Estimation of DALY loss due to heat stroke and sleep disturbance caused by air temperature rise in Tokyo, Japan

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1 Introduction

Daytime air temperature in Tokyo

Hot & humid summer!

*Patients transported by ambulance due to heat stroke

Many heat stroke patients.
1 Introduction

◆ Nighttime air temperature in Tokyo

Hot & humid summer nights!

No statistics.

But, there would be many sleep disturbances.
**1. Introduction**

**Heat stroke & sleep disturbance**

- Heat stroke is a large problem.
  
  We need to decrease daytime air temperature.
  Reflective & green roof (control of solar radiation heat)

- If sleep disturbance is a large problem,
  
  We may need to decrease nighttime air temperature.
  Reduction in anthropogenic heat

However, sleep disturbance is an important problem?

For answering this question, quantification of damage of sleep disturbance is needed.
2 Metrics

◆ Which metric should be used?

Deaths?

Sleep disturbance does NOT lead to death directly.

Patients?

Degree of severity is different!

DALY!
Disability-adjusted life year (DALY)

• An index developed by WHO to measure damage on human health.

\[
\text{DALY} = \text{Years of Life lost (YLL)} + \text{Years Lost due to Disability (YLD)}
\]

\[
\text{YLL} = \text{Number of deaths} \times \text{Life expectancy at age of death}
\]

\[
\text{YLD} = \text{Number of subjects} \times \text{Disability weight (0–1)} \times \text{Duration}
\]
3 Heat stroke

◆ YLL: Number of deaths

Daily max. WBGT vs. Daily transported patients

Yearly transported patients vs. Yearly deaths

“Today & Tomorrow’s Hotness Indexes”

- Heat stroke prevention information site by Ministry of the Environment, Japan
  http://www.nies.go.jp/health/HeatStroke/
3 Heat stroke

◆ YLL: Life expectancy at age of death

<table>
<thead>
<tr>
<th>Age</th>
<th>Death</th>
<th>Life expectancy [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>20-29</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>30-39</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>40-49</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>50-59</td>
<td>20</td>
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<td>60-64</td>
<td>43</td>
<td>9</td>
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<td>65-69</td>
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<td>16</td>
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<td>70-79</td>
<td>84</td>
<td>60</td>
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<td>80-89</td>
<td>55</td>
<td>96</td>
</tr>
<tr>
<td>90-</td>
<td>7</td>
<td>16</td>
</tr>
</tbody>
</table>

Average: 16.24 years
3 Heat stroke

◆ DALY

- **YLL**
  - Number of deaths (3.4% of transported patients)
  - Life expectancy (16.24 years)

- **YLD**
  - Number of subjects (hundredfold of deaths)
  - Disability weight (0.01?, 0.1?, 1?)
  - Duration (16 years?, 1.6 years?, 2 months?)

YLD can be ignored because it is relatively small compared to YLL.

Then,

\[ \text{DALY} \approx \text{YLL}. \]
4 Sleep disturbance

Definition of sleep disturbance

Definition: PSQI > 5.5 (Pittsburg Sleep Quality Index)

YLD: Number of subjects

Survey on daily sleep quality using daily PSQI

Heat-related sleep disturbance

4 Sleep disturbance

◆ YLD: Disability weight & Duration

• Disability weight

<table>
<thead>
<tr>
<th></th>
<th>Environmental</th>
<th>PSQI &gt; 5.5</th>
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</thead>
<tbody>
<tr>
<td>Specialists</td>
<td>0.101±0.0004</td>
<td>0.069±0.053</td>
</tr>
<tr>
<td>Primary care physicians</td>
<td>0.114±0.095</td>
<td>0.140±0.165</td>
</tr>
</tbody>
</table>


DW = approximately 0.1

• Duration
  – One day (because of daily survey to the same subjects)
  = 0.0027 years

4 Sleep disturbance

◆ DALY

- **YLL = 0**
  - Sleep disturbance does NOT directly lead to death.

- **YLD**
  - Number of subjects (judged by daily PSQI > 5.5)
  - Disability weight (0.1, defined by PSQI > 5.5)
  - Duration (0.0027 years)

\[
\text{DALY} = \text{YLD.}
\]
5 Impact assessment of heat stroke & sleep disturbance

Damage from May to Sep of 2010 – 2014

- Damage functions using DALY was applied to past five years’ temperature...

The orders of DALYs due to heat stroke and sleep disturbance are the same.
6 Conclusion

◆ Results

- DALY can quantify various heat impact leading to death / not to death.
- Damage of sleep disturbance is not small compared to that of heat stroke.
- We may have to consider decrease in nighttime air temperature.

◆ Acknowledgement

- This study was partly supported by the Environment Research and Technology Development Fund (S-14-4(3)) of the Ministry of the Environment, Japan.
Thank you for your kind attention.
1 Introduction
◆ Disability-Adjusted Life Year (DALY)

- An index developed by WHO to measure damage on human health.
- DALY = Years of Life Lost (YLL) + Years Lost due to Disability (YLD)

How to calculate DALY?

- Heat stroke (death) → YLL
  \[ \text{DALY (YLL)} = \text{Number of deaths} \times \text{Life expectancy at age of death} \]

- Sleep disturbance (disease not resulting in death) → YLD
  \[ \text{DALY (YLD)} = \text{Number of subjects} \times \text{Disability weight (0–1)} \times \text{Duration} \]
1 Introduction

Climate change in urban areas

Global climate change (global warming)

Urban heat island

Tokyo: +3.03 °C / 100 years

Japan: +1.40 °C

World: +0.90 °C

1 Introduction

◆ Change in daily max./min. air temperature in Tokyo

Days of $T_{\text{max}} \geq 30$ °C

Days of $T_{\text{min}} \geq 25$ °C


Days [°C]

Hot daytime

Hot nighttime

Heat stroke

Sleep disorder

Hot summer might pose various human health damages in our society.
1 Introduction

 Symptoms experienced in the middle of summer

• Results of questionnaire survey in Japan (2003 FY)

Restless sleep (sleep disorder?) is a more common health impact than heat stroke in our society.

1 Introduction

◆ Is sleep disorder serious?

• Heat stroke
  – Medical-defined disorder
  – Quantitative damages
    • Deaths
    • Patients transported by ambulance

• Restless sleep
  – Subjective symptom
    • “insomnia” is medical disorder
  – No quantitative damages

“Today & Tomorrow’s Hotness Indexes”

● Heat stroke prevention information site by Ministry of the Environment, Japan
http://www.nies.go.jp/health/HeatStroke/

Medical definition of restless sleep & quantification of its damage based on the definition are needed.
1 Introduction

◆ Disability weight (DW) of sleep disturbance

• Interviewee
  – Face-to-face survey to specialists (sleep medicine or psychiatry)
  – Internet survey to primary physicians

• Method
  – Text description of symptoms of 3 kinds of sleep disturbance
  – Showing of DW list of 33 mental diseases
    • Müller-Wenk (2002) + some mild mental diseases
  – Set of DWs by inserting to DW list

<table>
<thead>
<tr>
<th>Sleep disturbance</th>
<th>Environmental</th>
<th>Mild</th>
<th>Moderate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specialists (n=6)</td>
<td>0.101±0.0004</td>
<td>0.069±0.053</td>
<td>0.086±0.067</td>
</tr>
<tr>
<td>Primary physicians (n=57)</td>
<td>0.114±0.095</td>
<td>0.140±0.165</td>
<td>0.126±0.132</td>
</tr>
</tbody>
</table>

Description based on PSQI
Mild: PSQI = 5.5 – 7.4
Moderate: PSQI > 7.5

1 Introduction

◆ Disability-Adjusted Life Year (DALY)

- An index developed by WHO to measure damage on human health.
- DALY = Years of Life Lost (YLL) + Years Lost due to Disability (YLD)

How to calculate DALY?

- Heat stroke (death) $\rightarrow$ YLL

$$\text{DALY (YLL)} = \text{Number of deaths} \times \text{Life expectancy at age of death}$$

- Sleep disturbance (disease not resulting in death) $\rightarrow$ YLD

$$\text{DALY (YLD)} = \text{Number of subjects} \times \left(\frac{\text{Disability weight}}{1}\right) \times \text{Duration}$$

2 Survey on sleep

◆ How to define sleep disturbance?

• Pittsburg Sleep Quality Index (PSQI)
  
  
  – Questionnaire for subjective sleep quality over the past one month
  – Composed of 7 components (0-3 pt, global score: 0-21 pt)
    
    • (C1) subjective sleep, (C2) sleep latency, (C3) sleep duration,
      (C4) habitual sleep efficiency, (C5) sleep disturbance,
      (C6) use of sleeping medication, (C7) daytime dysfunction
  – Widely used in sleep medicine
  – Cut-off value: 5.5 pt

• Sleep Quality Index for Daily Sleep (SQIDS)


  – Questionnaire for subjective sleep quality over the past one day
  – Adopted the same items as PSQI

  Cut-off value of SQIDS was deemed to 5.5 pt.
2 Survey on sleep

◆ Epidemiological survey

• Epidemiological survey
  – Subject: 418 Internet survey company’s monitors living in Tokyo
  – Period: July 31st – August 9th, 2006 (total 8 days excl. Sat & Sun)

• Outdoor air temperature data
  – METROS
    (Metropolitan Environmental Temperature and Rainfall Observation System)
    by Tokyo Metropolitan Government
  – High resolution observation network

ECO Tokyo Net 62.
http://all62.jp/ecoacademy/11/01.html
3 Analysis

Regression analysis

- Dependent variable
  - Rate of subjects whose SQIDS ≥ 5.5 pt \( d \) [-]

- Independent variable
  - Outdoor air temperature at 0000 LST \( T \) [°C]

- Regression model
  - Smoothing spline (basis: cubic function)
  - Degree of freedom: minimizing general cross validation (GCV)
4 Results

Outdoor air temperature vs. rate of sleep disturbance

Sleep disturbances increase by 1% per 1 °C air temperature rise.

RMSE: 0.1020
Change in the rate of sleep disturbance by outdoor air temperature rise from June to September over the past 40 years (1967 → 2007) in Tokyo is calculated. (min: 10.4 °C, max: 32.7 °C).

0.48% of Tokyo residents became poor sleepers over the past 40 years.
5 Conclusion

◆ Sleep disturbance vs. outdoor air temperature
• SQIDS based on PSQI was developed as a sleep quality index which can be assessed with DALY.
• The analysis of SQIDS global score and outdoor air temperature at 0000 LST showed that the threshold temperature, where poor sleepers begin to increase, was 23.9 °C. Sleep disturbances increase by 1% per 1 °C rise.

◆ Sleep disturbances in Tokyo
• It is found that the ratio of poor sleepers was increased by 0.48% in the past 40 years in Tokyo, which has 9 million residents and 90 deaths due to heat stroke per year.
• DALY (approximate values)
  – Heat stroke: \( 90 \times 30 = 2,700 \)
  – Sleep disturbance: \( 9M \times 0.48\% \times 4/12 \times 0.1 = 1,440 \)
1 Introduction

◆ Disability-Adjusted Life Year (DALY)

• Concept & definition
  – An index developed by WHO to measure damage on human health.
  – One DALY can be thought of as one lost year of "healthy" life.

• Calculation
  – \[ \text{DALY} = \text{YLL} + \text{YLD} \]
  – \[ \text{YLL} = \text{N} \times \text{L} \]
    • Years of Life Lost due to premature mortality in the population
    • \( \text{N} \) = numbers of deaths, \( \text{L} \) = standard life expectancy at age of death
  – \[ \text{YLD} = \text{I} \times \text{DW} \times \text{L} \]
    • Years Lost due to Disability for incident cases of the health condition
    • \( \text{I} \) = number of incident cases, \( \text{DW} \) = disability weight,
      \( \text{L} \) = average duration of the case until remission or death

DALY can evaluate magnitude of diseases which does not reach to death.
### Disability weights

<table>
<thead>
<tr>
<th>Description of condition</th>
<th>Disability weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full health</td>
<td>0</td>
</tr>
<tr>
<td>Dental disease: periodontal disease (gingivitis)</td>
<td>0</td>
</tr>
<tr>
<td>Dental disease: periodontal disease (pockets &gt;6 mm deep)</td>
<td>0.01</td>
</tr>
<tr>
<td>Mild vision disorder (some difficulty reading small print, no difficulty recognizing faces at 4 m)</td>
<td>0.02</td>
</tr>
<tr>
<td>Adult-onset mild hearing loss (25-34 dBHTL)</td>
<td>0.02</td>
</tr>
<tr>
<td>Mild to moderate asthma (symptom-free with or without maintenance therapy)</td>
<td>0.03</td>
</tr>
<tr>
<td>Adult-onset mild hearing loss (35-44 dBHTL): (some difficulty understanding or actively participating in a conversation with one or more persons)</td>
<td>0.04</td>
</tr>
<tr>
<td>Benign prostatic hypertrophy (symptomatic)</td>
<td>0.04</td>
</tr>
<tr>
<td>Chronic hepatitis B infection without active viral replication</td>
<td>0.06</td>
</tr>
<tr>
<td>Uncomplicated diabetes mellitus</td>
<td>0.07</td>
</tr>
<tr>
<td>Mild stable angina pectoris (NYHA 1-2)</td>
<td>0.08</td>
</tr>
<tr>
<td>Mental retardation (IQ 70-84)</td>
<td>0.09</td>
</tr>
<tr>
<td>Primary insomnia</td>
<td>0.1</td>
</tr>
<tr>
<td>Problem drinking (physical, psychological, or social problems caused by excessive alcohol intake)</td>
<td>0.11</td>
</tr>
<tr>
<td>Mild to moderate congenital or early acquired hearing disorder</td>
<td>0.11</td>
</tr>
<tr>
<td>Moderate hearing disorder in the elderly (some difficulty understanding or participating in a conversation with one person but great difficulties with conversations with more than one person)</td>
<td>0.12</td>
</tr>
<tr>
<td>Unipolar depressive disorders: mild depressive episode</td>
<td>0.14</td>
</tr>
<tr>
<td>Unipolar depressive disorders: dysthymia</td>
<td>0.14</td>
</tr>
<tr>
<td>Osteoarthritis (grade 2) of hip or knee</td>
<td>0.14</td>
</tr>
<tr>
<td>Diabetes mellitus with neuropathy</td>
<td>0.19</td>
</tr>
<tr>
<td>Diabetes mellitus with nephropathy</td>
<td>0.29</td>
</tr>
<tr>
<td>Mild mental handicap (IQ 50-69)</td>
<td>0.29</td>
</tr>
<tr>
<td>Unipolar depressive disorders: moderate depressive episode</td>
<td>0.35</td>
</tr>
<tr>
<td>Severe asthma (not symptom-free despite maintenance medication)</td>
<td>0.36</td>
</tr>
<tr>
<td>Severe hearing disorder acquired as an adult (great difficulty understanding or participating in a conversation with one person)</td>
<td>0.37</td>
</tr>
<tr>
<td>Chronic hepatitis B with active viral replication</td>
<td>0.36</td>
</tr>
<tr>
<td>Severe vision disorder (unable to read small newspaper print, great difficulty recognizing faces at 4 m)</td>
<td>0.43</td>
</tr>
<tr>
<td>Moderate mental handicap (IQ 35-49)</td>
<td>0.43</td>
</tr>
<tr>
<td>Schizophrenia</td>
<td>0.528</td>
</tr>
<tr>
<td>Severe stable angina pectoris (NYHA 3)</td>
<td>0.57</td>
</tr>
<tr>
<td>Paraplegia, stable stage</td>
<td>0.57</td>
</tr>
<tr>
<td>Unipolar depressive disorders: severe depressive episode</td>
<td>0.76</td>
</tr>
<tr>
<td>Extreme mental handicap (IQ &lt; 20)</td>
<td>0.76</td>
</tr>
<tr>
<td>Tetraplegia, stable stage</td>
<td>0.84</td>
</tr>
<tr>
<td>Severe dementia (permanent supervision required)</td>
<td>0.95</td>
</tr>
<tr>
<td>Death</td>
<td>1</td>
</tr>
</tbody>
</table>
### 4 Results

- **Damage function**
  - Rate of sleep disturbance (SQIDS \( \leq 5.5 \) pt) \( d [-] \)
    \[
    d = k_i T^3 + l_i T^2 + m_i T + n_i \quad (T_i \leq T < T_{i+1})
    \]
    \[
    (0 \leq i \leq 98)
    \]

- **Outdoor air temperature vs. rate of sleep disturbance**

![Graph showing the relationship between outdoor air temperature and rate of sleep disturbance](image)

*2次微分が最大となる点を閾値とした。*
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
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<tbody>
<tr>
<td>i</td>
<td>T_i</td>
<td>k_i</td>
<td>l_i</td>
<td>m_i</td>
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<td>26.909</td>
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<td>-0.258</td>
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<td>26.938</td>
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<td>-0.443</td>
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<td>38</td>
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4. 解析結果

◆ 手法(1),(2),(3)の結果・精度の比較

プロットは毎日の個人値ではなく、毎日の地域平均値。

手法(1)は、正規分布を仮定したことにより罹患率の最小値・閾値ともに過大に評価している。回帰誤差も大きい。

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4 Results

各手法による睡眠困難罹患率の40年間の変化の予測（月平均）

東京の過去40年間（1967年→2007年）の6-9月の気温上昇に伴う睡眠困難罹患率の変化を評価した（最低10.4℃・最高32.7℃）。

手法(1)は平均1.16%睡眠困難率が上昇したのに対し、手法(2)は0.72%、手法(3)は0.48%にとどまり、手法(1)は他の手法より大きい。
Endpoint-type LCIA Methodology for Japan (LIME)

Inventory
- CO₂
- HCFCs
- TCDD
- Benzene
- Lead
- SO₅
- NOₓ
- Total N
- Total P
- NMVOC
- Land
- Waste
- Copper ore
- Oil

Concentration
- GHS in Air
- ODS in Stratosphere
- Toxic. in Air
- Toxic. in Water
- Toxic. in Soil
- Dep. of Acidifying sub.
- Consumption of DO
- Conc. Oxidant

Impact category
- Global warming
- Ozone depletion
- Air pollution
- Human toxicity (chemicals/metals)
- Ecotoxicity
- Acidification
- Eutrophication
- Oxidant creation
- Land use
- Waste
- Resource consumption

Category endpoint
- Thermal/Cold stress
- Malaria
- Dengue favor
- Disaster
- Cataract
- Skin cancer
- Cancer
- Respiratory disease
- Terrestrial
- Aquatic
- Plant
- Benthos
- Fishery
- Crop
- Materials
- Energy

Safeguard subject
- Human life
  - Human health (DALY)
  - Social assets (Yen)
  - Ecosystem
    - Biodiversity EINES
    - Primary productivity NPP

Weighting
- Fate Analysis
- Exposure Analysis
- Damage Assessment
- Quality Analysis
Methodology: LCIA

LCIA method for air temperature rise (based on LIME)

Air temperature

- Summer daytime
- Summer nighttime
- Winter daytime
- Winter nighttime

Air humidity

- Summer daytime
- Summer nighttime
- Winter daytime
- Winter nighttime

Wind

Impact category

Urban heat island

- Heat stress (Heat stroke, etc.)
- Cold stress (Stroke, etc.)
- Fatigue
- Mental disorder
- Sleep disturbance
- Infectious disease
- Influenza
- Photochemical oxidant
- Air pollution
- Heavy rain
- Crop
- Plant
- Energy in hot (Air conditioning, etc.)
- Energy in cold (Heating, etc.)

Category endpoint

Safeguard subject

Single index

Human life

Human health (DALY)

Social assets (Yen)

Ecosystem

Biodiversity EINES

Primary productivity NPP

Quality analysis

Weighting

Relation between air temperature and energy consumption for air conditioning/heating is assessed by CM-BEM