SITE SPECIFIC ASSESSMENT OF CLIMATE CHANGE IMPACTS ON GROUNDWATER TEMPERATURE

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1. INTRODUCTION

Groundwater temperature is a key parameter regulating the ecological balance of the ecosystems in groundwater dominated wetlands, estuaries and ponds. Climate change and its associate effects may adversely change the groundwater temperature which in turn affect for the fundamental ecological processes and the geographic distribution of aquatic species. The fourth assessments of the Intergovernmental Panel on Climate Change (IPCC AR4 2007) concluded that approximately 20-30% of plant and animal species assessed so far are likely to be at increased risk of extinction if increases in global average temperature exceed 1.5-2.5°C. The best estimates of projected globally averaged surface air temperature change at 2090~2099 relative to 1980~1999 span 1.8^0C (for B1 scenario with the likely range of 1.1^0C to 2.9^0C) to 4 ^{0}C (for A1F1 scenario with the likely range of 2.4^0C to 6.4^0C), warning the fears of substantial changes in aquatic ecology. Therefore, the main objective of this research is to estimate the potential groundwater temperature change in future in Sendai plain by different GCM scenarios.

2. THEORY

The governing equation for heat transport in one dimensional homogeneous porous media

$$\alpha\left(\partial^2 T/\partial z^2\right) - \beta\left(\partial T/\partial z\right) = \partial T/\partial t\,, \qquad (1)$$

where T is temperature; z is the depth from the ground surface; t is time, α (= $k/c\rho$) is the thermal diffusivity of the aquifer; and $\beta = vc_0\rho_0/c\rho$ where v is the vertical groundwater flux (positive downward), $c_0\rho_0$ is the heat capacity of the water, and $c\rho$ is the heat capacity of the porous medium. The initial boundary conditions, considering a linear increase in ground surface temperature, can be written as,

$$T_{(z,0)} = T_0 + az \qquad (2)$$

$$T_{(0,t)} = T_0 + bt\,, \qquad (3)$$

where T_0 is the ground surface temperature at t = 0, a is the general thermal gradient, and b is the rate of surface warming. Under the above initial boundary conditions, Carslaw et al. 1959 obtained an analytical solution for the temperature distribution as a function of depth and time;

$$T = T_0 + a(z - \beta t) + \{(b + \beta a)/2\beta\} \times [(z + \beta t)\exp(\beta z/\alpha)$$
$$\mathrm{erfc}\{(z + \beta t)/2(\alpha t)^{1/2}\} + (\beta t - z)\mathrm{erfc}\{(z - \beta t)/2(\alpha t)^{1/2}\}] \quad (4)$$

3. METHODOLOGY

Area about 500 km^2, including the Natori and Nanakita rivers was selected. There are five water level observations stations (5-60m depth) are located within the area where, one hour groundwater level and water temperatures were measured. The transfer function method was used to downscale the coarse resolution temperature and precipitation from the GCM grid box to the Sendai metrological station. The regression relationships are calibrated using parallel time series of GCM output and local scale observations for the period of 1967-2006 for corresponding variable. Those transfer functions were then used to downscale the 1927-1966 GCM data to the Sendai plain and later verified with the observed precipitation. For climate prediction, those transfer functions were further used to downscale 2060-2099 GCM variables.

Observed temperature-depth profiles were first used to estimate the groundwater recharge in the Sendai plain. These results were validated using the observed water levels. Moreover, water budget technique was applied and representative parameters were adjusted to cope with site conditions which gives reasonably match groundwater recharge value as estimated from the temperature-depth profiles. Later, downscale temperature and precipitation were used to estimate the ground surface temperature change and recharge variations in future. Finally, these changes were applied in the **Equation 4** to estimate the potential groundwater temperature changes.

4. RESULTS AND DISCUSSION

The curvature of the observed temperature-depth profile can be matched with the calculated profile based on **Equation 4** to find the value for unknown β (**Fig.1**). Annual mean air temperature in the Sendai plain has increased at a rate of 2.2 0C/100 years during the last 80 years. Therefore, b is set as 0.0221 0C/ year and t is 80 years.

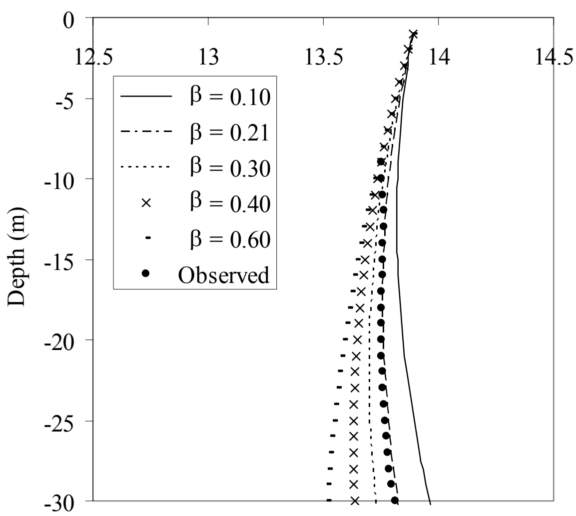

Fig. 1 Simulated temperature-depth profiles at W4

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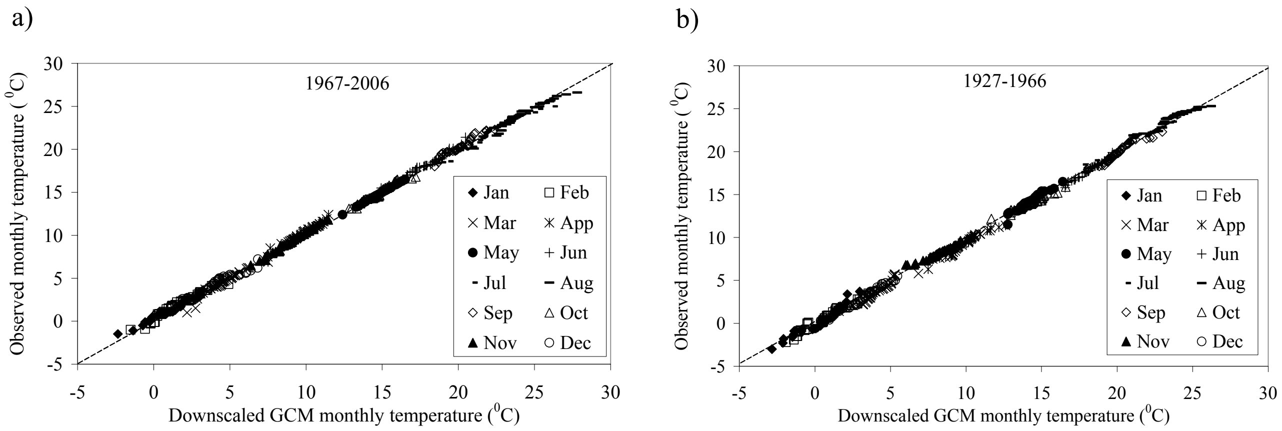

Fig. 2 qq-plots of observed vs. downscaled temperature for HADCM3 A2 scenario

We calculated the recharge rates from the obtained β values ($\beta = vc_0\rho_0/c\rho$) to be 100 mm/year at W1, 135 mm/year at W2, 120 mm/year at W3, 125 mm/year at W4, and 90 mm/year at W5. In order to estimate the representative recharge rate for the whole catchment, the Thiessen polygon method was applied. The approximate annual recharge rate in the Sendai plain was estimated to be 120 mm. This value is reasonably matched with the recharge rate estimated from the water budget technique (135 mm/year). Based on the observed water level records, 0.08 m/m, 0.17 m/m and 0.15 m/m of hydraulic gradients were estimated in the W1, W2 and W4 respectively for shallow sub surface layer. According to the Darcy's low, high hydraulic gradient (HG) produces large water flow and therefore, estimated HGs further verify the slight changes of recharge values estimated from the T-D profiles.

The determination coefficient (r^2) of the linear and non-linear regressions was considered for the appropriate transfer functions selection. Both linear and non-linear functions were used such a way that the r^2 of the corresponding transfer function is always above 0.9. The downscaled temperature values for HADCM3 A2 scenario were plotted with observed temperature in **Fig. 2** for all months of the year, illustrating how well the selected transfer functions reproduce the temperature values to the Sendai station. Unlike temperature, sea level patterns govern the local variability in precipitation. Therefore, fitting a linear or a simple non-linear transfer function for precipitation is rather difficult for the precipitation than the temperature. Thus, compare with the temperature, downscaling results for precipitation show lesser agreement with the observed records. Verified results during 1927-1966 indicate several significantly deviated points from the 1:1 line suggesting a poor match for August and September, while the other months show reasonably good agreement for the predictions. However, in general all scenarios show comparatively good results for precipitation that can be used for long term impact predictions.

Compare with the time period of 1967-2006, A2 scenario gives the highest temperature rise in future (3.9^{0}C) followed by A1B and B2 scenarios (3.8^{0}C and 2.5^{0}C, respectively). Similar to surface warming, HADCM3 projected increasing trend of precipitation for the 2060-2099 time periods than the annual average of past 40 years (1967-2006). A2 scenario produces the highest annual precipitation rise (345 mm; about 28% change from past 40 year's average) followed by A1B (210mm) and B1 (87mm). To account the climate change impacts, the estimated changes were compared with the present climate and results are shown in **Table 1**.

Table 1 Groundwater temperature change in future

Scenario	Temperature rise (^{0}C)	
	Ground surface	Groundwater
A2	3.9	3.2
A1B	3.8	3.1
B1	2.5	1.7
If continue the present trend	2.2	1

5. CONCLUSIONS

In this study, potential impacts of climate change on groundwater temperature were estimated. Recharge rate, estimated from the T-D profiles (average 120 mm/year) reasonably match with the one estimated from the water budget method. HADCM3 monthly data were downscaled to the local scale. A2 scenario shows the most robust effect than the other two scenario which produces 3.2^{0}C groundwater temperature change in future. These results will be significance for the ecological balance of the eco-system and decision makers can make more resilient decisions by incorporating these results in their considerations.

ACKOWNLEGEMENTS

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