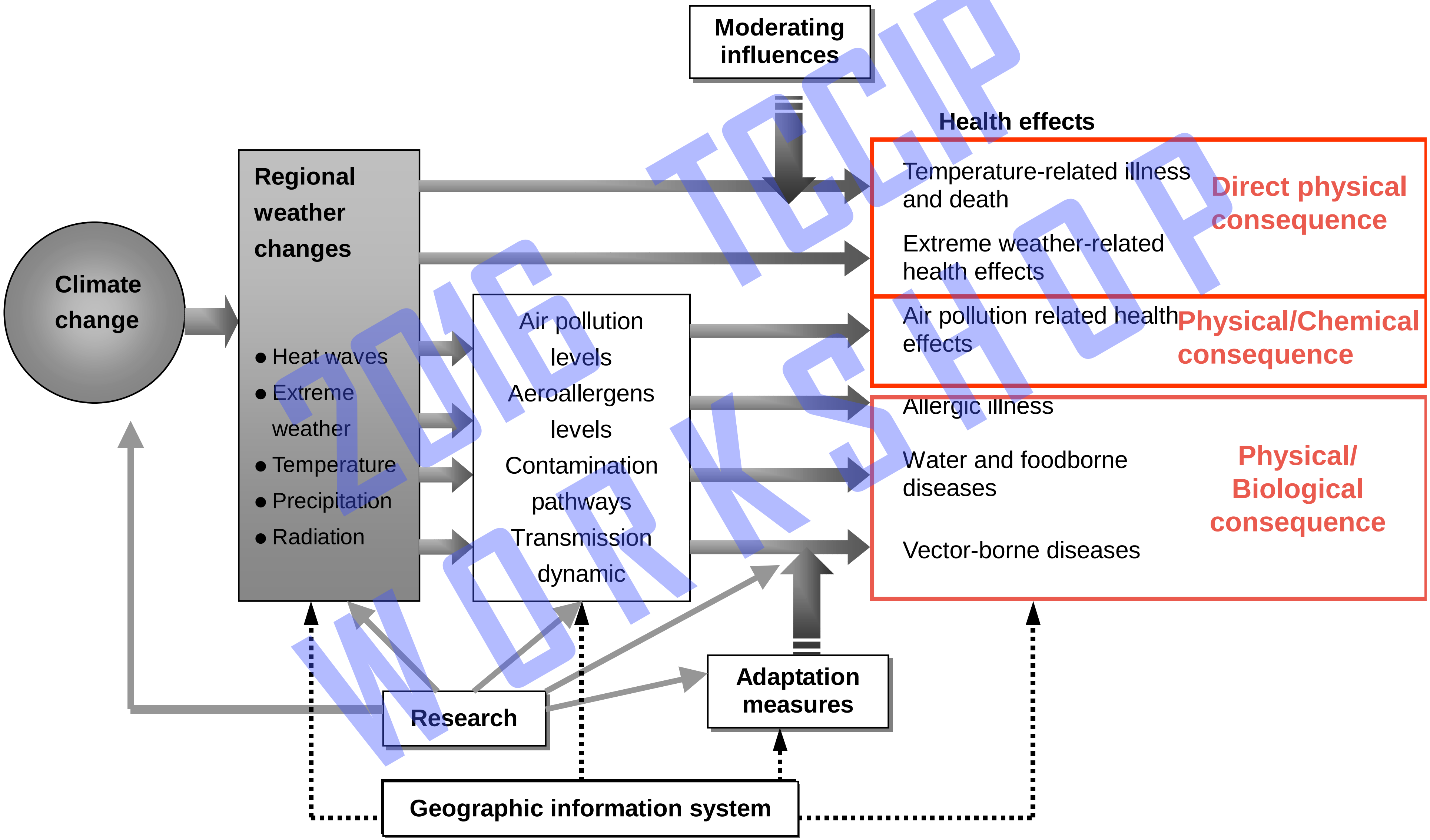
Evaluation of health impacts under climate change projection in Taiwan –

Dengue fever and heat related mortality

Pei-Chih Wu*, Chi-Yu Chuang

長榮大學職業安全與衛生學系
Dept. of Occupational Safety and Health,
Chang Jung Christian University, Taiwan

Associations between potential health effects and climate variability and changes



[Modified from Patz, 2002]

Projection- Risk of dengue fever epidemics and heat-related mortality

Historical models

- **Dengue fever — 1998~2006 (Wu et al. 2009)**
- **Heat-related mortality — 1994~2008 (Sung et al. 2013)**

Validation

Data updated

- Meteorological database (NCDR)— 1998-2013 (5km*5km)
- Dengue fever notification data (CDC) — 1998-2014 (Township)
- Mortality (Ministry of Health and Welfare)— 2010 (Township)
- Demographic and housing census (Ministry of Interior affairs) — 2010 (Township)

Projection IPCC AR5 RCP8.5
(2016-2035, 2046-2065, 2081-2100)

TCCIP (IPCC AR5)

The global distribution and burden of dengue

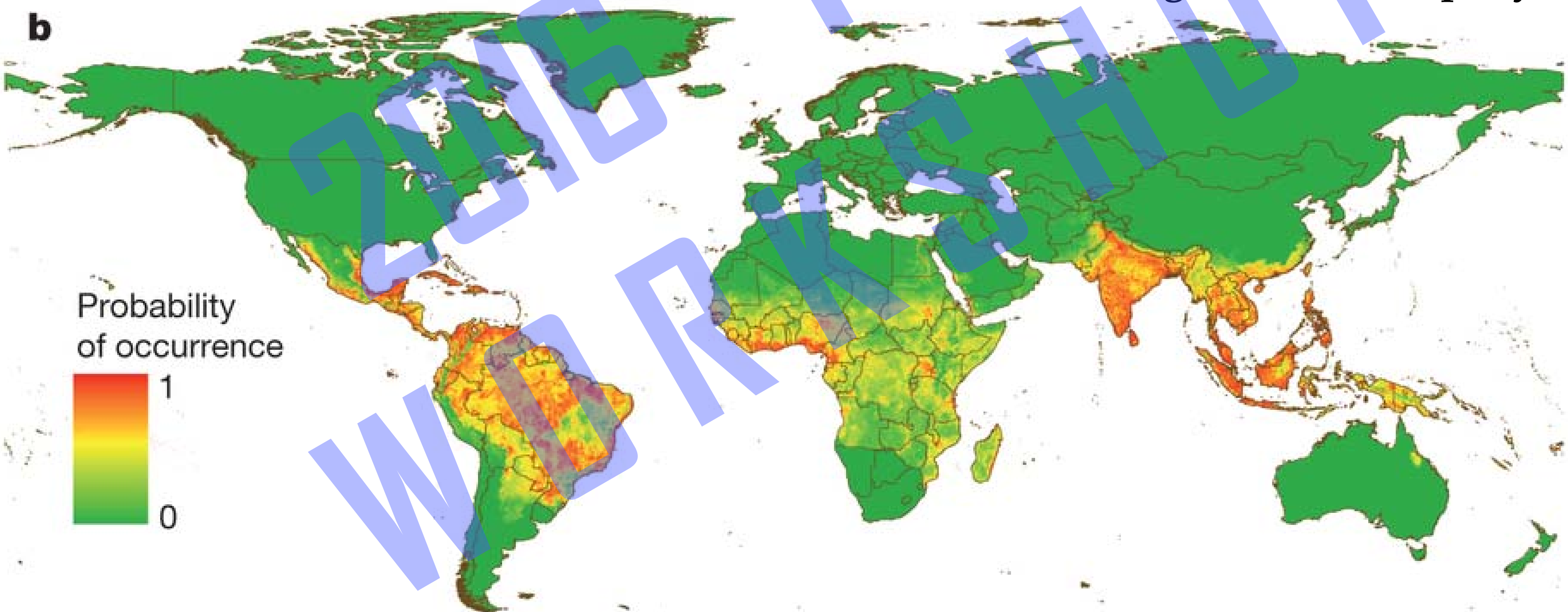
[Bhatt et al. 2013]
nature

Aedes aegypti

Aedes albopictus

We predict dengue to be ubiquitous throughout the tropics, with local spatial variations in risk influenced strongly by rainfall, temperature and the degree of urbanization.

Around 390 million dengue infections per year



Probability of dengue occurrence at 5 km × 5 km spatial resolution of the mean predicted map from 336 boosted regression tree models (2010)

The association between different climatic drivers and the global prevalence and geographic distribution of selected vector-borne diseases observed over the period 2008-2012

Disease	Area	Cases-yr	Climate Sensitivity and Confidence in Climate Effect	Key references
Mosquito-borne diseases				
Malaria	Mainly Africa, SE Asia	about 220 million	> +- 1 > +- 1 < - > +-	WHO 2008, Kelly-Hope et al 2009, Omumbo et al 2011, Alonso et al 2011
Dengue	100 countries esp Asia Pacific	about 50 million	> + > + < - < - > +-	Beebe 2009, Descloux 2012, Earnest et al 2012, Pham et al 2011, Astrom et al 2012
Tick-borne diseases				
Tick-borne encephalitis	Europe, Russian Fed Mongolia, China	about 10,000	> +	Tokarevich et al 2011
Lyme	Temperate areas of Europe, Asia, North America	about 20,000 in USA	> + > +	Bennet 2006, Ogden et al 2008
Other vector-borne diseases				
Hemorrhagic fever with renal syndrome (HFRS)	Global	0.15 – 0.2 million	> + > + > +	Fang et al 2010
Plague	Endemic in many locations worldwide	about 40,000	> + > +	Stenseth et al 2006, Xu et al 2011, Ari et al 2010

Climate drivers

Temperature Precipitation Humidity

Climate driver variables

Increase or decrease: > Increased < Decreased

# of cases: + More - Fewer

Footnote: 1 Effects are specific to Anopheles spp

Confidence levels

High confidence in global effect

High confidence in local effect

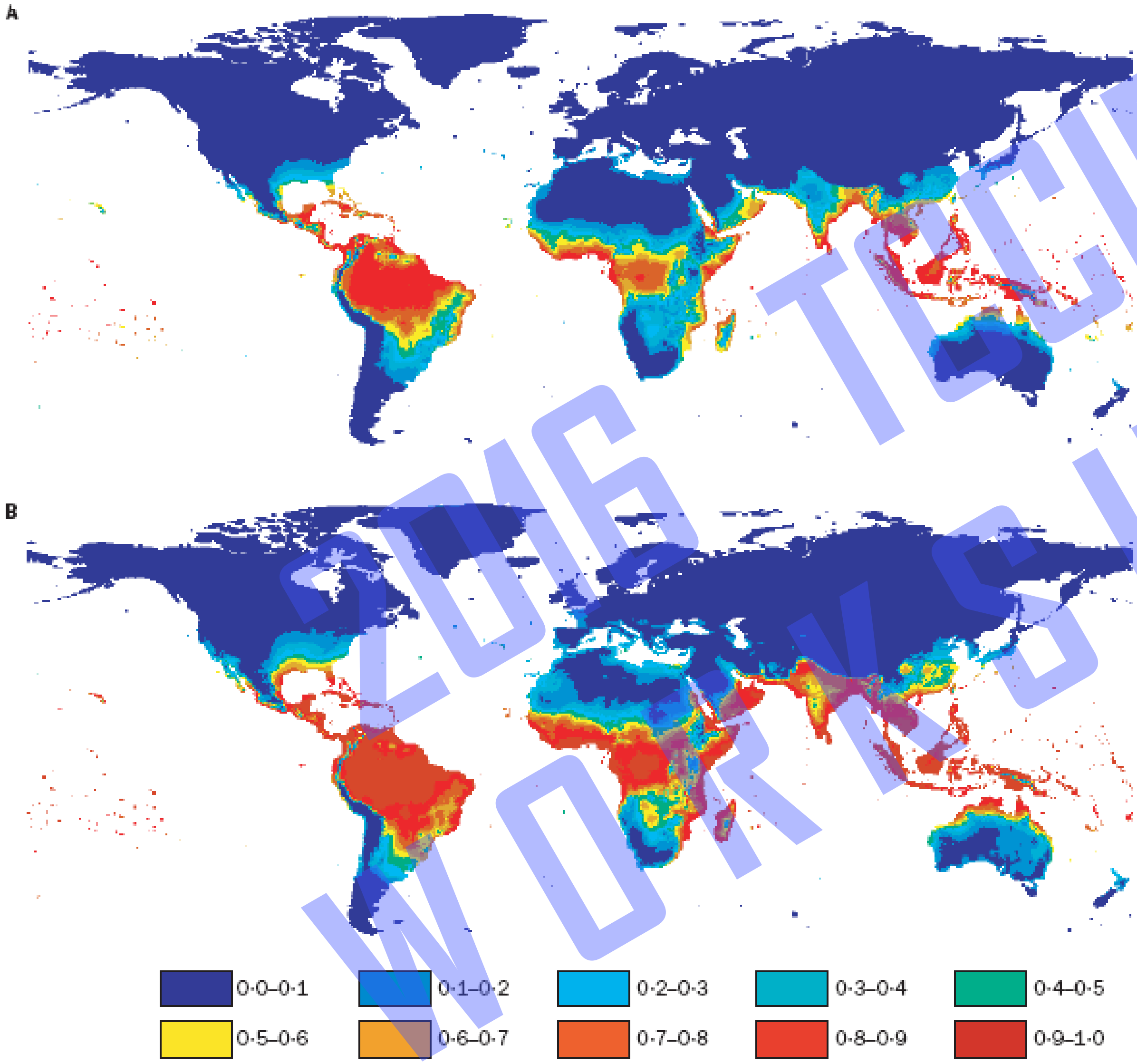
Low confidence in effect

[IPCC AR5, 2013]

Research scheme for infectious diseases

	Long-term pattern	**Effects of extreme weather**
Size of epidemic in endemic areas	✓ Time-series analysis (ARIMA) or Poisson regression	✓ Relative risk during event period (Relative Risk; RR)
The geographic distribution of infectious diseases	✓ spatial regression model	✓ spatial regression model
Outbreak and the region have potential for disease outbreak		✓ temporal-spatial cluster analysis
Socioeconomic factors and regional vulnerability	✓ PCA spatial regression model	✓ PCA spatial regression model

Estimated baseline population at risk in 1990 (A) and estimated population at risk in 2085 (B)

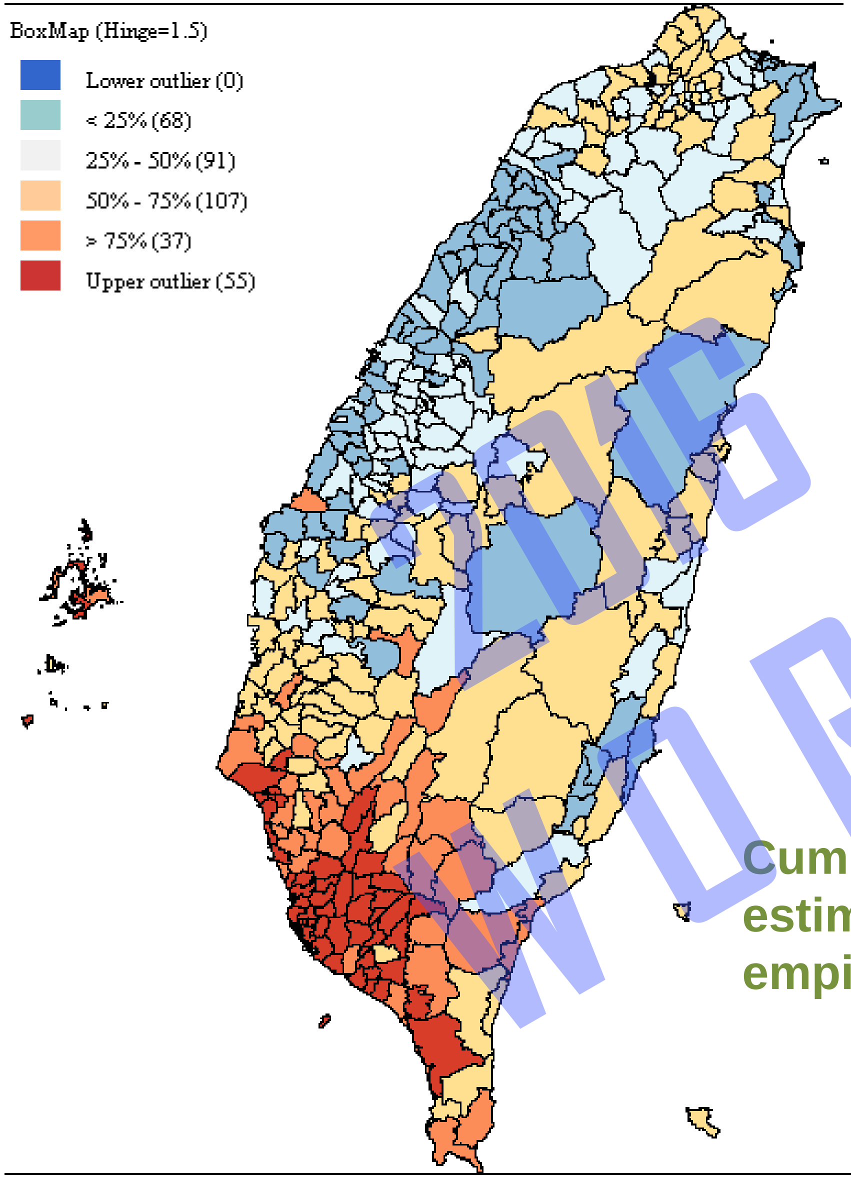


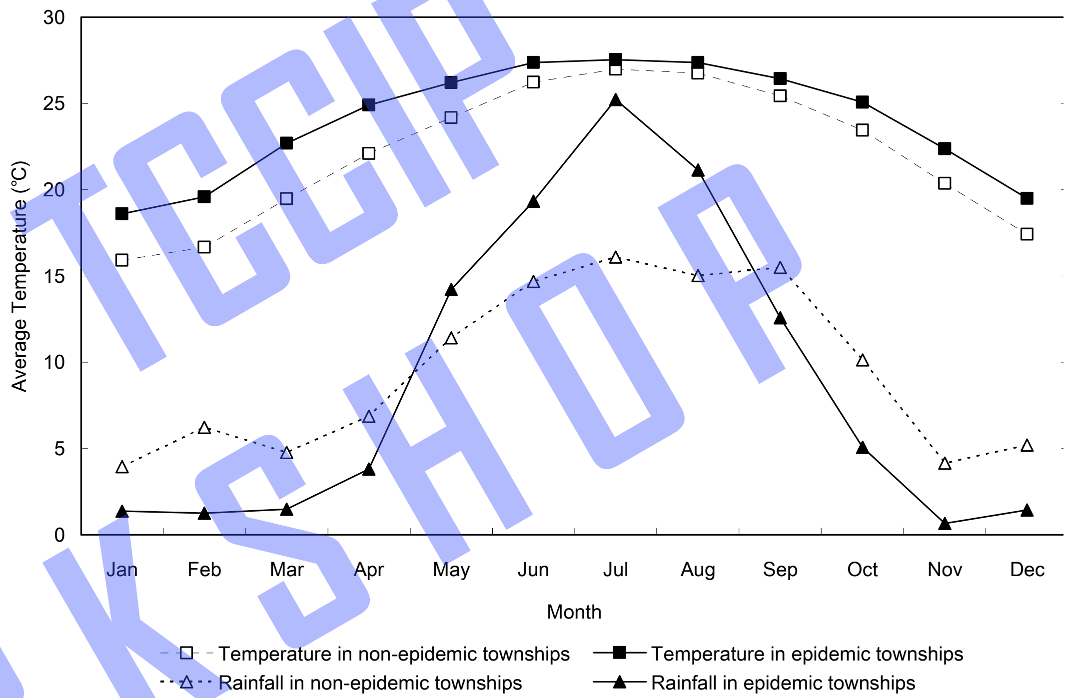
Results of a logistic regression model with vapour pressure (humidity) as the predictor of dengue fever risk, using climate data from 1961 to 1990 (A).

Forecast geographical distribution of dengue transmission based on climate projections for 2080–2100 from a global circulation model (CCGCMA2) (B).

[Hales, 2002]

Higher temperature and urbanization affect the spatial patterns of dengue fever transmission in subtropical Taiwan





Cumulative incidence during 1998-2002 estimated by estimated by using spatial empirical Bayes smoothing method

[Science of total Environment, 2009]

Factors loading and percentage of variance explained

Components	Variance explained	Loading
PCA 1: Urbanization	35.782%	
Average population density (person/km2)		0.840
Service industry (1/10000)		0.841
Agriculture industry (1/10000)		-0.625
House ownership (1/10000)		-0.741
Numbers of clinics		0.846
Median of income		0.722
PCA2: Elder population	24.189%	
Elders living alone (1/10000)		0.906
Elders (1/10000)		0.845
Disability (1/10000)		0.584
Over crowed in residence		0-.744
PCA3: Aborigine	14.119%	
Aborigine		0.920
Sum of variance explained	74.090%	

Examining the spatial relationships among dengue occurrence during 1998 to 2002, climatic, environmental, socioeconomic and demographic factors by using spatial regression

	Cumulative incidence from 1998 to 2002[a]	
Coefficients	Ordinary Least Squares (OLS) **R^2=0.151**	Spatial lag model **R^2=0.446**
Imported incidence from 1998 to 2002	0.091	-0.248
The household vectors recovery rate	0.111	0.073
Annual rainfall	-0.073	-0.055
Annual numbers of months with average temperature higher than 18 °C	9.373**	2.807**
Factor 1: Urbanization	15.798**	8.590**
Factor 2: Elder population	-0.373	0.287
Factor 3: Aborigine population	5.772	4.503
Constants	-69.709**	-17.176
Rho	--	0.870**
Moran's I value of residues	0.3088	-0.0487

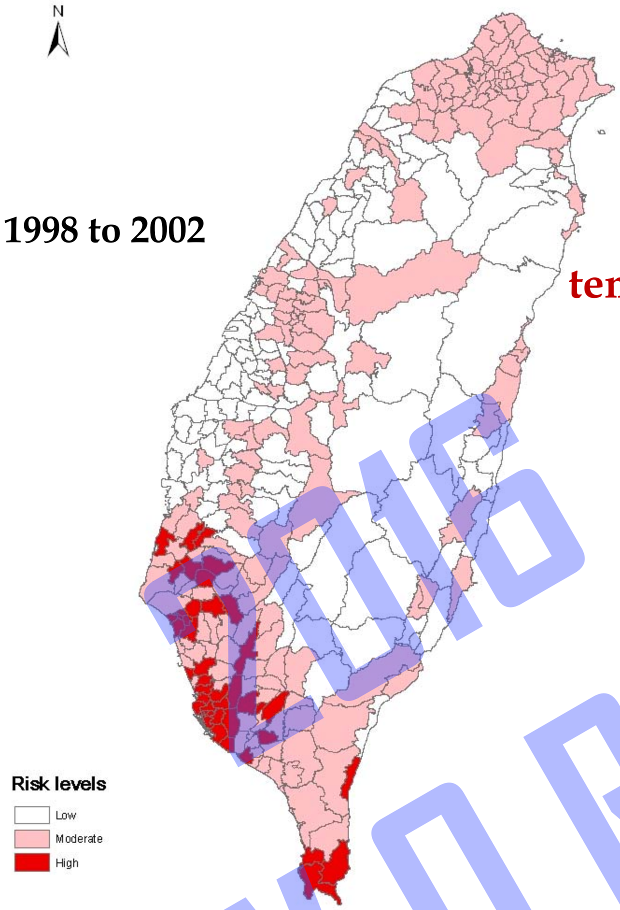
****p<0.05**

[Science of total Environment, 2009]

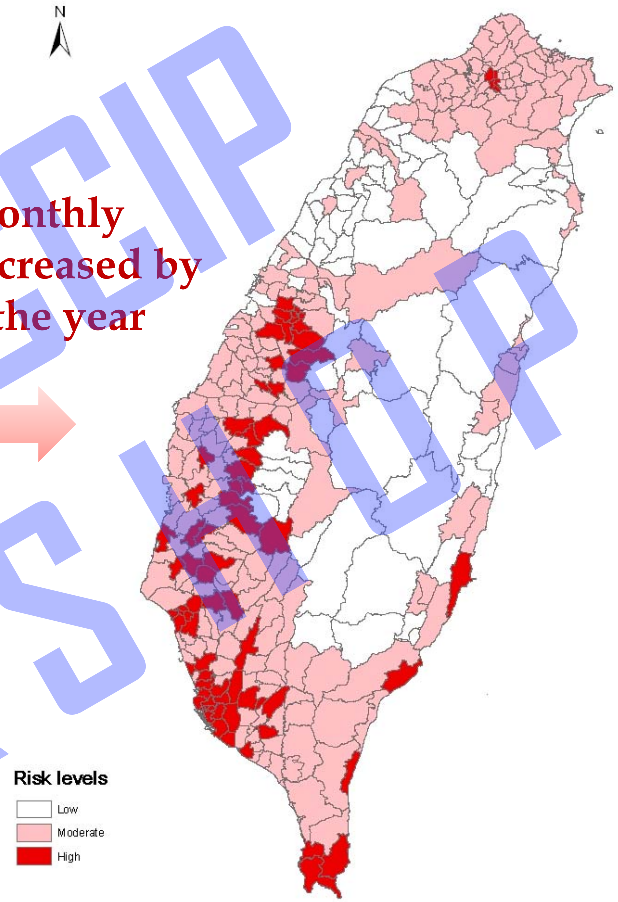
[Wu et al., 2009]

Risk map of dengue fever transmission

1998 to 2002



Average monthly temperature increased by 1 ˚C across the year



48 high risk areas

86 high risk areas

<u>Vulnerable indicators:</u>

- Higher numbers of warmer months (>18 ˚C)
- Higher urbanization

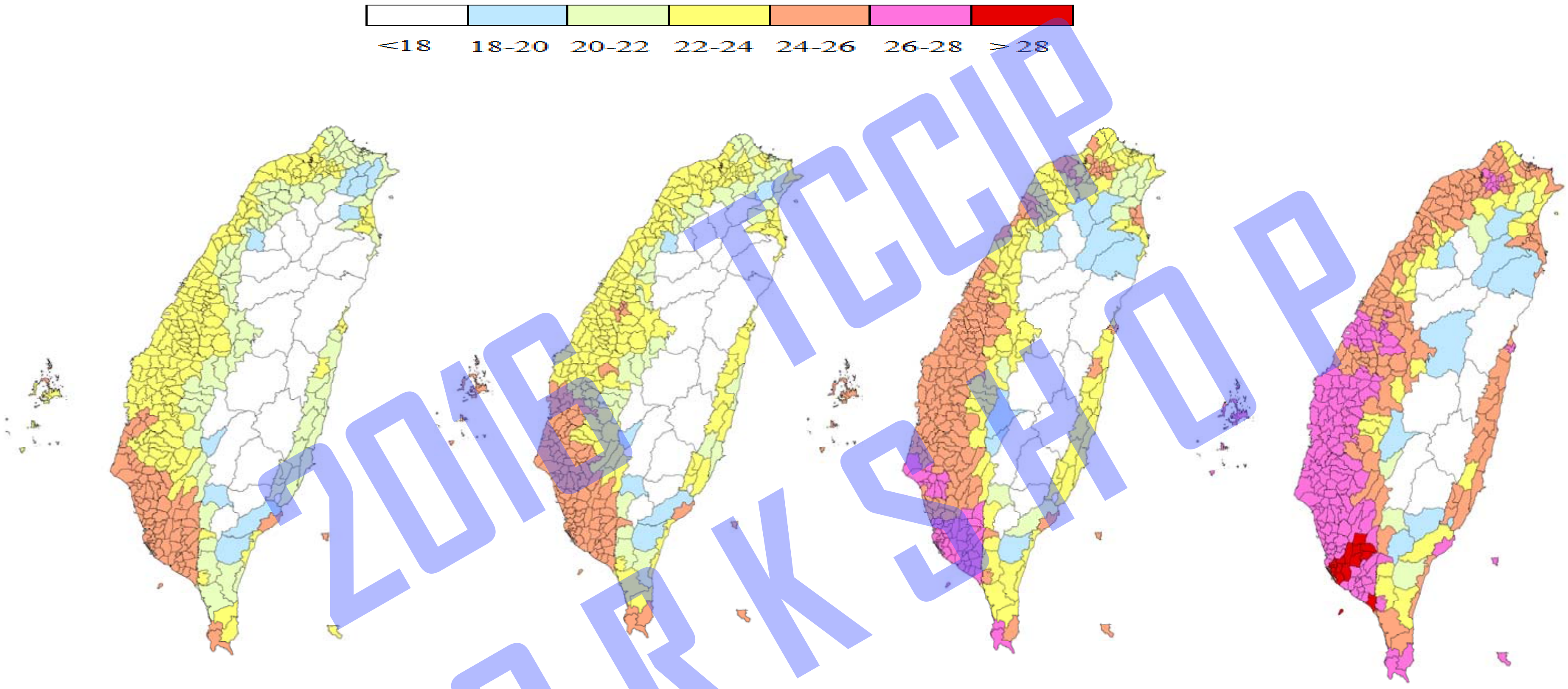
Examining the spatial relationships among cumulative incidence from 1998 to 2002 and 2003 to 2013, climatic, environmental, socioeconomic and demographic factors by using spatial regression

	Cumulative incidence from 1998 to 2002	Cumulative incidence from 2003 to 2013	Average incidence from 2003 to 2013
Coefficients	Spatial lag model R^2=0.446	Spatial lag model R^2=0.438	Spatial lag model R^2=0.438
Imported incidence	-0.248	0.2319	0.2319
The household vectors recovery rate (% of BI>1)	0.073	0.3263	0.0297
Annual rainfall	-0.055	-0.1609	-0.0146
Annual numbers of months with average temperature higher than 18 ºc	2.807**	6.8211***	0.6200***
Factor 1: Urbanization	8.590**	14.5283***	1.3208***
Factor 2: Elder population	0.287	1.4071	0.1279
Factor 3: Aborigine population	4.503	9.1730**	0.8339**
Constants	-17.176	-46.0041	-4.1822
Rho	0.870	0.5666	0.5666

** p<0.05 ***p<0.01

Annual temperature

[TCCIP, 2015]



Baseline
2003-2013

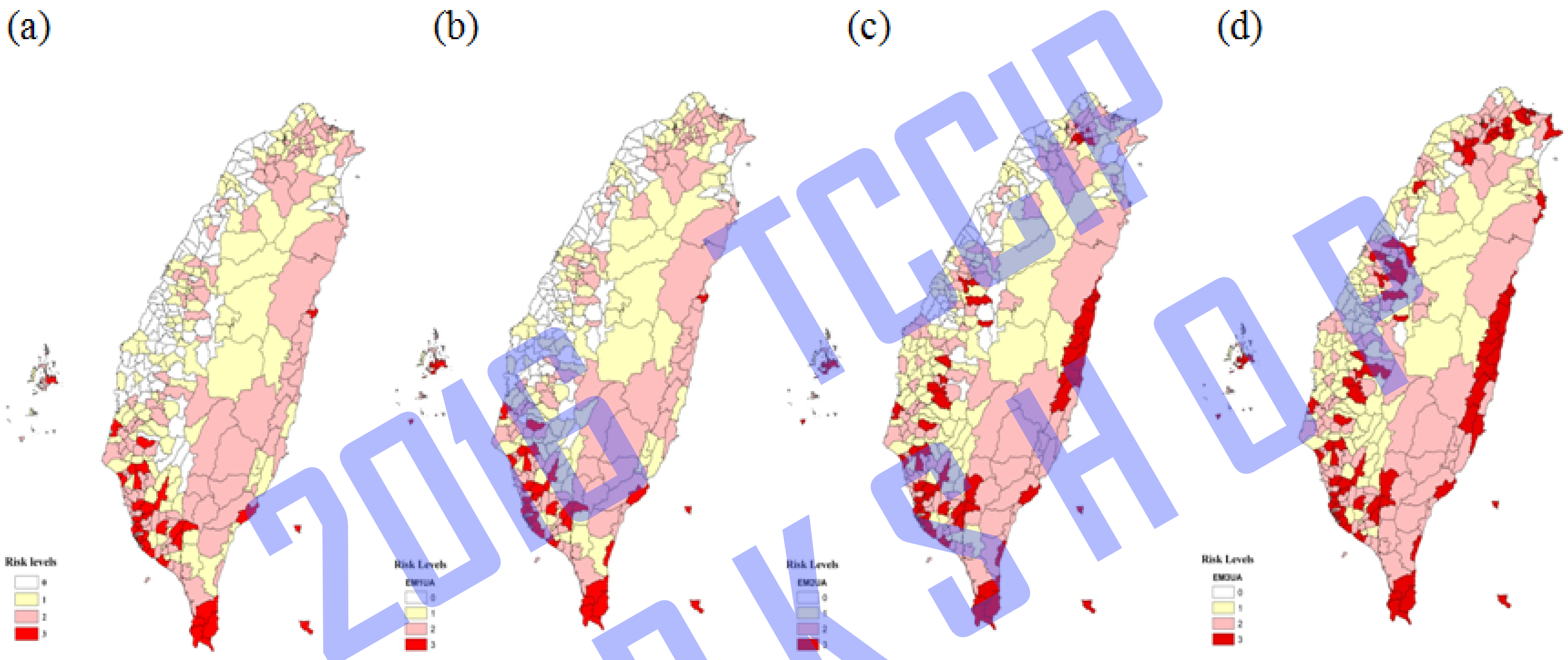
AR5 RCP8.5
2016-2035

AR5 RCP8.5
2046-2065

AR5 RCP8.5
2081-2100

Risk map of dengue fever transmission

[TCCIP, 2015]



Baseline 2003-2013

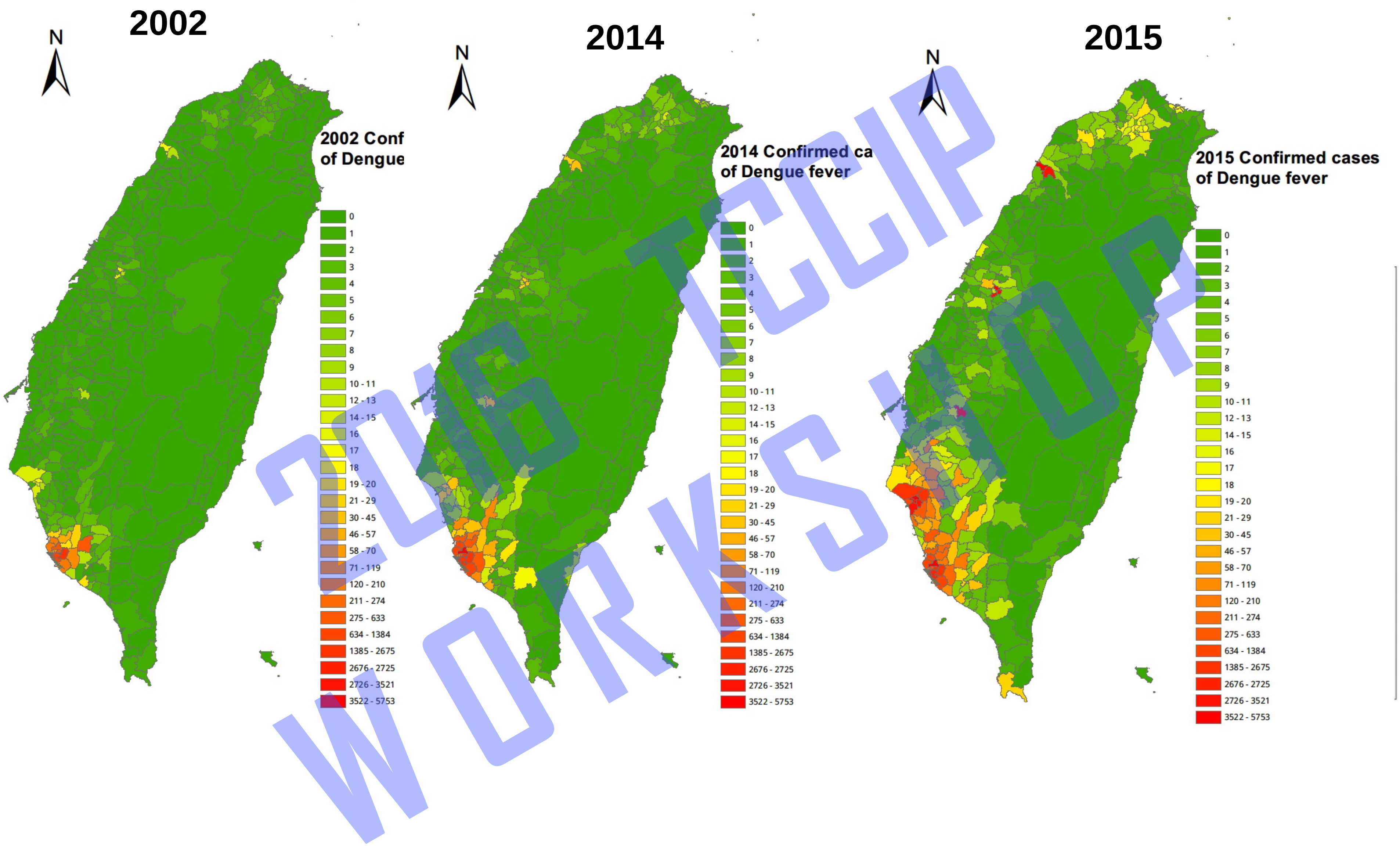
AR5 RCP8.5 2016-2035

AR5 RCP8.5 2046-2065

AR5 RCP8.5 2081-2100

Risk level	Baseline 2003-2013	AR5 RCP8.5 2016-2035	AR5 RCP8.5 2046-2065	AR5 RCP8.5 2081-2100
High	35	38	63	91
Medium	122	122	135	136

Epidemic of dengue fever in Taiwan



Climate change and Dengue fever epidemics in Taiwan

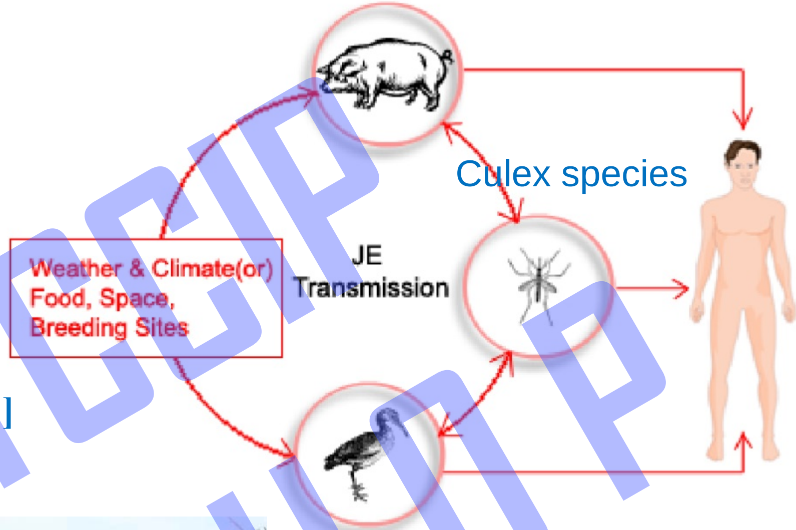
- Numbers of warmer months, higher urbanization, and higher indigenous population were found to be the determinant risk factors for dengue fever epidemics at township level.
- The risk of temperature threshold could adapt to predicting future impacts of global warming on vulnerable population distribution for dengue fever transmission in Taiwan.
- Preliminary estimation showed that trend of island-wide warming in the future would likely cause large-scale geographical expansion for areas at risk for dengue fever outbreak in Taiwan.
- This model and risk map could facilitate prioritize the regions of disease control program now and in the future under climate change threaten.

How about other vector-borne diseases in Taiwan?

Japanese encephalitis

- Early onset of peak and more cases with higher annual temperature

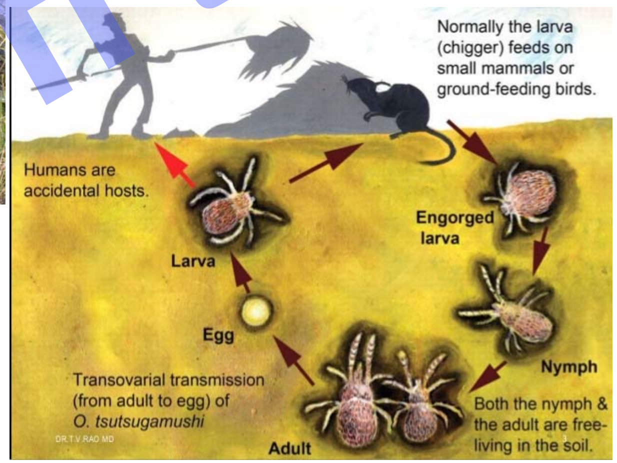
[Su et al., 2006, NSC95-EPA-Z-006-001]



Scrub typhus

- Spring temperature and rainfall tend to associated with increasing cases

[Su et al., 2006, NSC95-EPA-Z-006-001]

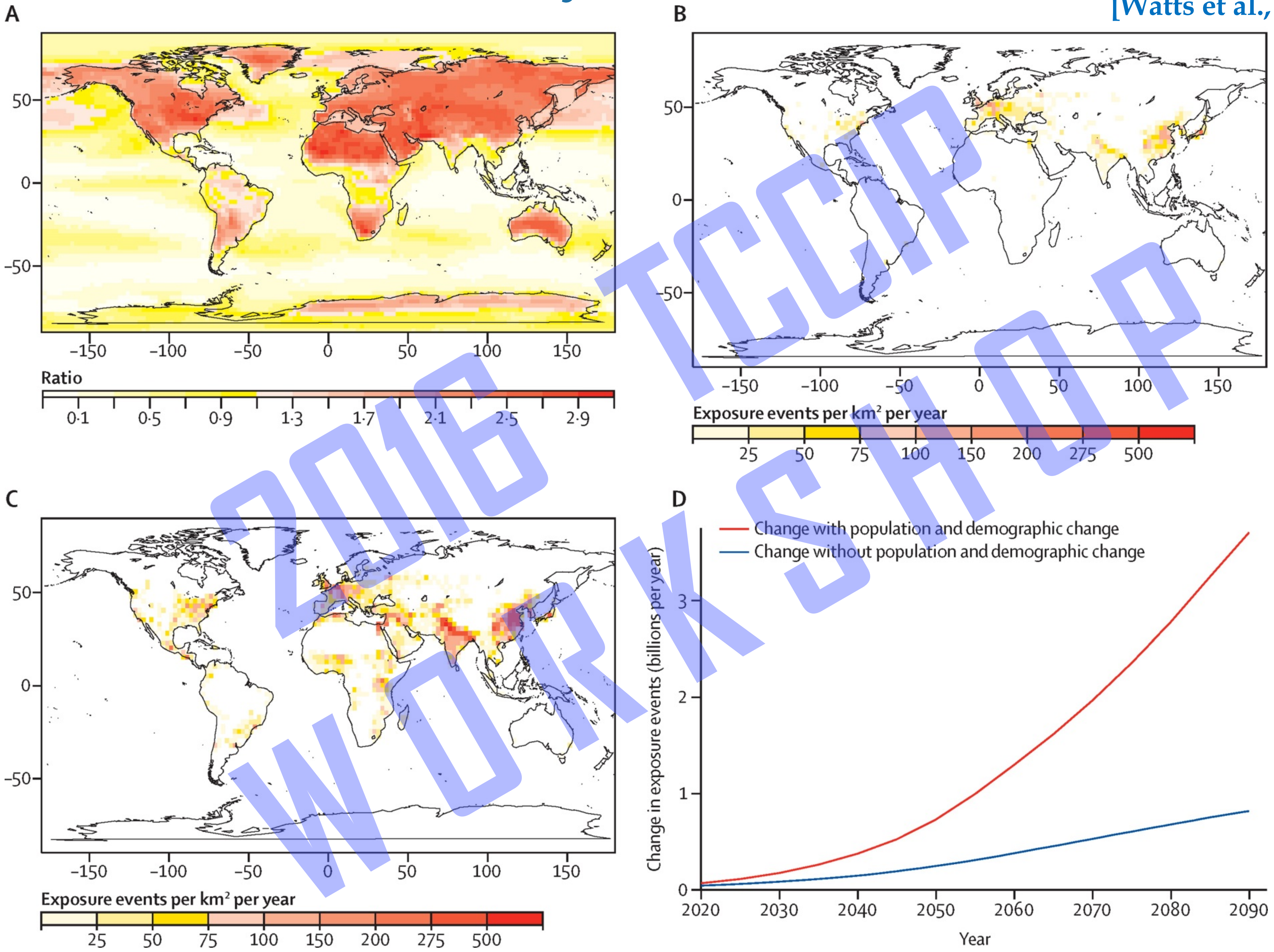


Emerging diseases?

- Chikungunya
- Zika virus infection
- ….

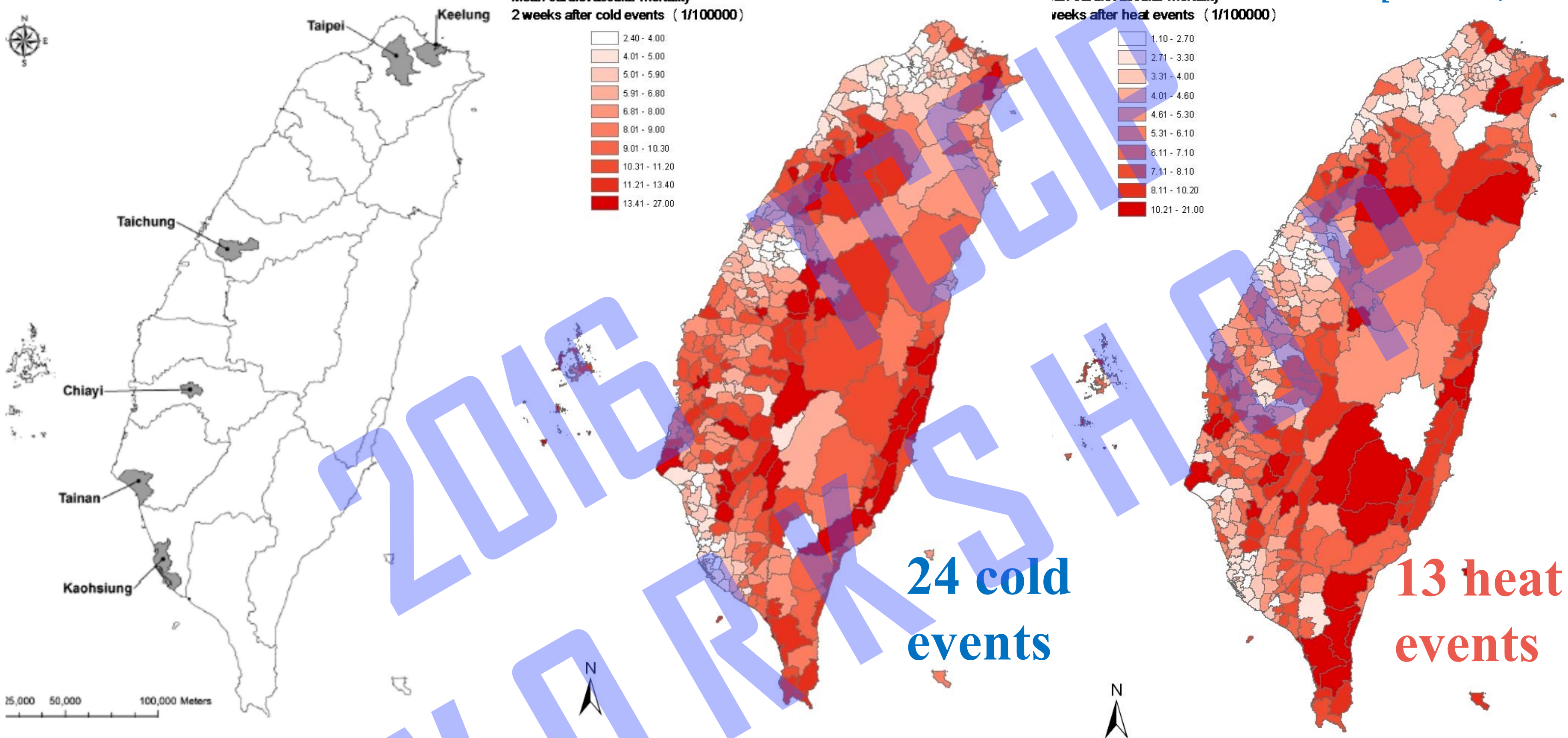
More Intense Hot Days and Heat Waves

[Watts et al., 2015]



Cardiovascular mortality 2 weeks after cold and heat events

[Wu et al., 2010]

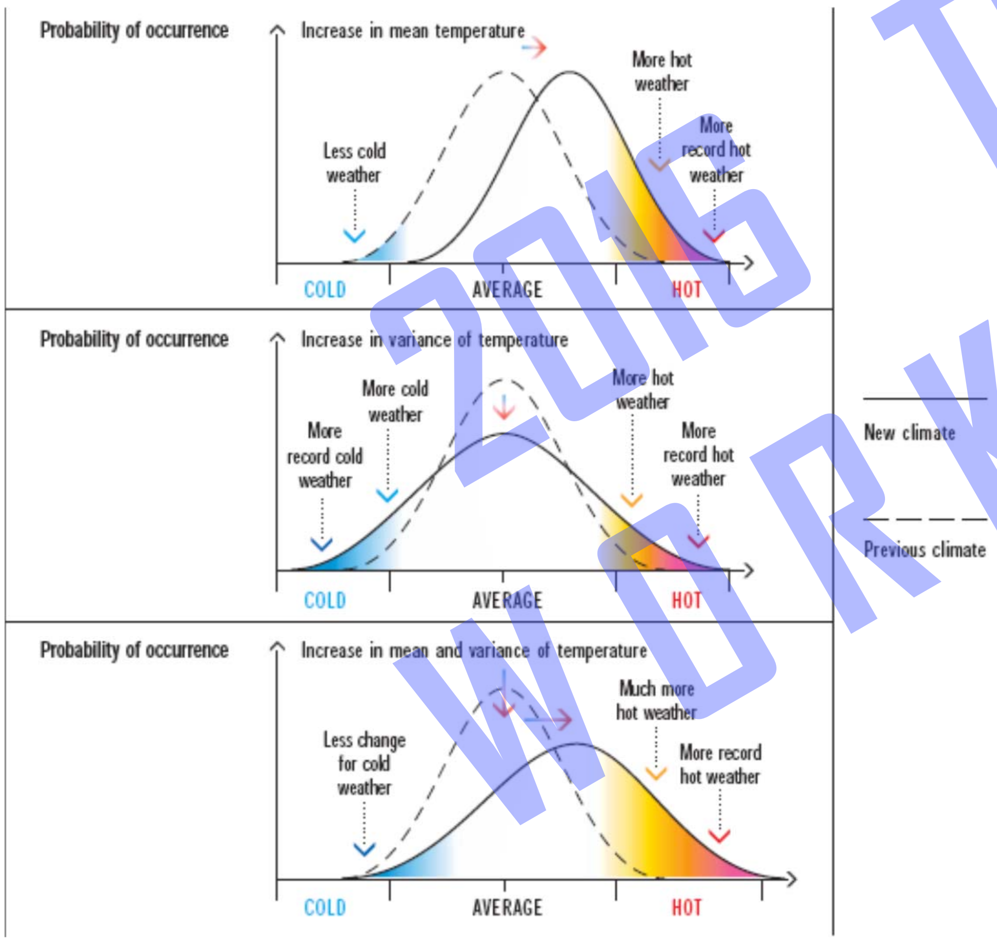


<u>Vulnerable indicators:</u>

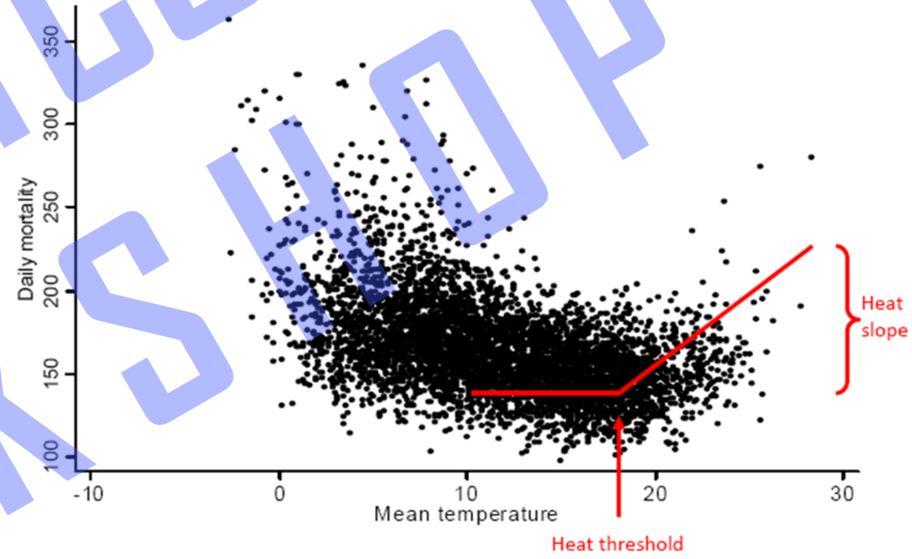
- Higher baseline of mortality
- Lower medical resources and urbanization
- Higher Susceptible population (elders, elders living alone, disability)
- Higher indigenous population

Identify the "heat threshold" in different region

WHO 2003-「Method of assessing human health vulnerability and public health adaptation to climate change」

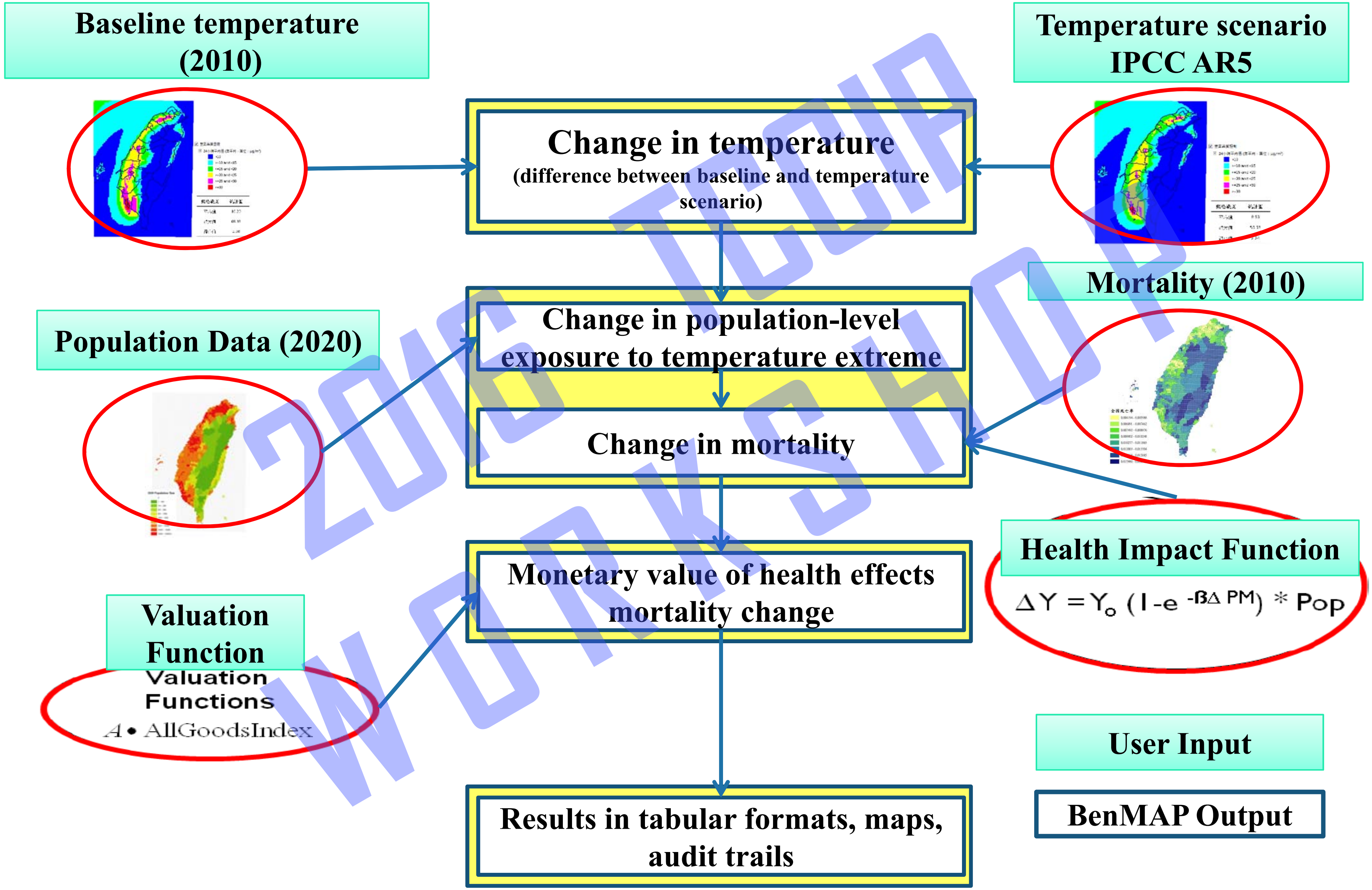


Daily mortality in London: 1993-2006



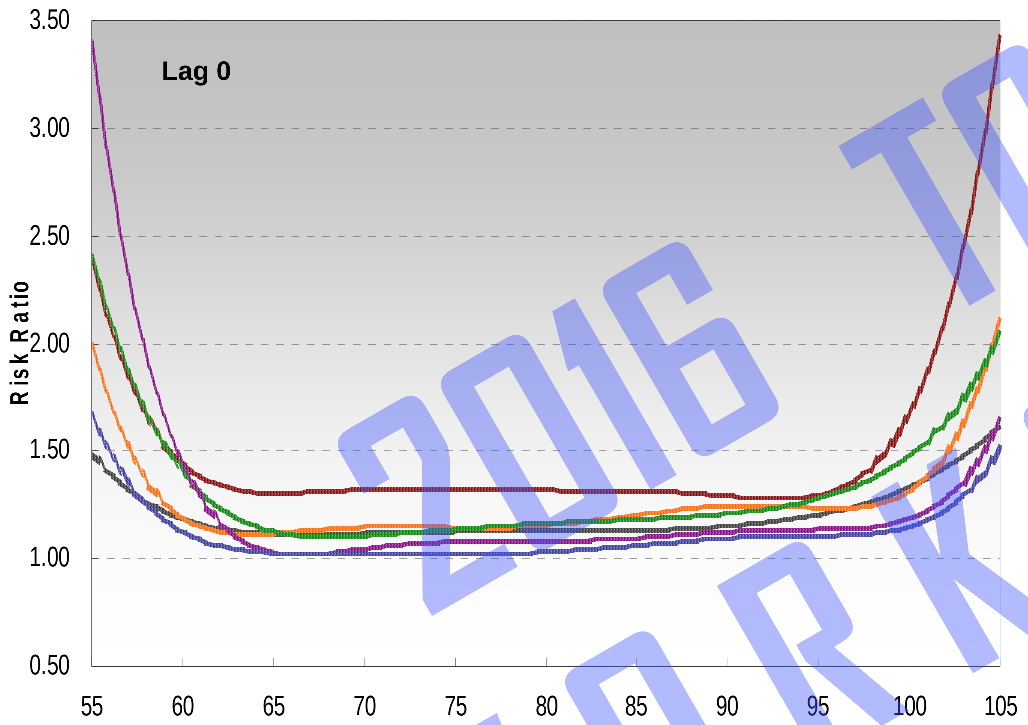
Benefits Mapping and Analysis Program (BenMAP)

行政院環境保護署
Environmental Protection Administration
Executive Yuan,R.O.C(Taiwan)



Relationship between heat index and mortality of 6 major cities in Taiwan

Threshold effects of heat index were apparently at 95-100˚F (35-38˚C)in six major cities



$$\begin{aligned}\mathrm{HI}\ (^\circ\mathrm{F}) = & -42.379 + 2.04901523\,T + 10.14333127R \\ & -0.22475541TRH - 6.83783 \times 10^{-3}\,T^2 \\ & -5.481717 \times 10^{-2}RH^2 + 1.22874 \times 10^{-3}\,T^2RH \\ & +8.5282 \times 10^{-4}TRH^2 - 1.99 \times 10^{-6}\,T^2 \times RH^2\end{aligned}$$

[Sung et al., 2013]

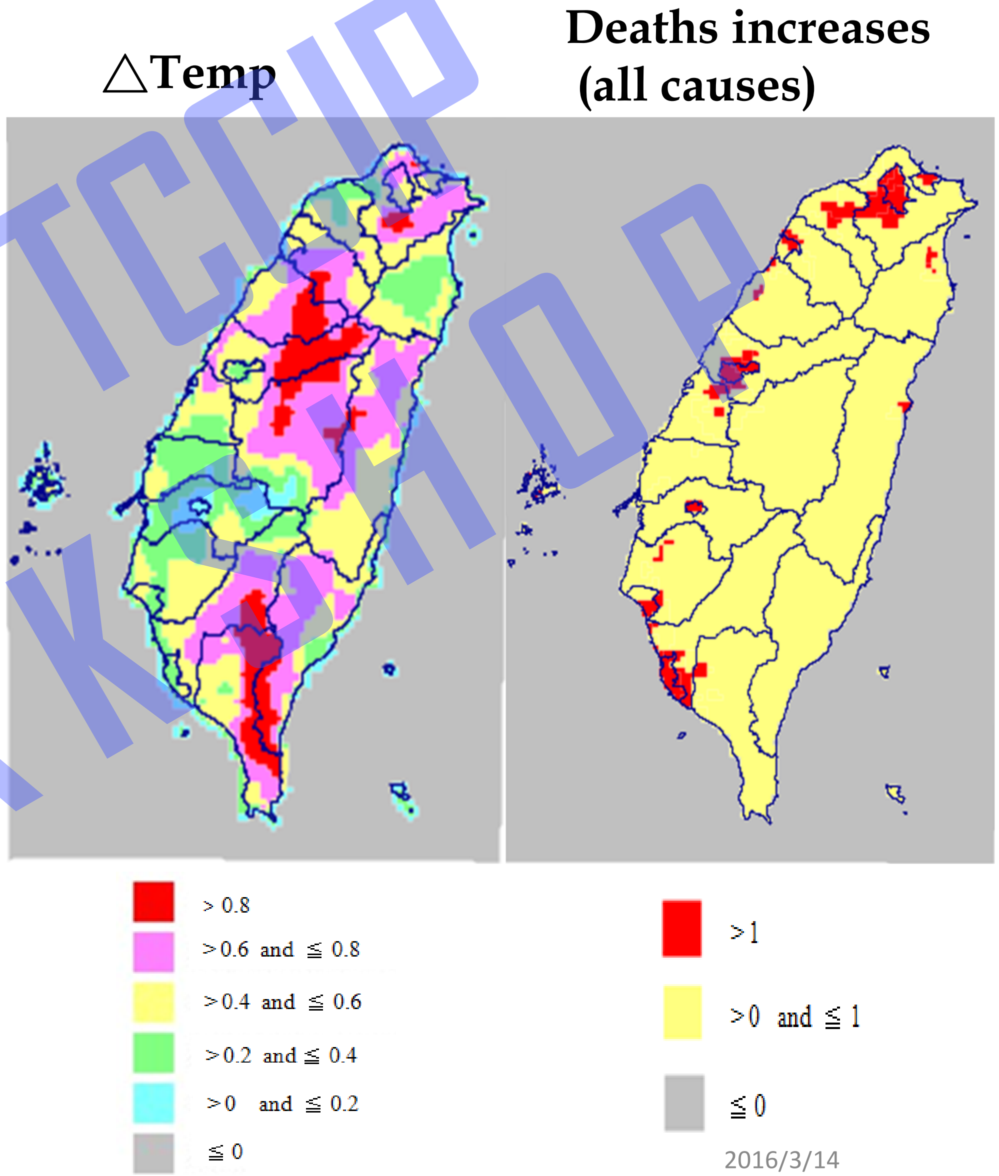
Warming and mortality projection (AR5)

[TCCIP, 2015]

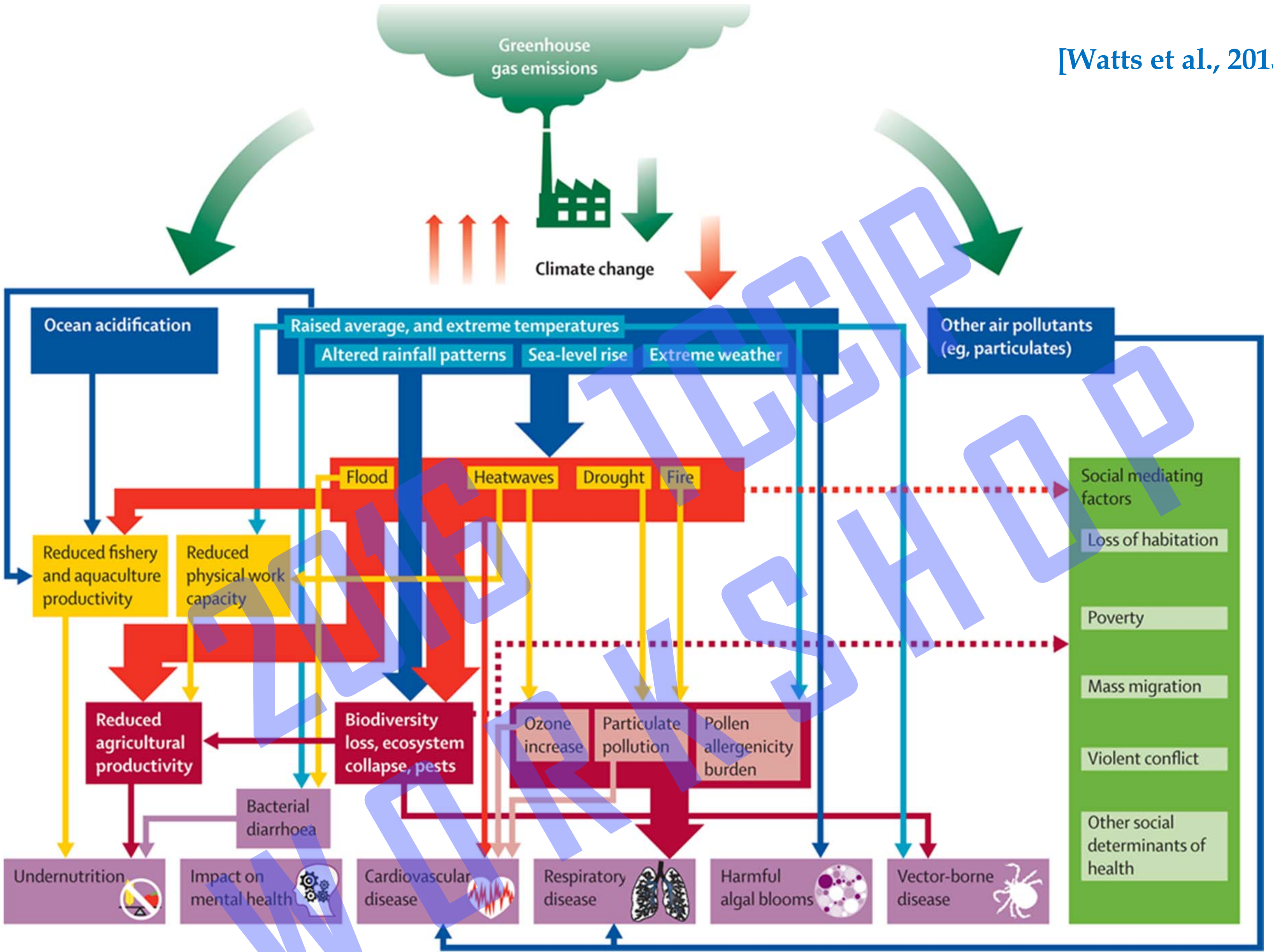
Township	Temperature	Relative Risk(RR)	RR (95% C.I.)
Keelung	34.8 ℃	1.01	(0.93, 1.09)
Taipei	36 ℃	1.11	(1.07, 1.14)
Taichung	34.5 ℃	1.11	(1.05, 1.19)
Chiayi	35 ℃	1.21	(1.09, 1.34)
Tainan	36.8 ℃	1.14	(1.07, 1.21)
Kaohsiung	36.5 ℃	1.14	(1.08, 1.20)

[Sung et al., 2013]

IPCC AR5 RCP8.5 (2016-2035)



[Watts et al., 2015]



➲ **Climate change is the biggest global health threat of the 21th century.** [Costello et al. Lancet 2009; 373: 1693–733]

Climate change is not a new threat to human health

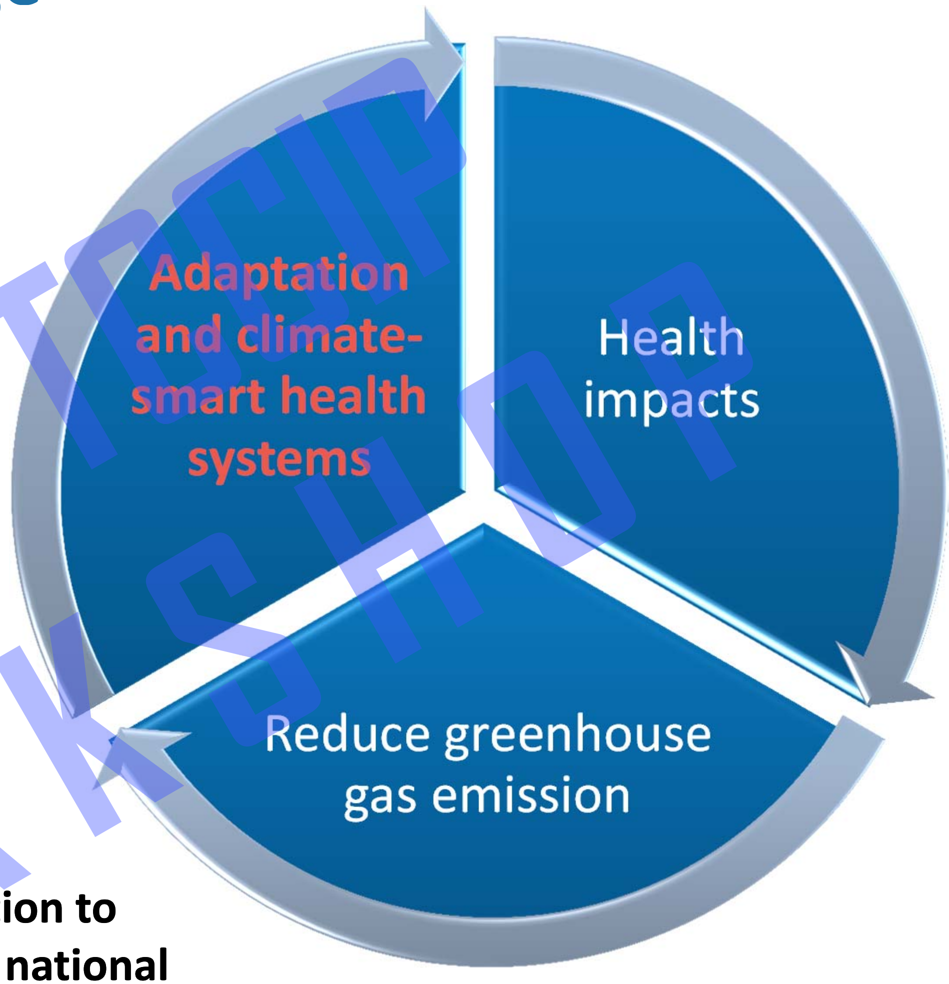
~ Climate change will amplify existing hazards, deficits, and inequities, jeopardizing the already low status of population health and well-being of disadvantaged population ~

~ It is important to identify those populations most at risk of adverse effects from climate changes, to reduce their vulnerability~

[McMichael, 2004]

Health professional have a vital part to play in tackling climate change

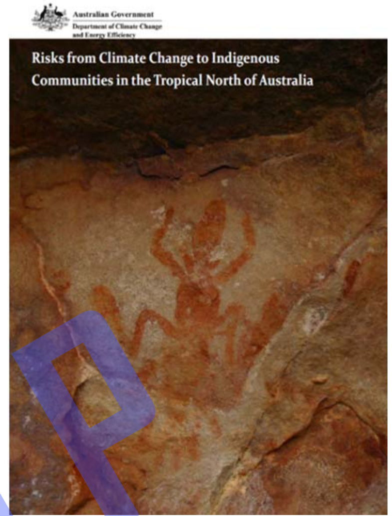
- Poverty reduction and reductions in inequities
- Vulnerability and exposure reduction in high-risk populations
- Food security in poor countries
- Communication of climate risks and community engagement for local solutions
- Development of climate resilient, low-carbon health systems



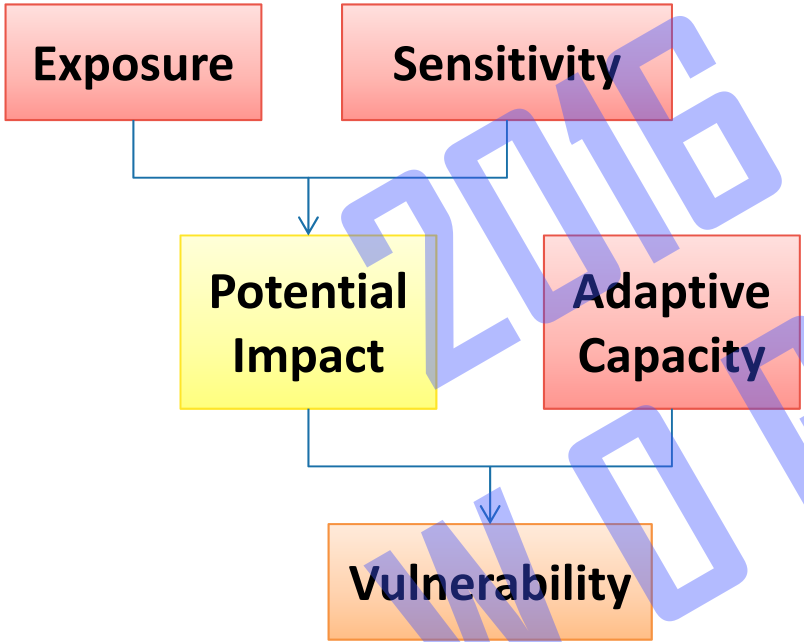
Strengthening the health sector's contribution to decision making across sectors at local and national levels adaptations.

International multidisciplinary approach
Think globally, Act locally

Health Impacts of Climate Change on Vulnerable Populations: Indigenous Peoples



- Certain people and communities are especially vulnerable, including children, the elderly, the sick, the poor, and some communities of color (Melillo et al., 2014)



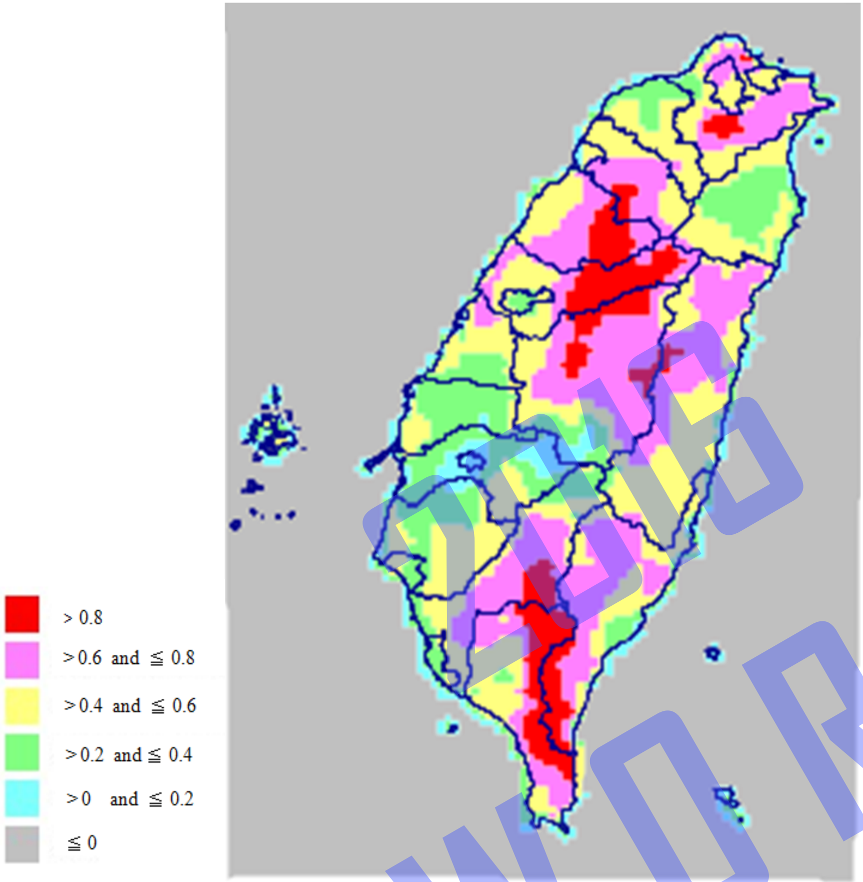
Model of vulnerability and its components
(Allen Consulting Group, 2005)

Determine vulnerability of indigenous health systems
1. Poverty
2. Limited technological capacity
3. Socio-political values and inequality
4. Constrained institutional capacity
5. Information deficit

(Ford et al., 2010)

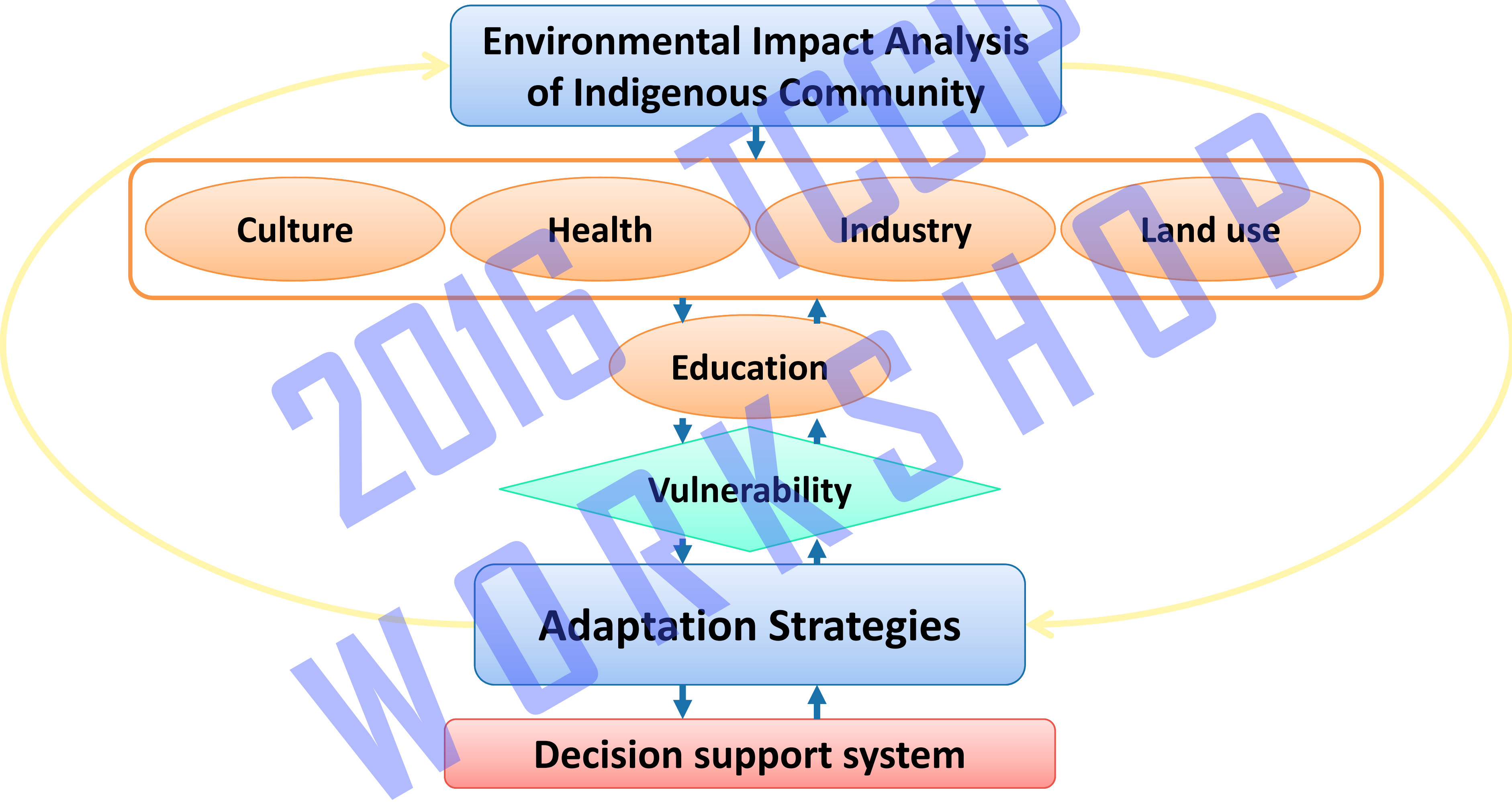
Indigenous peoples in Taiwan

2% of total population in Taiwan



IPCC AR 5 RCP8.5 (2016-2035) from TCCIP

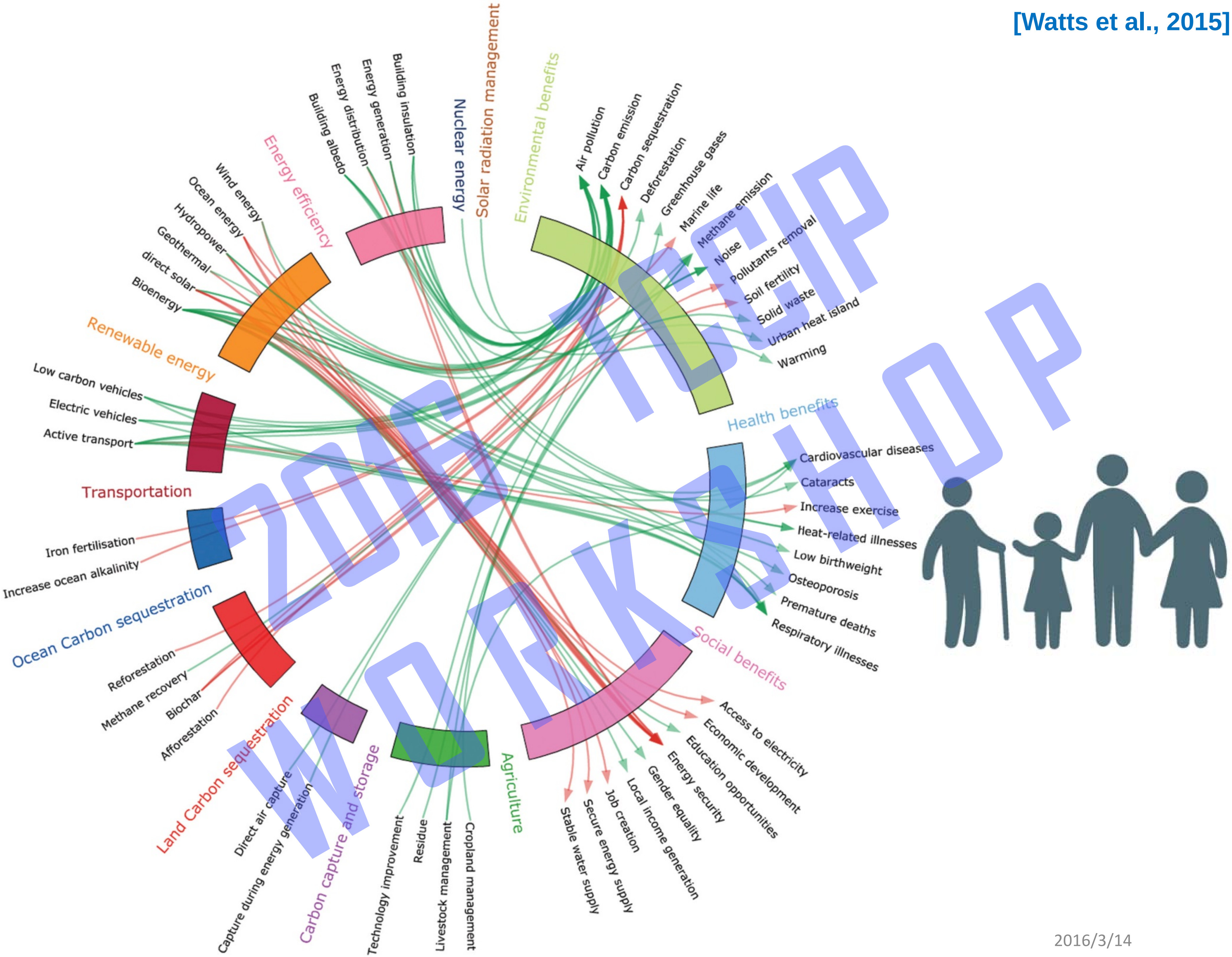
Climate Change and Health Impact and Adaptation Strategies for Indigenous Community in Southern Taiwan

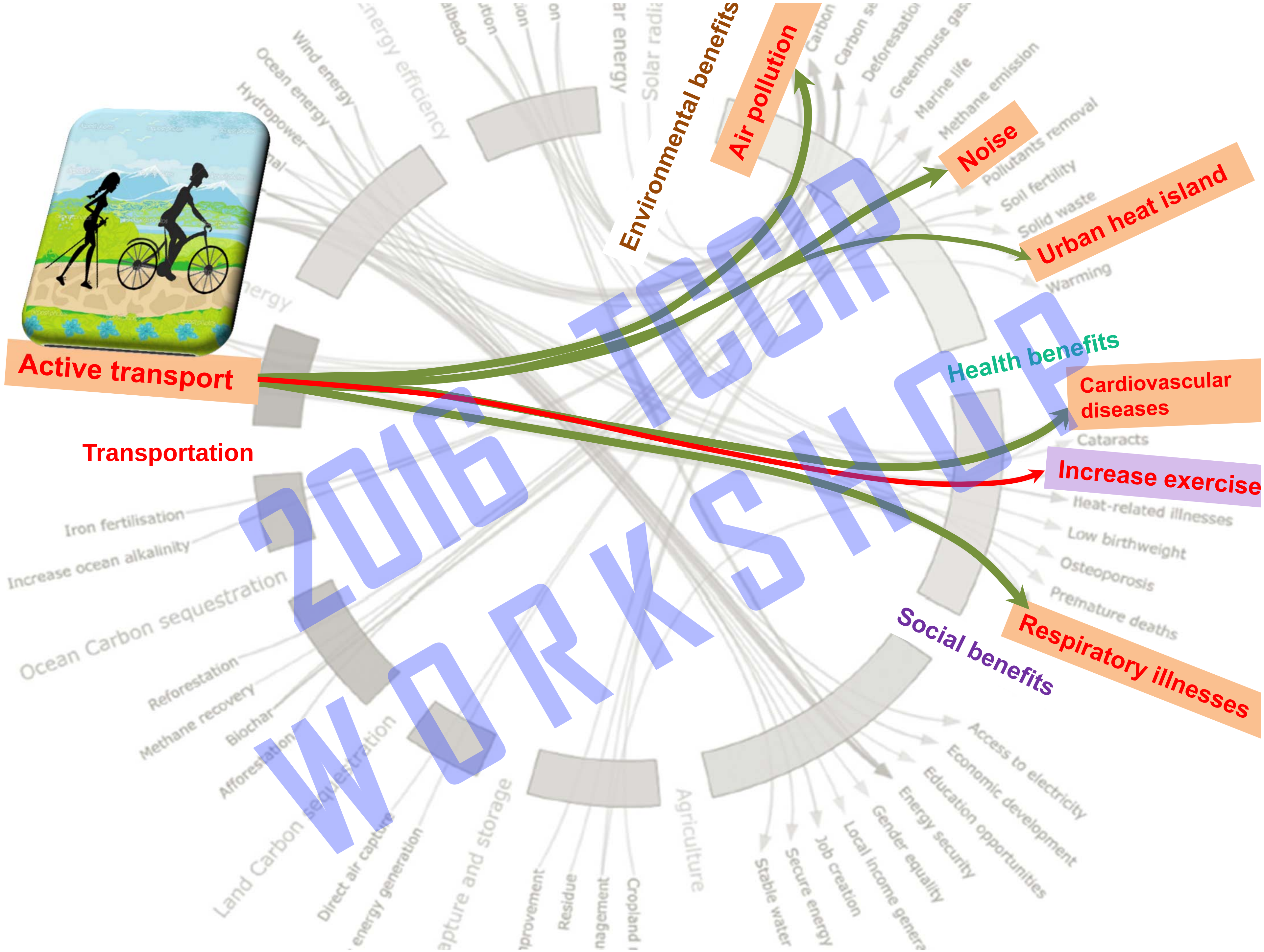


[Wu et al., 2016, NSC105-23420-H-309-001]

三地門鄉公所
鄉長許重慶 代表會主席鍾富來向鄉親請安
2016 TCCIP WORKSHOP

[Watts et al., 2015]





Active transport
Transportation
Environmental benefits
Air pollution
Noise
Urban heat island
Health benefits
Cardiovascular diseases
Increase exercise
Respiratory illnesses
Social benefits
Cataracts
Heat-related illnesses
Low birthweight
Osteoporosis
Premature deaths
Warming
Solid waste
Soil fertility
Pollutants removal
Methane emission
Marine life
Greenhouse gas
Deforestation
Access to electricity
Economic development
Education opportunities
Energy security
Gender equality
Job creation
Secure energy
Stable water
Agriculture
Iron fertilisation
Increase ocean alkalinity
Ocean Carbon sequestration
Reforestation
Methane recovery
Biochar
Wind energy
Ocean energy
Hydropower
Direct air capture
Residue
2016 TCCIP WORKSHOP

Greatest health threat or greatest opportunity?
Without action on climate change...
Heatwaves
led to
70,000 excess deaths
in Europe in 2003.
Events like this will become more frequent, and more intense.
Elderly people & children
are most vulnerable to the effects of heat stress on health.
There are
3400 road deaths
around the world every day – 1.2 million each year.
The pollution cars produce kills a similar number.
THE GLOBAL CLIMATE & HEALTH ALLIANCE
If we act on climate change...
Renewable energy
reduces air pollution and so can prevent diseases like asthma, pneumonia, heart attacks and stroke.
Well-insulated homes
could save thousands of lives, prevent illness, and reduce energy consumption.
Local, seasonal fruit & veg
is good for health, better for the environment, and the community.


Greatest health threat or greatest opportunity?
Without action on climate change...
If we act on climate change...
Air pollution
both contributes to, and is made worse by warming.
It now causes
1 in 8
of all deaths globally.
Each year, coal plant emissions in Europe lead to
18,200
early deaths, and cost an estimated
€42.8 billion
Obesity
is related to unhealthy diets, often high in red meat, and increasing car use.
Flooding
will become more severe.
One estimate for 2030 puts the number displaced in 4 US coastal areas at
12 million
THE GLOBAL CLIMATE & HEALTH ALLIANCE
Creating and protecting
green spaces
reduces air pollution and so can prevent diseases like asthma, pneumonia, heart attacks and stroke.
Sustainable diets
has many benefits for physical and men's health, and reduces heat island effect.
Active travel
(walking & cycling)
could help to prevent many of the 3,200,000 early deaths caused by physical inactivity every year.


Greatest health threat or greatest opportunity?
Without action on climate change...
If we act on climate change...
Child malnutrition
is projected to increase by
20-25 million
by 2050
Climate change can increase risks of
Infectious diseases
migration and conflict
such as dengue and malaria will spread and affect more people
by causing economic crises and exacerbating poverty
water-borne diseases
like diarrhoea and cholera, are projected to increase significantly, due to more flooding and more droughts across the world
THE GLOBAL CLIMATE & HEALTH ALLIANCE
Sustainable development
and poverty reduction will be easier to achieve, the economic impacts of extreme weather will be lower, and livelihoods more secure
Clean water & sanitation
can improve health now, and reduce vulnerability to climate change
Crop yields
and consequently nutrition - will be improved, due to fewer droughts, floods and better growing temperatures,if we cut emissions and invest in adaptation.


Greatest health threat or greatest opportunity?
Without action on climate change...
Tropical storms
are expected to become more intense, with heavier rainfall. They are a major threat to health:
Typhoon Haiyan affected 14 million people
killing over 6000.
Sea level rise
means that 100 million more people will be at risk of coastal flooding by 2080.
Fish stocks,
shellfish, and coral are all highly vulnerable to the combined effects of climate change and ocean acidification.
THE GLOBAL CLIMATE & HEALTH ALLIANCE
If we act on climate change...
Investing in green jobs, can provide stable growth in emerging economies.
Access to sustainable, reliable, and clean energy can help strengthen health systems and essential infrastructure.
Through sustainable fishing and tackling climate change, we can protect food security
for the 1 billion people whose main source of animal protein is fish

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CHANG JUNG CHRISTIAN UNIVERSITY
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CHANG JUNG ACADEMY