

Study on Inundation in the Coastal City Due to Heavy Rainfall Considering the Effect of Global Warming

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Abstract

Urbanization in the coastal area leads to inundation during heavy rainfall is the common problem. The reason for inundation is heavy rainfall, tidal phenomenon, sewerage system, and also rise of sea water level due to global warming. The frequency of heavy rainfall increasing in the recent year cause severe flooding .Flooding poses a threat to life and safety and can cause severe damage to public and private property.

The aim of this study is to analysis the inundation situation of Nagoya city due to heavy rainfall considering the effect of global warming .The analysis region is around the Nagoya bay area, Nagoya city, rivers and streams which terminated into Nagoya bay area. Nagoya city is one of the largest city locates in central Japan. Sewerage system in the Nagoya city is also considered in this analysis .Sewerage system performs a vital role to drain the city area during heavy rainfall. The sewerage system is connected to the sea and rivers. Sewerage water is discharged to the sea and river through pumps.

In this study, the water behavior due to heavy rainfall and other several cases such as tidal phenomenon existing sewerage system is considered .A synthetic analysis model is developed which includes sea model, inundation model, river model and sewer system model. Developed hydrodynamic model based on finite volume method solving the shallow water equation. The inundation water depth during heavy rainfall is examined by numerical simulation. Moreover, rise of sea water level due to global warming is also considered in this analysis. The inundation in two different cases such as

considering global warming and without global warming (i.e. sea water level set 0.95m and 0m) are analyzed. Moreover, the inundation situation is evaluated and finally recommends appropriate mitigation measure is recommended..

Introduction

A rise of sea level by the end of next century, caused by predicted greenhouse climate warming, would endanger human populations, cities, ports and wetlands in low lying coastal areas through inundation, erosion and salinization. Various studies utilizing tide-gauge data find an average global rate of sea level rise of 1-2 mm/year over the last 100 years. Due to rise in sea level permanently inundated coastal zone would extend to a depth equivalent to the vertical rise in sea level. Major river deltas, coastal wetlands and coral islands would be most affected. Intergovernmental panel for Climate Change (IPCC) recommends four major factors for sea level rise they are thermal expansion of the ocean, mountain glaciers and small ice cap, Greenland ice sheet, Antarctic ice sheet. Future sea levels are predicted using models representing relevant factors such as thermal expansion of the ocean, melting of mountain glaciers etc. Changes in the radioactive balance of the Earth due to an increase in GHGs (greenhouse gases) will alters atmospheric and oceanic temperatures and circulation of weather patterns. Global warming and climate change are the general terms for these changes. Since the industrial revolution the atmospheric concentrations GHGs have been increasing dramatically. The Inter Governmental Panel on Climate Change (IPCC) reported that global mean surface temperature has increase by 0.3 to 0.6^{o}c over the last 100 years (IPCC, 1996).

The urbanization trend increases in the coastal cities rapidly due to easy access and industrial development. Coastal cites have great concern on the sea level .Researcher already warn many coastal city in the world may be sink due to sea level rise. Intergovernmental Panel for Climate Change (IPCC) has estimate the rise of sea level from 0.15m to 0.95m in the next century due to global warming. The inundation in the urban area may cause heavy damage of infrastructure, loss of property, loss of life, displace the people and affect the normal life of the people. Besides application of many types protection measures, the trend of inundation is in increasing order. The majority of the world's climatologists agree that climate change is underway. They draw attention to the strong possibility of increasing frequency and severity of extremes of rainfall that can lead to both droughts and floods, to the likelihood of rising sea level affecting low lying islands and to significant changes in river flows with severe impacts in water availability for people, crops and industry.

Nagoya city one of the largest City of Japan lies in the pacific coast. In the past, Nagoya city suffered inundation problem many times due to water disaster .The Isewan typhoon in September 26, 1959 and Tokai heavy rain occurred in September 2000 are the major water disaster causes severe flooding in the Nagoya city. Besides the study of past disaster, now we should focus on impact due to global phenomenon. In this study the inundation scenario of Nagoya city due to heavy rain with consideration of sea level rise due to global warming is analyzed studied by using numerical simulation model. The numerical simulation model applied here is explained in Takeda et al (2004).

The inundation in the Nagoya city with rainfall of 10 years return period and the tidal phenomenon in two different cases with rise of sea level or without rise of sea level are compared in each hour lag time. The lag time is the time delay to overlap the peak of rainfall to the peak of tide. It is seen that, the inundation is maximum at the time when the peak of rainfall overlap with peak of high tide. Moreover, the effectiveness of sewer system is also studied by numerical simulation .The simulation results are also presented

Numerical Analysis Model

The inundation flow model applied here treats the flow dynamics in sea, river, urban area and sewer system simultaneously. The each model is shown below.

Rivers. The continuity and momentum equation denoted below are used for analysis in rivers.

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q \qquad (1) \qquad\qquad \frac{\partial u}{\partial t}+\frac{\partial uu}{\partial x}+g\cos\theta\frac{\partial h}{\partial x}-g\sin\theta+\frac{gn^2u|u|}{R^{4/3}}=0 \qquad (2)$$

where A : area of cross section, Q : discharge, q : lateral inflow discharge, u : water velocity $(=Q/A)$, h : water depth, θ : bed slope, R : hydraulics radius, x : axis of downstream, t : time.

Urban Area. The method with unstructured grid system of Inoue et al (1999) is used. Discharge flux (M,N) and water depth (h) are set at center of side and grid, respectively. The algebraic equations expanded by finite volume method are as follows

$$\frac{h^{n+3}-h^{n+1}}{2\Delta t}+\frac{1}{A}\sum_{l'=1}^{m}\left\{M_{l'}^{n+2}(\Delta y)_{l'}-N_{l'}^{n+2}(\Delta x)_{l'}\right\}=q \qquad (3)$$

$$\frac{M_l^{n+2} - M_l^n}{2\Delta t} + M1 + M2 = -g\tilde{h}^{n+1}(\nabla H)_x - \frac{gn^2 \frac{M_l^{n+2} + M_l^n}{2}\sqrt{(u_l^n)^2 + (v_l^n)^2}}{(\tilde{h}^{n+1})^{4/3}} \quad (4)$$

$$\frac{N_l^{n+2} - N_l^n}{2\Delta t} + N1 + N2 - g\tilde{h}^{n+1}(\nabla H)_y - \frac{gn^2 \frac{N_l^{n+2} + N_l^n}{2}\sqrt{(u_l^n)^2 + (v_l^n)^2}}{(\tilde{h}^{n+1})^{4/3}} \quad (5)$$

where m: number of side surrounding the grid. A: area of grid, $M_{l'}, N_{l'}$: flux at the centre of side l' in x, y direction, respectively, $(\Delta x)_{l'}, (\Delta y)_{l'}$ are difference of x, y coordinate value at the both side of l' (l' means the side around grid), u_l, v_l: flow velocity of x, y coordinate at the centre of side l respectively, $(\nabla H)_x$,$(\nabla H)_y$: gradient of water surface in x, y coordinate at the centre of side l, $\tilde{h}$: water depth analyzed by h at the centre of side, $M1, M2$ or $N1, N2$: advection terms presented by below equations.

$$M1 + M2 = \frac{1}{A_{cv}}\sum_{l'=1}^{m'}\left\{(u_{l'}\tilde{M}_{l'})(\Delta y)_{l'} - (v_{l'}\tilde{M}_{l'})(\Delta x)_{l'}\right\} \quad (6) \qquad N1 + N2 = \frac{1}{A_{cv}}\sum_{l'=1}^{m'}\left\{(u_{l'}\tilde{N}_{l'})(\Delta y)_{l'} - (v_{l'}\tilde{N}_{l'})(\Delta x)_{l'}\right\} \quad (7)$$

where, A_{cv}: area of control volume in Fig.2, m': number of side surrounding the control volume, $\tilde{M}, \tilde{N}$: flux analyzed by M, N at the centre of grid. The analysis of equation (6) and equation (7) are used for flux calculation in upstream.

Sea Areas. The plane 2D Model based on shallow water equation is used for analysis

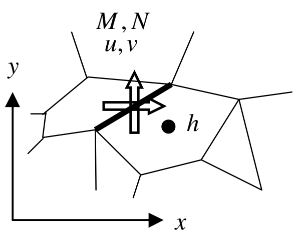


Fig. 1 Arrangement of Physical quantities

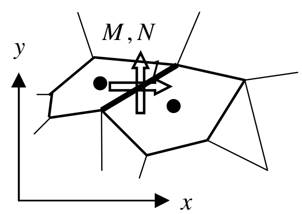


Fig.2 Control volume of momentum equation

in sea area.

$$\frac{\partial h}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \quad (8)$$

$$\frac{\partial M}{\partial t} + \frac{\partial uM}{\partial x} + \frac{\partial vM}{\partial y} = -gh\frac{\partial H}{\partial x} + \frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial M}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial M}{\partial y}\right) - \frac{\tau_{bx}}{\rho_w} + fN \quad (9)$$

$$\frac{\partial N}{\partial t} + \frac{\partial uN}{\partial x} + \frac{\partial vN}{\partial y} = -gh\frac{\partial H}{\partial y} + \frac{\partial}{\partial x}\left(\varepsilon_x \frac{\partial N}{\partial x}\right) + \frac{\partial}{\partial y}\left(\varepsilon_y \frac{\partial N}{\partial y}\right) - \frac{\tau_{by}}{\rho_w} - fM \quad (10)$$

where u, v : flow velocity in x, y direction respectively, h : water depth, M, N : discharge flux in x, y direction respectively $(M = uh, N = vh)$, H : water level, τ_{bx}, τ_{by} : component of shear stress at water bottom in x, y direction respectively, g : gravity acceleration, $\varepsilon_x, \varepsilon_y$: eddy viscosity in x, y direction, respectively, f : Coriolis parameter, x, y : axis of plane, t : time.

Shear stress at bottom is presented by using of water density (ρ) and roughness coefficient of Manning(n).

$$\tau_{bx} = \rho g n^2 M \sqrt{u^2 + v^2} \Big/ h^{4/3} \qquad (11) \qquad\qquad \tau_{by} = \rho g n^2 N \sqrt{u^2 + v^2} \Big/ h^{4/3} \qquad (12)$$

Sewer System. This analysis model treats behavior of inundation water in sewer pipe and manhole. The interaction between overland and sewer system on inundation water is taken into consideration in manhole model. The model on sewer pipe flow used equation (1) and equation (2) as governing equation and slot model for pipe flow. Slot width is analyzed by $B = gA_S / C^2$ (g is gravity acceleration, A_S is area of cross section, C is wave velocity, 20m/sec).

The water level at manhole is computed by below continuity equation.

$$A_m \frac{\partial H}{\partial t} = \sum Q + Q_{in} - Q_{out} \qquad (13)$$

where A_m: area of manhole, H: water level of manhole, $\sum Q$: net inflow discharge from sewer pipe, Q_{in}: inflow discharge from overland, Q_{out}: outflow discharge of pump ($Q_{in} = \mu L h \sqrt{gh}$: μ is discharge coefficient, L is circumference of manhole, h is water depth).

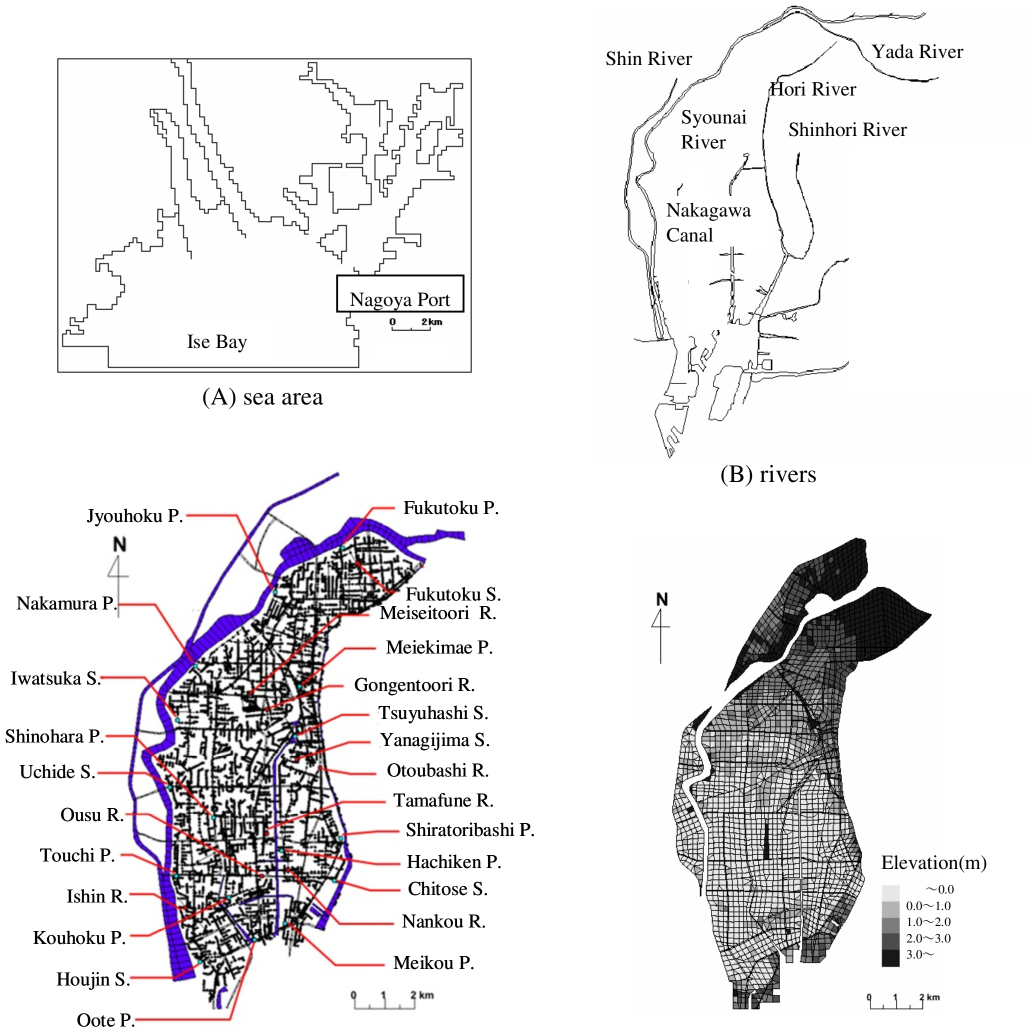
Numerical Analysis Method

The numerical analysis methods except the one of urban area are denoted here.

Finite volume method is used as numerical simulation method. In the 1-D analysis for river and sewer pipe and 2-D analysis for sea region, forward deference scheme is used on time terms, DONOR scheme is used on advection terms and center scheme is used on other terms.

Analysis Region

The analysis area includes Nagoya city, Nagoya port sea area, Rivers, sewer system. Nagoya city is one of the largest city in Japan locates about the centre part of Japan with the population about two millions. The Shonai River, Shin River, Hori River, Yada River and Nakagawa canal flow through densely populated area are terminated into the Pacific Ocean. Sewer system is connected to the river through pumps .The elevation of some part of the Nagoya city is below river bed. The drainage of sewer water is affected by the rise of river water level. Fig 3 (A) shows the sea area with Nagoya port, fig 3 (C) is the sewer system of the Nagoya city and the location of pumps and storage facilities fig. 3(B) shows the river network terminate into Nagoya port and fig.3 (D) is the ground



(A) sea area

(B) rivers

(C) urban area

(D) ground elevation

Fig.3 Analysis regions

elevation of analysis region in Nagoya city.

Analysis condition

The expected rainfall data of 10 years return period is treated here for inundation analysis. The inundation of Nagoya city due to heavy rain with considering and without considering global warming is analyzed.

1) Case A: Without considering global warming i.e. mean sea level 0.0m

2) Case B: Considering sea level rise due to global warming i.e. mean sea level 0.95m.

In case A mean sea level is zero i.e. the present situation of the sea level. In case B rise of sea level due to global warming. In each case, a 12 hours periodic fluctuation of sea level is considered. The inundation scenario due to possibility rainfall 10 years return period of probability rainfall is analyzed. The validity of the inundation model is explained in Takeda et al (2004) and Parameshor et al (2006). In this case, storm surge is not considered and the estuary gate of the Hori River is remains open in this analysis.

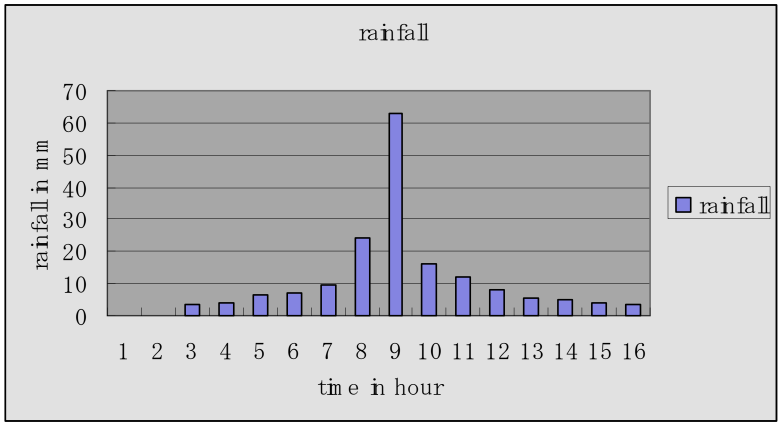
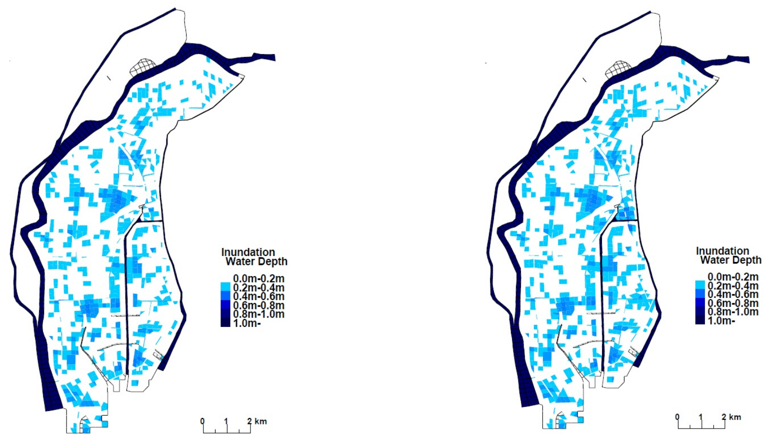


Fig. 4 Rainfall

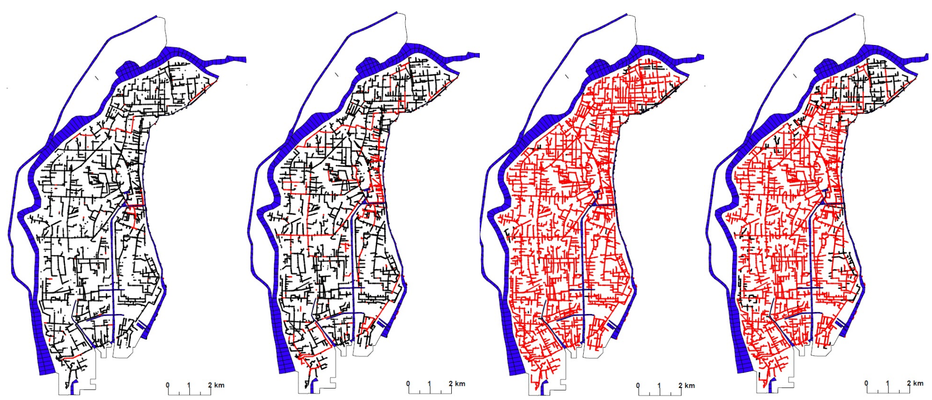
Results and Discussion

The inundation situation of the Nagoya city is studied. Simulation of inundation due to heavy rain with considering global warming (Case A) and without considering global warming (Case B) at each hour of lag time are analyzed. Maximum inundation appears at zero lag time i.e., the peak of rainfall overlap with peak of high tide. Maximum inundation appears at 9 hours of computation period. Fig.5 Case A and Case B shows the maximum inundation .By comparing case A and Case B of Fig. 5, it is found that inundation in the case B is more than the inundation in the case A it is due to the rise of sea level. The city drainage is connected to the river through pumps hence the depth and area of inundation is depends on pump capacity. Fig. 6 and shows the simulation of sewer system. The black color in the figure is the sewer line and the red color is the sewer line full of water. Simulations at 3 hours, 6 hours, 9 hours and 12 hours of computation period in case A and case B are shown in figure. Figure shows that initially more red lines appear in case B than in case A, but whole sewer lines are filled with water at 9 hours of computation period. After 9 hours of computation period, the water spread out from the man hole and inundated. Fig. 7 shows the inundated water volume with time. In case B, the peak of inundated water volume is larger than in case A due to the rise of sea level. Then up to 9 hours of computation period, the inundated water volume is more or less same.



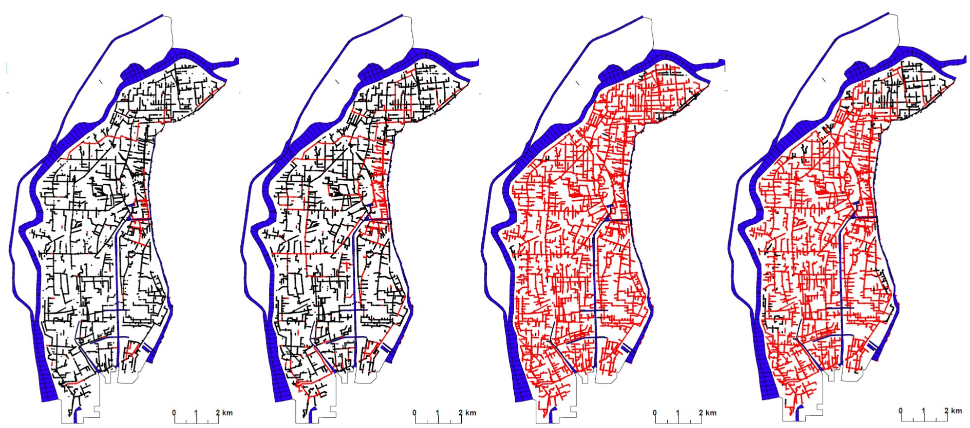
Case A Case B

Fig. 5 Maximum inundation



3 hours 6 hours 9 hours 12 hours

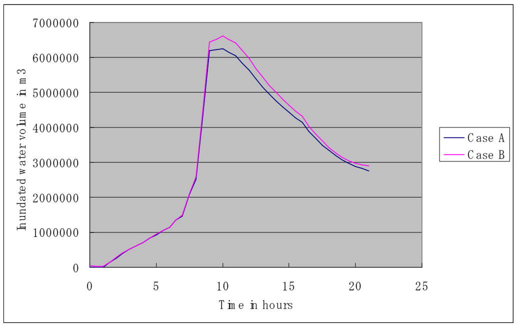
Case A



3 hours 6 hours 9 hours 12 hours

Case B

Fig 6 Simulation of sewer system



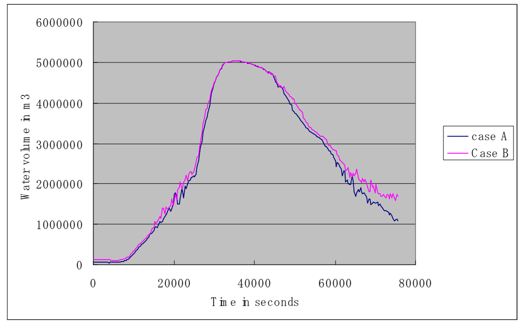


Fig. 7 Inundated water volume Fig. 8 pump discharge

After 9 hours of computation the inundation water volume in the case B is more than in the case A. Fig. 8 shows the water discharge through pumps. Fig. 8 shows the pump discharge with time. The maximum pump discharge in both cases is shown in figure 8

Conclusion

From this study, it is found that the Nagoya city will be suffered from the inundation problem caused by sea level rise due to global warming .The main affected area will be the densely populated city area which lies between Hori River and Nakagawa canal. Inundation situation is not severe in the case of expected rainfall of 10 years return period and considering effect of global warming. Moreover, the existing sewer system is effective to control the inundation. Analysis result can be used for future planning of the city.

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