bohol Marine Triangle in the Philippines - without looking for impacts of climate change. The economic impacts of EWEs or slow-onset changes could happen via losses in e.g. fishery, aquaculture or direct losses of goods and lives, but could also be an impact on the tourism sector, which is of large importance for the region. Roughly 4.2% of the country's GDP in 2013 was a direct contribution (total contribution 11.3%) from tourism (World Travel and Tourism Council, 2014). Perch-Nielsen (2010) analyzed the vulnerability of beach tourism worldwide and found the Philippines among the most vulnerable countries. In Philips and Jones (2006) more impacts on tourism could be found. To evaluate the vulnerability of primary fishery commodities to changing climate in the Philippines, Jacinto et al (2015) used a sector-based fisheries vulnerability assessment tool.

> Many of the cited research can be found in the report of the IPCC (2014): Giri et al. (2011), Gedan et al. (2011), De'ath et al. (2012), Villanoy et al. (2012), Chung et al. (2019) McLeod et al. (2010) and Penaflor et al. (2009). Again we can in particular recommend these publications.

5.3 Overview-matrix of relevant publications

In the following vulnerability matrix, we want to assign the above-mentioned publications (and more) that are related to climate change impacts in the Philippines. The idea is to sort them by the climate impact and the vulnerable sector they are dealing with. We have to state that this assignment is not always very clear, as sometimes more than one class is possible. We additionally added the citation frequency (taken from www.scholar.google.com). Due to time constraints also, publications are listed in the matrix that are not referred to in the text above. We still assess them as being relevant for climate change impacts in the Philippines.

All the citations have been collected with the Mendeley research paper managing program (www.mendeley.com).

Climate Impact Vulnerable Sector	Climate Change in general	Weather extremes (WE)			Slow-onset changes: precipitation, temperature, SLR, saltwater intrusion, SST
		WE general	Storms / Floods /Monsoon	Droughts / Heat / ENSO	
General, no specific sector	ADB (2009) Amadore et al. (2005) Balangue (2013) Brooks & Adger (2003) – 62 Cinco et al. (2013) Cruz et al. (2007) – 1531 DENR (1999) Garcia R.&Virtucio (2008) – 3 IPCC (2007) - 6646 IPCC (2013) - 13 IPCC (2014) – 42 Jabines & Inventor (2007) Murphy (2010) Villarin et al .(2008) – 5 UNU-EHS (2011) World Bank (2010) World Bank (2013a) World Bank (2013c) Yumul et al. (2011)	IFRC (2013) Jourdain et al. (2013) - 20 Meheux et al. (2006) – 42 Sillmann et al. (2013) - 100 Ueda & Hori (2006) – 1 Yumul et al. (2008) - 7 Yumul et al. (2011) - 22 Yusuf&Francisco (2009) - 145	Caron & Jones (2008) – 29 Chan (2006) Chan et al. (2009) Chang et al. (2005) – 103 Chang (2011) - 11 Cayanan et al. (2011) – 3 Elsner et al. (2008) – 461 Emanuel (2005) – 2309 Emanuel (2007) – 145 Emaanuel et al. (2008) – 410 Gaillard et al. (2007) – 46 Geng & Sugi (2003) - 142 Held & Zhao (2011) – 44 Huigen & Jens (2006) – 15 Hung & Yanai (2004) - 47 Murakami et al. (2011) – 62 Murakami et al. (2012) - 58 Loo et al. (2014) – 3 Mendelsohn et al. (2012) – 83 Park et al. (2014) - 2 Knutson et al. (2010) - 743 Kubota & Chan (2009) – 32 Sugi et al. (2009) - 67 Webster et al. (2005) – 2027 Zhao & Held (2012) - 33	Chang (2010) Endo et al. (2009) – 23 Hilario et al. (2009) - 2 Holden (2012) – 3 Jaranilla-S et al. (2011) - 22 Manton et al. (2001) Lyon et al. (2006) – 28 Lyon&Camargo (2009) – 32 Ropelewski&H. (1996) Sillmann et al. (2013) Taylor et al. (2012) – 6 Villafuerte II et al.(2014a) Villafuerte II et al.(2014b) Yumul et al. (2010) - 7	Akasaka (2010) - 4 Caesar et al. (2011) – 39 Choopprateep&McNeil (2015) Cinco et al. (2014) - 1 Cruz et al. (2012) – 6 Endo & Matsumoto (2010) Klein Tank et al. (2006) – 176 Manton et al.(2001) – 486 Perrette et al. (2014) - 21 Tangang et al. (2006) – 34 Yao et al. (2009) - 16 Villafuerte II et al. (2014)

Climate Impact Vulnerable Sector	Climate Change in general	Weather extremes (WE)			Slow-onset changes: precipitation, temperature, SLR, salt water intrusion, SST
		WE general	Storms / Floods /Monsoon	Droughts / Heat / ENSO	
Agriculture / Food / Water / Forestry	Amano et al. (2012) – 0 Buan et al. (1996) Bordey et al. (2013) Fuentes&Concepcion (2007) Garcia et al. (2013) – 3 Tolentino&Landicho (2013) - 0 UPLB (2011) Wassmann et al. (2009) - 125	Gibb&Veuthey (2011) - 0 Fuentes&Concep. (2007) - 2 Lansigan et al. (2000) - 48	Huigen and Jens (2006) - 15	Dawe et al. (2008) - 12 Warren (2013) - 0 PAGASA (2014)	Buan et al. (1996) – 61 Dasgupta et al. (2007) – 292 Jose et al. (1996) - 22 Jose & Cruz (1999) – 25 Lansigan et al. (2007) Peng et al. (2004) – 986 Peras et al. (2008) – 1 Rodolfo&Siringan (2012) - 64
Coastal Vulnerability (Ecosphere)	ADB (2014) Bayani-Arias et al.(2012) - 2 Boquiren et al. (2010) - 2 Brander et al. (2012) - 19 Burke et al. (2011) – 21 Capili et al. (2005) – 14 Carpenter et al. (2008) – 549 Combest-Fr. et al.(2012) – 14 Daw-as et al. (2010) – 0 De'ath et al. (2012) - 229 Ferguson&Gl. (2012) – 41 Giri et al. (2011) - 352 Gedan et al. (2011) - 132 Insigne & Kim (2010) – 0 Jacinto et al. (2010) – 0 Newton et al. (2007) – 181 Orencio & Fujii (2013) – 4 Perch-Nielsen (2010) – 36 Perez et al. (1999) – 22 Perez (2002) – 5 Praveena et al. (2012) – 1 Ranjan et al.(2009) – 21 Sale et al. (2014) – 4 Samonte-T. et al.(2007) - 36 Valiela et al. (2001) - 704 Walters (2003) - 63		Lapidez et al. (2014) Peduzzi et al., (2012) Villanoy et al. (2012) - 2 Zhang et al. (2004)		Arceo et al. (2001) – 44 Blankespoor et al. (2012) - 6 Gedan et al. (2010) Giri et al. (2011) McLeod et al. (2010a) – 27 McLeod et al. (2010b) – 20 Meissner et al. (2012) - 17 Orencio et al. (2013) Penaflor et al. (2009) - 36 Reyes&Blanco (2012) - 3 Sales (2008) Zhang et al. (2004) - 305
Human livelihood - Migration, Health, Gender … (Anthropogenic sphere)	Acosta-Michlik (2005) - 21 Acosta-M.&Esp. (2008) - 61 ADB (2011) ADB (2012) Aquino et al.(2010) – 1 Brody et al. (2008) - 78 Dodman (2009) – 18 Khasnis&Nettleman (2005) - 192 Lasco & Boer (2006) Lee (2013) Lorenzo et al.(2011) Mias-Mamonong&F. (2010) Perch-Nielsen (2010) Peralta (2009) Satterthw. et al.(2007) - 344 Su (2008) – 31 Tatlonghari&Paris(2013) - 2 Tseng et al. (2008) – 19 Wilbanks & Fernandes (2012) WWF (2009)	Asuero et al. (2012) - 0 Hanson et al. (2011) Nicholls et al. (2008) - 289 Kreft et al. (2015) - 7	Balica et al. (2011) - 41 Bankoff (2003) - 76 Brecht et al. (2012) - 16 Dolhun (2013) - 0 IDMC (2013) Muto et al. (2010) - 6 Peduzzi et al. (2012) – 63 Porio (2011) - 10 Pulhin et al. (2006) - 6 Predo (2010) – 0 See et al. (2013 Uy et al. (2011) Yamada & Galat (2014) - 0 Zoleta-Nantes(2003) - 22	Tiangco et al. (2008)	Arnfield (2003) – 1032 Bravo et al. (2014) - 2 Dulay et al. (2013) - 1 Edillo & Madarieta (2012) - 2 Ferguson & Gleeson (2012) Hii et al. (2009) - 66 Khan et al. (2011) - 4 Oke (1982) – 1335 Picardal and Elnar (2012) - 1 Rudolfo and Siringan (2006)
Adaptation	ADPC (2013) Allen (2006) – 197 Butardo-T.&Tenef.(2011) CCC (2010) – 4 FAO (2013) Lasco et al. (2009) – 21 Lasco et al. (2011b) - 0 Lasco et al. (2012) - 6 NCCAP (2011) Perez et al. (2013) - 1 Smith Barry & O. (2001) - 907 Tanner (2010) - 13 Uy et al. (2011) - 13 Wassmann&D.(2007) - 25				Lasco et al. (2011a) - 12 Sales (2008) - 4 Sales (2009) - 19

Table 1: Vulnerability matrix - overview of relevant literature for the impact of climate change on the Philippines.

5.4 Overview of case studies

In Table 2, we include all the publications that have a specific focus on local case study assessments. Due to time constraints, we could not further refer to these works.

Author	Aim	Social group / sector	Where
Acosta et al. (2014)	Loss and Damage of floods and landslides	Communities	Philippines
Acosta-Michlik (2005)	Intervulnerability Assessment	Various study areas	Philippines
Acosta-Michlik et al. (2008)	Vulnerability assessment	Farming communities	Philippines
Amano et al. (2012)	DRR and CCA	Rainfed and agro-ecological zones	Buhi, Camarines Sur; Guinobatan, Albay; Gubat, Sorsogon
Asuero et al. (2012)	Social Characteristics	Disaster-prone communities	Infanta, Quezon
Balangue (2013)	Vulnerability Assessment	Different	Various regions
Bayani-Arias et al. (2012)	Economic vulnerability and adaptation options	Coastal erosion	San Fernando, La Union
Boquiren et al. (2010)	Vulnerability Assessment	Coastal Areas	Verde Island Passage
Butardo-Toribio (2011)	Assess Socio-economic Factors Influencing Community Adaptive Capacity	Communities	Bayawan City
Coral Cay Conservation (2013)	Assessing status of reefs under threat of Seastars	Coral Reefs	Napantao, San Francisco, Southern Leyte
FAO (2013)	Adapt to disasters in general	Agriculture	Bicol Region
Huigen and Jens (2006)	Socioeconomic Impact of Typhoon Harurot	Agriculture	San Mariano, Isabela
Lasco et al. (2010)	Assessing impacts, vulnerability and adaptation	Mostly agriculture and forestry	Pantabangan-Carranglan Watershed
Lasco et al. (2012)	Assessing Role of Governments for CCA	Climate hazards	PROVINCE OF ALBAY
Lee (2013)	COMMUNITY-BASED ADAPTATION	Urban Poor	Metro Manila
Mias-Mamonong& Flores (2010)	Vulnerability and resilience to climate change	General	Sorsogon City
Orencio and Fujii (2013)	Apply coastal community vulnerability index (CCVI)	Climate hazards	Municipality of Baler, Aurora
Palacio & Palacio (2014)	Perceptions of climate change potential for public health effects	Local health department	Albay
Perez et al. (2013)	Economic analysis of adaptation	Coastal areas	Honda Bay, Palawan and Batangas
Pulhin (2006)	Assess Vulnerability to climate variability and extremes	communities	Pantabangan–Carranglan Watershed
Predo (2010)	Adaptation to disasters (flooding and storm surge)	Communities and Households	Ormoc and Cabalian Bay
Reyes and Blanco (2012)	Assess coastal vulnerability to SLR	SLR	BOLINAO, PANGASINAN
Rodolfo and Siringan (2006)	Anthropogenic subsidence	Coastal area	Northern Manila Bay
Sales (2009); Sales (2008)	Adapt to climate variability and sea-level rise	CBA in coastal management	Cavite City
Samonte-Tan et al. (2007)	Economic Valuation	Coastal and Marine Resources	Bohol Marine Triangle
See et al. (2013)	Social Vulnerability of Urban Poor Households	Flooding	Metro Manila
Tatlonhari & Paris (2013)	Analyzing gendered adaptation strategies	Flooding events	Nueva, Ecija
Uy et al. (2011)	Micro-level enabling conditions for CCA	Coastal villages	Bacacay in the province of Albay
Zoleta-Nantes (2002)	DIFFERENTIAL IMPACTS	Different social groups	METRO MANILA

Table 2: Overview of case studies related to climate change impacts or adaptation in the Philippines.

6 Conclusion

The aim of the report is to give an overview of the existing literature for climate change impacts in the Philippines and to compile the corresponding publications.

In case of the **temperature**, the literature argues consistently for a significant increase in the past (Tangang et al., 2006; Cruz et al., 2007; Cinco et al., Chooprateep and McNeil, 2014). This warming trend will persist in the future, although with higher increasing rates. Future increases in heat extremes have been confirmed also for the past (Manton et al., 2001) and for the future (Sillmann et al., 2013).

For **precipitation**, it is fairly complex. A clear statement for the observed changes in precipitation is hard to state due to the heterogeneous precipitation patterns in the country and the different methods, analyzed data, time horizons and considered indicators of the various publications. One should consider that each of the statements given by the literature (Cruz et al., 2007; Lyon and Camargo, 2008; Endo et al., 2009; Yao et al., 2009; Endo and Matsumoto, 2010; Caesar et al., 2011; Cruz et al., 2012; Villafuerte et al., 2014) is relevant and correct under their specific assumptions. Mentioning the assumptions should allow for referring to each of them. Projections for precipitation are also challenging, which is reflected in differences that are present in the climate models. It is expected to have a slight increase in total precipitation. The IPCC (2014) stated that there is a medium confidence of a moderate increase in rainfall in SEA.

For the issue of **extreme precipitation**, literature is relatively homogenous. They all found for the past increasing trends – both for intensity and frequency (Ende et al., 2009; Yao et al., 2009; Chang, 2011; Cinco et al., 2014; Villafuerte et al., 2014). The importance of this type of precipitation for the whole water budget can be relatively high as for some time and regions the share of the total rain can reach up to 60% (Yao et al. (2009) (apart from the importance for hazard assessments).

Villafuerte et al. (2014) confirmed an extension of **dry periods** in the past. For future development in droughts, Taylor et al. (2012) and Sillmann et al. (2013) published an increasing drought risk for the future in the region.

Sea level rise will be greater in the region compared to the rest of the world (Perrette et al., 2013). This impact of climate change is related to the issue of **land subsidence** which itself strongly depends on natural or anthropogenic factors. **Groundwater extraction** is such a human influence that can further lead to saltwater intrusion into the freshwater storages.

For the major burden of the Philippines, **tropical cyclones,** the conclusions found in the literature are hard to generalize (similar to precipitation). The literature shows increasing intensity (Elsner et al., 2008; Webster et al., 2008; Knutson et al., 2010), but no significant trends in frequencies of the storm events (Chan and Xu, 2009; Kubota and Chan, 2009) for the past. Park et al. (2014) found different but insignificant trends for different data sets for the region. The future changes in TCs are well summarized in Knutson et al. (2010). The global average of intensity is increasing; simultaneously, we will see a decreasing frequency. Only for the most intense TCs a rising occurrence rate is assumed for the future (Sugi et al., 2009; Knutson et al., 2010; Held and Zhao, 2011; Murakami et al., 2012). Constrained by the dependency of the regional characteristics to SST distributions in the future, this is also assumed for the region of SEA (Sugi et al. (2009). We will further see an increase in storm centered rainfall (Emanuel et al., 2008; Knutson et al., 2010).

All in all, the importance of the **ENSO phenomenon** for the variability of TCs (Emanuel, 2007; Kubota and Chan, 2009) and precipitation (Jose and Cruz, 1999; Lyon et al., 2006; Yumul et al., 2008; Hilario et al., 2009; Jaranilla-Sanchez et al., 2011) is large. But according to IPCC, the confidence in projected changes for the future is low.

All the mentioned impacts of climate change represent a large burden for human livelihood and natural diversity in the country. Many are directly dependent on agriculture or aquaculture, sectors themselves strongly dependent on climatic conditions. For agriculture, many burdens are listed in the literature; droughts, saltwater intrusion, SLR, TCs, temperature increase (in particular nighttime), precipitation patterns, diseases, insects and land degradation. SLR and saltwater intrusion only play a minor role, as agriculture in the country does not take place in coastal areas (World Bank, 2013). For the other stressors, it is not possible to judge which one is the most important. This depends on the region and the present conditions, i.e. type and variety of crops, distance to flood prone areas, etc. Droughts have been shown to have a widespread impact on the country's food supply in the past. According to the literature, this could be more frequent in the future (Taylor et al., 2012; Sillmann et al., 2013; Villafuerte et al., 2014) and will also be amplified by population growth. As these burdens will impact agricultural yields that are already under the above-mentioned pressures, adequate adaptation measure should be taken. Famines can be buffered with the national or global market. Therefore, infrastructures and logistics have to be available. Another interesting argument in the literature is that people had already in the past shown their ability to deal with certain climate variability but, in combination with more stressors, this could be overextended (Fuentes and Conception, 2007; IPCC, 2014). They further argue for using this indigenous knowledge for future adaptation strategies.

As the country with the longest coastline in the world, the impacts related to the ocean are of particular interest (i.e. sea level rise, typhoons, floods, ocean acidification…). The past and future developments in these issues have been addressed, but their influence on certain sectors will depend more on the pure exposure. In that manner, most studies point out that the impacts of climate change are often strongly interrelated with human activities that lead to a worsening of the particular problem (e.g. human induced subsidence by groundwater extraction; Rudolfo and Siringan, 2006). Coral reefs provide a meaningful example here. De'ath et al. (2012) showed that the corals are obviously able to cope with a certain level of pressure from climate change, but only if additional pressure by human activities is omitted.

Independent of the future changes in cyclone activity, we have to assume a growth in the amount of damages as more and more people, assets and economic power is situated in exposed areas. Only adequate infrastructure and adaptation measures can lower their vulnerability (Dodman, 2009). In particular, the fast growing urban settlements have to tackle that problem. Climate-related burdens (i.e. UHI, SLR, floods…) can only be solved by meeting the challenges of the non-climatic stressors (high urbanization rate, migration, informal settlements, lack of important basic living standards…). Examining the relationship of climate and non-climate pressures reveals levers where adaptation activities could relieve the burden of climate change. For instance, providing access to clean water and adequate sanitation (under risk by storm activity and saltwater intrusion) strengthens people's coping capacity, in particular in the light of infectious diseases. Studies have attempted to reveal the relationship between occurrence rate and climatic conditions. Some found a relationship to temperature and/or precipitation for dengue (Su et al., 2008; Tseng et al., 2009; Hii et al., 2009), but other results seemed not to be consistent and significant. This can be traced back to non-climatic reasons being a large factor in the distribution of the illness (Khasnis and Nettleman, 2005), but also to the varying conditions in the country (particularly precipitation), which is often discussed as a factor.

The study could only supply a limited amount of knowledge about the spatial distribution of vulnerability to climate change. The most vulnerable areas are arguably the areas that are prone to droughts and whose inhabitants are strongly dependent on agricultural yields as food and income source. Above, we mentioned the reason why densely populated areas are strongly affected by climate change – so population density can be taken as a measure to localize vulnerable regions. If these regions are further situated at the coast – additional risks contribute to an even higher vulnerability. All the coastal areas where coral reefs and mangroves are still present should be seen as vulnerable and the same for the corresponding communities nearby. The possible disappearance of an ecotype seems to be of particular importance as reversal is almost impossible. A lot of detailed knowledge regarding the spatial distribution can potentially be found in the listed case studies of Table 2. The combination of the sector-wise vulnerability evaluation of this report and the spatial information of the case studies should be done in a follow-up report.

While compiling the literature on the impacts of climate change in the country, some research questions remain unanswered. For example, the impacts on mortality and morbidity due to changes in climate have to be analyzed in more detail with epidemiological studies.

This literature review was completed at the end of April 2017.

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