International Conference on Sustainable Built Environments

Special Session:
Natural Systems to Control "Water Resources Pollution" and "Water Hazards"

13th & 14th December, 2010

University of Peradeniya
and
Earl's Regency Hotel, Kandy,
Sri Lanka

Supported by

Asia Africa Science Platform Program
By Japan Society for the Promotion of Science (JSPS)

December 2010

Proceedings of the Special Session of the International Conference on:

SUSTAINABLE BUILT ENVIRONEMENTS

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Asia Africa Science Platform Program by Japan Society for the Promotion of Science (JSPS)

PROGRAMME

Date *13-December*
Venue *Executive Lounge @ Earl's Regency Hotel, Kandy*

Session 1 – Chair*- Dr. Gemunu Herath / Dr. Shoichiro Hamamoto*

13:30 Welcome Speech and Introduction for AA-CORE program
Dr. M.I.M. Mowjood/University of Peradeniya

13:40 Guest Speech
Prof. S.B. Weerakoon / Dean, Faculty of Engineering, University of Peradeniya

13.50 Prof. Norio Tanaka / Saitama University
Key note Speech
Tsunami force mitigation by tropical coastal trees, Pandanus odoratissimus and Casuarina equisetifolia, considering the effect of tree breaking

14:10 Dr. Jagath Manatunge / University of Moratuwa
Socioeconomic consequences due to alterations of coastal lagoon ecosystems

14:25 Prof. Yasushi Sasaki / Saitama University
The Role of human activities for the wetland ecosystem and water qualities, in case of Japanese wetland

14.40 Dr. Tilak P. D. Gamage / University of Ruhuna
Impact of hydrological changes on the stability of coastal water-bodies and its consequences; a study based on four lagoons in southern Sri Lanka

14.55 Dr. Junji Yagisawa / Saitama University
Effect of physical tree characteristic and substrate condition on maximum overturning moment

15.10 Mr. Gayan Gunaratne / University of Moratuwa
Water Balance and Renewal time of Rekawa Lagoon, Sri Lanka; A restorative approach.

15:25-15:45 Tea Break

Session 2 - Chair *Dr. Jagath Manatunge / Dr. Junji Yagisawa*

15:45 Invited Presentation
Mr. M.A.M.S.L. Attanayake / Deputy General Manager, National Water Supply & Drainage Board

16.00 Mr. Harsha Ratnasooriya / University of Moratuwa
Tsunami Hazards: Impact Mitigation Characteristics of Coastal Vegetation

16:15 Dr. Shoichiro Hamamoto / Saitama University
Effects of Moisture Content and Shrinkage on Soil-Thermal Properties for Peat Soils in Japan

16.30 Dr. S. K. Weragoda / National Water Supply and Drainage Board
Application of Floating Wetlands at Tropical Context for Lake Water Reclamation

16.45 Mrs. Ayomi Witharana
Zinc Adsorption by Low-cost Sorbent materials: Clay tile, Brick, Sawdust and Rice husk

17.00 Mr. Methsiri Samarakoon / Saitama University
Effectiveness of coastal forests in mitigating tsunami damage at eastern coast of Sri Lanka

17:15 Mrs. G.M.P.R. Weerakoon / University of Peradeniya
Performance evaluation of subsurface flow constructed wetland systems under variable hydraulic loading rates

17:30 Mr. Yuta Yanase / Saitama University
Consolidation characteristics for Sri Lankan and Japanese clays: Void index in relation to stress states and sedimentation environment

17.45 Mr. Sisira Karunaratne / University of Peradeniya
Analysis of drag force characteristics of real trees with three different types of vegetation for bio-shield in coast

18.00 Mr. I.S.K. Wijayawardane / University of Moratuwa
Coastal Erosion: Investigations in the South - West Coast of Sri Lanka

18.15 Closing Remarks Dr. Shameen Jinadasa

Preface

The JSPS AA Science Platform Program is designed to create high potential research hubs in selected fields within the Asian and African regions, while fostering the next generation of leading researchers. The three-year program proposed by Saitama University collaborating with three Sri Lankan universities (Univ. of Moratuwa, Univ. of Peradeniya and Univ. of Ruhuna) has been selected as one of the promising distinguished programs by the Japan Society for the Promotion of Science (JSPS). Exchanges will be conducted under the leadership of the core institution (Saitama University) and joint research, seminars and other scientific meetings, and researcher exchanges will be organized and carried out effectively under the program. It is also anticipated that the hubs formed by the core institutions will continue to carry out important research activities after funding for the project has ended.

I am very happy to hold the seminar of the program entitled 'JSPS AA Science Platform Program ' with The special session of International Conference on Sustainable Built Environments.

I hope the seminar will provide an excellent opportunity to establish fruitful international collaboration between the above-mentioned universities.

I would like to thank to Prof. S.B. Weerakoon, Prof. K.D.W. Nandalal, University of Peradeniya, Dr. Gemunu Herath, Dr. M.I.M. Mowjood and Dr. Shameen Jinadasa, coordinators from Univ. of Peradeniya, Dr. Jagath Manatunge, Sri Lankan Coordinator for the JSPS AA Science Platform Program from University of Moratuwa and Dr. Tilak Priyadarshana, Coordinator from University of Ruhuna, for their efforts in organizing this seminar. I also thank Mr. M.A.M.S.L. Attanayake for delivering an invited presentation at this seminar. Finally, postgraduate student coordinators Mr.Sisira Karunarathne, Gayan Gunarathne and Mr. Methsiri Samrakoon have played a key role in planning of this special session at International Conference.

Norio Tanaka
Coordinator of JSPS AA Science Platform Program on
'Development of bio-engineering by vegetation and for wetlands as a solution of environmental and natural disaster problems for expanding urban fringe zone in Asia'
Institute for Environmental Science and Technology,
Graduate School of Science and Engineering,
Professor at Saitama University,
Japan

Message from Co-Chairs

Prof. Ranjith Dissanayake
University of Peradeniya

Prof. M. T. R Jayasinghe
University of Moratuwa

Prof. P. A. Mendis
University of Melbourne

The building sector needs a new wave of innovation to drive dramatic reductions in environmental impacts while sustaining economic growth and improving social outcomes.

The International Conference on Sustainable Built Environment (ICSBE) –state of the art, brings together academics, students, other researchers and practitioners from Sri Lanka and overseas to exchange ideas and experiences on their recent research in all areas of sustainable built infrastructure. As awareness of climate change, natural disasters, diminishing natural resources and energy costs increases, the demand for sustainable design and construction is increasing at an unprecedented rate. Participants will attend high quality presentations related to those areas by scientists representing both industry and academia.

In addition there are special sessions on nanotechnology in construction organized by NANCO and the session on Natural Systems to Control "Water Resources Pollution" and "Water Hazards" Conducted by Saitama University, Japan. There is also the preconference International workshop on "Performance Based Review and Design of Tall Buildings". There are a number of world recognized experts presenting keynote speeches during the conference.

This conference represents a unique opportunity for meeting colleagues and friends, exchanging ideas, and those about research development work. The support of Institution of Engineers Sri Lanka (IE SL) is deeply appreciated. We must also express our sincere thanks to all who contributed their time and great effort to make the conference possible. Our special thanks go to the organizing committee. We would also like to thank all the reviewers of papers, whose reviews have been very important to maintain the quality of the conference.

We are delighted that the Hon. Prime Minister, Mr. D.M. Jayaratne and Hon. Higher Education Minister, Mr. S. B. Dissanayake have accepted our invitation to open the conference.

The Conference will deliver an awesome volume of information on sustainability initiatives in all building sectors from around the globe, with up to 9 sessions from a diversity of focus groups and organisations presenting their latest findings. We would like to invite participants from all sectors, private and public, to join this important

Message from the Dean, Faculty of Engineering, University of Peradeniya

I am pleased to send this message to the publication of the special session on 'Natural systems to control water resources pollution and water hazards' jointly organized by the Civil Engineering Departments of Saitama University, University of Peradeniya, University of Moratuwa, University of Ruhuna at the International Conference on Sustainable Built Environments.

With the economic development and urbanization, increase of waste generation demands sustainable means of pollution control to preserve water resources. On the other hand, the water related natural disasters caused by inland water have become more frequent, the damage in coastal regions by coastal storms and tsunamis are enormous. Therefore, the utilization of natural systems to protect the people, infrastructure and the environment by natural system itself needs to be investigated and adopted as much as possible for eco-friendly development. I believe this special session would provide a forum to discuss and share the knowledge and finding based on research and practice on this subject.

I congratulate the organizers and contributors to this special session who made another activity under our existing collaboration with Saitama University a reality. I wish the special session of the conference all the success and wish the collaboration among our partner institutions grow further.

Prof. S .B. Weerakoon,
Professor in Civil Engineering
Dean, Faculty of Engineering
University of Peradeniya
Peradeniya,
Sri Lanka

Message from AA – CORE project coordinator

It indeed gives me a great pleasure to send a message to the ICSBE Special Session to be held at the Earl's Regency Hotel, Kandy on 13th of December 2010. I am happy to note that the ICSBE Special Session would be an important academic event of the partner Universities. It is a very good opportunity for our academic staff and researchers to present their research endeavors. Research, or the incessant search for new knowledge, is an integral part not only of any university worthy of its name, but also of all human enterprise.

The academics circle engaged in this programme together with other staff are making their name in many fields of knowledge and expertise. The ICSBE Special Sessions will facilitate our academics, staff and students in developing and shaping their research skills and capability.

I am sure that the publication of the research papers presented at the ICSBE Special Session will be an incentive to our researchers for future endeavors in their research areas of interest and expertise.

Dr Tilak P. D. Gamage

Dean, Faculty of Fisheries and Marine Sciences & Technology,

University of Ruhuna,

Matara,

Sri Lanka

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TSUNAMI FORCE MITIGATION BY TROPICAL COASTAL TREES, *PANDANUS ODORATISSIMUS* AND *CASUARINA EQUISETIFOLIA*, CONSIDERING THE EFFECT OF TREE BREAKING

Norio Tanaka [1, 2], Nguyen Ba Thuy [3]

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Abstract: A numerical model based on two-dimensional nonlinear long-wave equations that include drag forces and turbulence induced shear force due to the presence of vegetation was developed for estimating tree breaking. The numerical model was then applied to a coastal forest, where two dominant tropical vegetation tree species were considered, *Pandanus odoratissimus* and *Casuarina equisetifolia*. Quantitative effects of the coastal forest destruction by tsunami on the decrement of tsunami force behind the forest were evaluated with or without including the destruction mode into the model. The analysis satisfies the previous field investigation knowledge that the critical breaking tsunami water depth is around 80% of the tree height when tree height is larger than 2m for *P. odoratissimus*. *P. odoratissimus* can reduce tsunami force higher than *C. equisetifolia* due to the complex of aerial root structures. Even when the trees are destructed at just above the aerial roots, tsunami force reduction rate are decreased by 20%, 10% for 2-4m trees, 6-8 m trees, respectively, because of the existence of dense aerial roots in case of a *P. odoratissimus*. The previous numerical models that do not include the breaking phenomena have a possibility to overestimate the vegetation effect for reducing tsunami force. The reduction of tsunami mitigation effect by breaking is larger for *C. equisetifolia*, however their growth rate is larger than *P. odoratissimus* and is hardly broken. The combination of *P. odoratissimus* and *C. equisetifolia* was recommended as a vegetation bioshield to protect coastal area from tsunami hazards.

Keywords: Vegetation bioshield, Trunk breakage, *Pandanus odoratissimus*, *Casuarina equisetifolia*, Tsunami force and moment acting on tree trunk

1 Introduction

Coastal vegetation has been found to play a significant role in reducing the tsunami energy and damage to humans and properties (Shuto, 1987; Danielsen et al. 2005; Tanaka et al., 2007), although their role is still questioned due to the absence of adequate studies (Kerr and Baird, 2007). Based on the field investigations carried out in Sri Lanka and Thailand after the Indian Ocean tsunami and in Indonesia after the Java tsunami on 2006, Tanaka et al. (2007) pointed out that *Pandanus odoratissimus* grown on beach sand is especially effective in providing protection from tsunami damage due to its density and complex aerial root structure, but it is not strong enough to withstand more than 5m-tsunami. The tsunami water depth for bending or breaking *P. odoratissimus* was observed above 80% of the tree height (Tanaka and Sasaki, 2007). On the other hand, *Casuarina equisetifolia*, one of the other dominant vegetation was found to be effective in providing protection from tsunami due to its higher density, especially they are young. *C. equisetifolia* does not have aerial roots and its trunks were rarely broken, however, young *C. equisetifolia* (less than 10cm-trunk diameter) were broken at the Indian Ocean tsunami (Tanaka et al., 2007, 2009). Observation reported that most of the damage to *C. equisetifolia* of which trunk diameter is larger than 15 cm was uprooting by scouring around roots. However, the uprooting was limited at the front region of forest against tsunami.

Some previous studies have discussed the effects of vegetation on tsunami mitigation based on the numerical simulation results (Nandasena et al. 2008, Tanaka et al. 2009, Thuy et al. 2009a and b, Thuy et al. 2010). However, the effect of tree breakage was not considered, because the tsunami water depth in their simulation range was less than 80% of the tree height.

Therefore the objective of this study is to know quantitatively how the breaking of trees in a forest affects on the tsunami disaster mitigation effects. In the present paper, a coastal forest of *P. odoratissimus* or *C. equisetifolia* was considered and potential tsunami force and bending moments on a tree were studied by numerical simulations. The numerical model is based on two-dimensional nonlinear long-wave equations as the same in Thuy et al. (2009a) which was developed for including tree breaking effect. The numerical results are validated with field measurement data of the threshold water depth for tree breaking, and then breaking length, reduction of water depth and potential tsunami force are discussed with the tree growth stage.

2 Mathematical model and calculation procedure

2.1 Governing equations

The governing equations are two-dimensional nonlinear long-wave equations that include drag and eddy viscosity forces due to interaction with vegetation. The continuity and the momentum equations are respectively:

$$\frac{\partial \zeta}{\partial t} + \frac{\partial (dV_x)}{\partial x} + \frac{\partial (dV_y)}{\partial y} = 0 \tag{1}$$

$$\frac{\partial V_x}{\partial t} + V_x \frac{\partial V_x}{\partial x} + V_y \frac{\partial V_x}{\partial y} + g\frac{\partial \zeta}{\partial x} + \frac{\tau_{bx}}{\rho d} + \frac{F_x}{\rho d} - \frac{E_{Vx}}{d} = 0 \tag{2}$$

$$\frac{\partial V_y}{\partial t} + V_x \frac{\partial V_y}{\partial x} + V_y \frac{\partial V_y}{\partial y} + g\frac{\partial \zeta}{\partial y} + \frac{\tau_{by}}{\rho d} + \frac{F_y}{\rho d} - \frac{E_{Vy}}{d} = 0 \tag{3}$$

where,

$$\vec{\tau}_b = \frac{\rho g n^2}{d^{1/3}} \vec{V}\left|\vec{V}\right| \tag{4}$$

$$\vec{F} = \gamma \frac{1}{2} \rho C_{D-all} b_{ref} \vec{V}\left|\vec{V}\right| d \tag{5}$$

$$E_{vx} = 2\frac{\partial}{\partial x}\left(d\nu_e \frac{\partial V_x}{\partial x}\right) + \frac{\partial}{\partial y}\left(d\nu_e \frac{\partial V_x}{\partial y} + d\nu_e \frac{\partial V_y}{\partial x}\right) \tag{6}$$

$$E_{vy} = 2\frac{\partial}{\partial y}\left(d\nu_e \frac{\partial V_y}{\partial y}\right) + \frac{\partial}{\partial x}\left(d\nu_e \frac{\partial V_x}{\partial y} + d\nu_e \frac{\partial V_y}{\partial x}\right) \tag{7}$$

x and *y* are the horizontal coordinates; V_x and V_y are the depth-averaged velocity components in *x* and *y* directions respectively; *t* is the time; *d* the total water depth ($d=h+\zeta$); *h* the local still water depth (on land, the negative height of the ground surface); ζ the water surface elevation; *g* the gravitational acceleration; ρ the water density; *n* the Manning roughness coefficient (=0.025 in this tudy); γ the tree density (number of trees/m^2). $C_{D\text{-}all}$ is the depth-averaged equivalent drag coefficient considering the vertical stand structure of the trees, which was defined by Tanaka et al. (2007) as:

$$C_{D-all}(d) = C_{D-ref}\,\frac{1}{d}\int_0^d \frac{b(z_G)}{b_{ref}}\frac{C_D(z_G)}{C_{Dref}})dz_G = C_{D-ref}\,\frac{1}{d}\int_0^d \alpha(z_G)\beta(z_G)dz_G \tag{8}$$

where $b(z_G)$ and $C_D(z_G)$ are the projected width and drag coefficient of a tree at the height z_G from the ground surface, and b_{ref} and $C_{D\text{-}ref}$ are the reference projected width and reference drag coefficient of the trunk at z_G=1.2 m in principle, respectively. The eddy viscosity coefficient v_e is expressed in the *SDS* turbulence model (Nadaoka and Yagi 1998, Thuy et al. 2009a). For details of $\alpha(z_G)$, $\beta(z_G)$, and $C_{D\text{-}all}$ of *P. odoratissimus* and *C. equisetifolia*, see Tanaka et al. (2007) and Thuy et al.(2010).

2.2 Definitions of tsunami force and bending moment on a tree

The tsunami force vector ($\vec{F}^*$) in the present study is defined by the following equation:

$$\vec{F}^* = \frac{1}{2}\rho d\vec{V}|\vec{V}| \qquad (9)$$

This is the potential tsunami force integrated over the inundation depth and corresponds to the total drag force due to the tsunami acting on a virtual tall column of unit width and a unit drag coefficient (Thuy et al., 2010).

On the other hand, the tsunami bending moment vector ($\vec{M}_{Tree}$) at a critical height (h_c) of the tree from the ground surface is expressed as follows:

$$\begin{aligned}\vec{M}_{Tree} &= \frac{1}{2}\rho C_{Dref} b_{ref}\vec{V}|\vec{V}|\int_{h_c}^{d}\alpha\beta(z_G - h_c)dz_G, \quad h_c < d \le H_{Tree} \\ &= 0, \qquad d \le h_c\end{aligned} \qquad (10)$$

where h_c= is critical height (top of aerial of for *P. odoratissimus*, =0 for *C. equisetifolia*). The notation of $\vec{M}_{Tree}$ is replaced by $\vec{M}_P$ and $\vec{M}_c$ hereafter for *P. odoratissimus* and *C. equisetifolia*.

Tanaka et al. (2009) proposed an empirical formula to calculate the breaking moment (unit: Nm) M_{BP} and M_{CP} of *P. odoratissimus* and *C. equisetifolia*. The equation converted into SI unit is as follows:

$$\begin{aligned}&M_{BP}=4.45\ (100b_{ref})^{2.62} \qquad \text{for } P.\ odoratissimus \\ &M_{BC}=4.90\ (1.5 \times 100b_{ref})^{3} \qquad \text{for } C.\ equisetifolia\end{aligned} \qquad (11)$$

where the empirical constants 4.45 and 4.90 have a dimension.

2.3 Method of numerical simulations, Coastal topography and forest conditions

A set of the above equations is solved by the finite-difference method of a staggered leap-frog scheme which is widely used in numerical simulations of tsunami. The numerical scheme is described in detail in Thuy et al. (2009a). A sinusoidal incident tsunami was given as a time-dependent boundary condition at the most offshore side of the wave-generation zone. In the numerical simulation, the uniform grid size of 2.5 m was applied.

A uniform coastal topography with the cross-shore section perpendicular (*x*-axis) to a straight shoreline, as shown in Figure 1(a), was selected as a model case. The bed profile of the domain consists of four slopes, *S*=1/10, 1/100, 1/50, and 1/500. The offshore water depth at an additional wave-generation zone with a horizontal bottom is 100 m below the datum level of *z*=0. The tide level at the attack of the tsunami was considered to be 2 m, and therefore the still water level is 2 m above the datum level. The direction of the incident tsunami is perpendicular to the shoreline. In the present paper, the run-up of the first wave only is discussed. The coastal forest starts at the starting point of the 1/500 slope on the land (*x*=5700 m), where the ground is 4 m above the datum level (2 m above the tide level at the tsunami event). The forest was assumed to extend finite in the direction of the shoreline (*y*-axis). The value of $C_{D\text{-}all}$ varied with the total depth *d* (inundation depth) because the projected width *b* and the drag coefficient C_D vary with the height from the ground surface z_G. Figure 1 (b) shows the variation of $C_{D\text{-}all}$ of *P. odoratissimus* by water depth with tree growth stage (2, 4, 6 and 8 m tree height).

3 Results and discussion

3.1 Tsunami bending moment on a tree –Breaking of P. odoratissimus

Figure 2(a) and (b) shows the comparison of time profile of water depth and velocity in front and behind the forest for two models: N.B.M. and B.M.. The velocity and water depth behind the forest is increased after tree breaking owing to the reduction in drag resistance. However, in front of vegetation, the water depth decreases while the velocity increases due to the reduction of the reflection from vegetation.

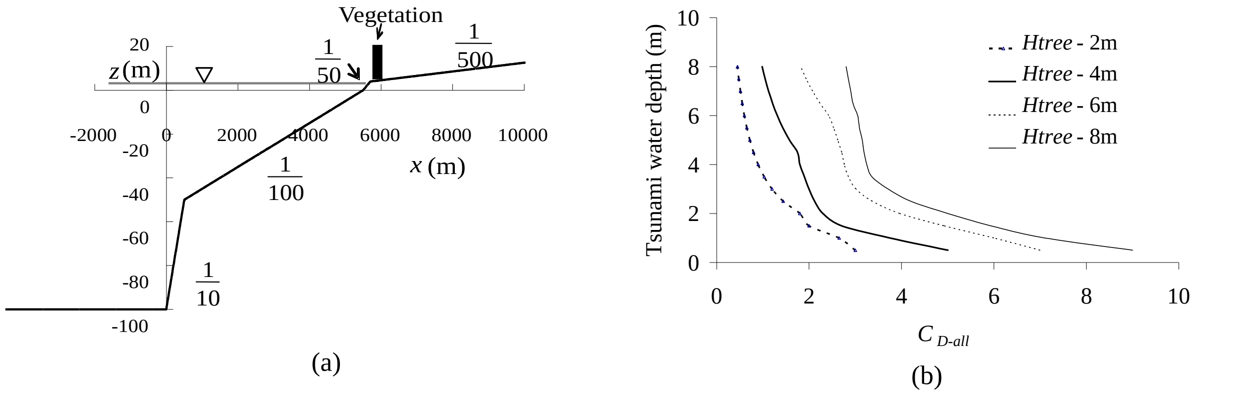


Figure 1: *Condition of numerical simulation, (a) schematic of topography for numerical simulation, (b) variation of $C_{D\text{-}all}$ with water depth for four cases of P. odoratissimus height*

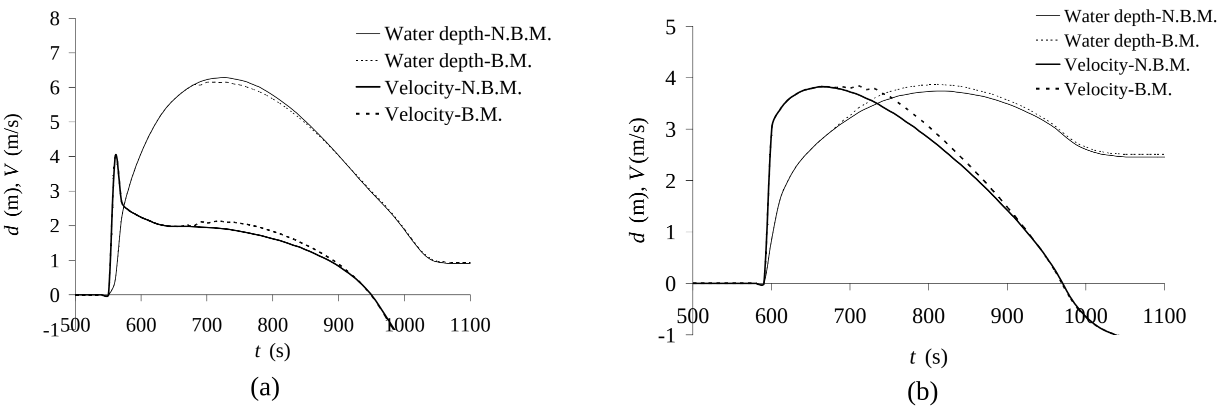


Figure 2: *Time profile of water depth and velocity. (a) at front of forest, (b) at behind the coastal forest*

Figure 3 shows spatial distribution of the maximum tsunami moments along the forest for two models. According to the result, the damage length of forest by B.M. is about 77.5 m (77.5%), and increased in comparison with N.B.M. due to the decrease in vegetation resistance in the front area where vegetation was broken.

Figure 4 shows the relationship between the reduction rate of water depth (d_{max}/d_{max0}), tsunami force (F^*_{max}/F^*_{max0}) and survival rate of *P. odoratissimus* (number of unbroken trees /total tree) and incident tsunami water depth, where subscript 0 indicates the case of no forest. The results show that trees start breaking at H_{F0}=4.8 m. When H_{F0} reaches to 5.5 m, all the trees are broken. The reduction of water depth and tsunami force is about 25 and 54 % respectively, and it decreases when the incident tsunami water depth exceeds the initial breaking of water depth (I.B. in the figure).

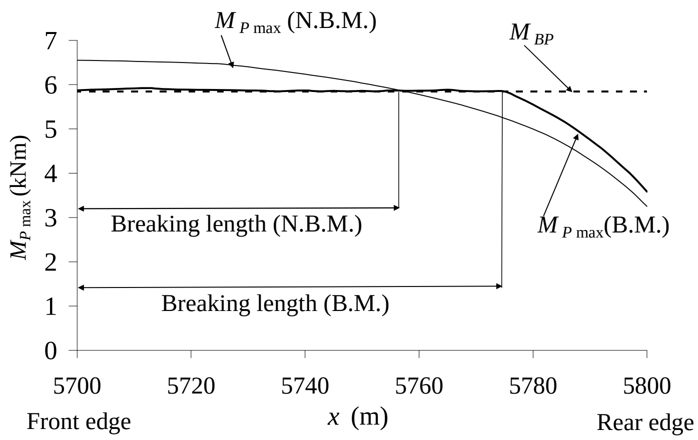


Figure 3: *Damage length simulated by two numerical models*

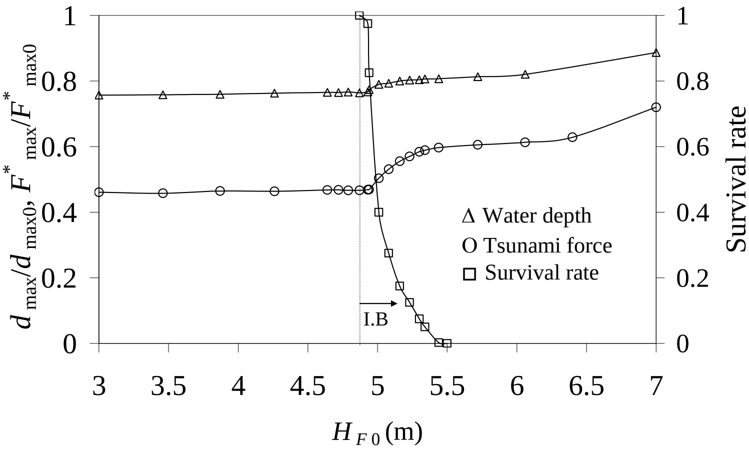


Figure 4: *Relationship between incident tsunami water depth (at the front of forest) and reduction rate of water depth (d_{max}/d_{max1}), tsunami force (F^*_{max}/F^*_{max1}) and survival rate (number of unbroken trees /total tree) of P. odoratissimus, where subscript 0 indicates the case of no vegetation*

3.2 Damage of P. odoratissimus by tsunami with tree growth stage - Validation the numerical results with field measurement data

The threshold water depths for tree breaking obtained from field measurement in Sri Lanka and Thailand after Indian Ocean tsunami in 2004 and Indonesia in Java tsunami 2006 were used to validate the numerical model. Breaking of vegetation depends on the tsunami height and the tree height. Figure 5(a) shows the observation of tree conditions (broken or not) against tsunami water depth for different tree height. As already discussed by Tanaka et al. (2009), most of the tree was broken when the tsunami water depth exceeds 80% of tree height. To validate the numerical model for the observed threshold values of water depth for tree breaking with tree growth stage, the critical height for tree height of 2, 4, 6, 8 m were selected as 0.5, 1, 2, 2 m respectively, and corresponding the reference diameters are 0.1, 0.124, 0.155 and 0.195 m respectively based on the field observation. The breaking moment for tree height of 2, 4, 6 and 8 m are 10.7, 5.85, 3.25 and 1.85 kNm, respectively. Figure 5(b) shows the numerical result of the threshold water depth (including the increase of water surface elevation due to reflection by the vegetation) of tree breaking for different tree height with different forest width. The line represents the height of 80% of tree height. This is the minimum height of water depth for tree breaking (Tanaka et al. 2009). The threshold water depth is simulated around the observed breaking line, and it increases with increasing in forest width, mainly due to the decrease of velocity.

The reduction of tsunami energy behind a coastal forest depends on the height of tree due to the effect of vertical configuration and tree diameter. $C_{D\text{-}all}$ depends on the height of tree and vertical configuration. Figure 6 shows the reduction rate of tsunami force against incident tsunami water depth, where the forest width was selected of 100 m and tree density of 0.2 trees/m^2 for each tree height case. The initial incident tsunami water depth for tree breaking for the tree height of 2, 4, 6 and 8 m are of 3.9, 4.2, 4.8 and 5.3 m respectively. The taller tree can be reduced higher tsunami energy than the shorter tree. For each tree height case the reduction rate of tsunami force increases as the incident tsunami water depths is higher than the I.B. values. However, for tree height of 2 and 4 m, the reduction rate of tsunami force increases suddenly, and become almost constant as the incident tsunami water depth increases. This is due to all trees can be broken when water depth is larger that the threshold value and the drag resistance by the remaining short aerial root is smaller than the case of 6 and 8 m-trees.

3.3 Breaking of C. equisetifolia and effect of two layers vegetation

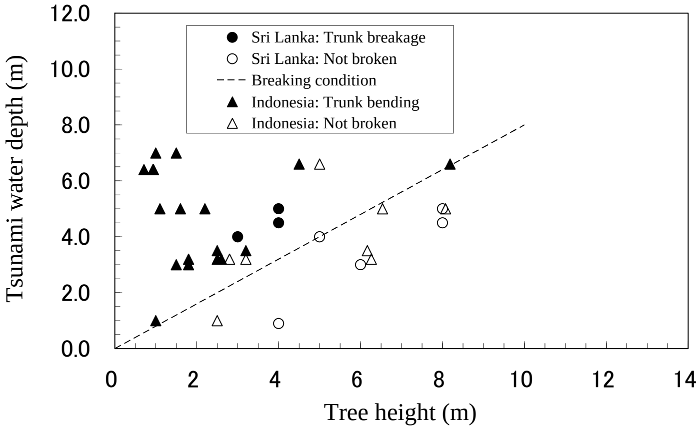
In this section, the effect of young *C. equisetifolia* trees on tsunami reduction was discussed with considering the bending effect. *C. equisetifolia*. Observation in Laem Son National park in Thailand (Tanaka et al., 2007) showed that only young *C. equisetifolia* with the trunk diameter about 0.07 m was bending and inclined under the tsunami height of 5 m. The angle φ between the trunk and ground was observed as 15-45º. The bending tree as well as the inclined angle of trunk would make a role on the reduction of tsunami energy, and therefore the bending effect of *C. equisetifolia* should be discussed.

For the cylinder inclined to the flow direction, the drag coefficient may change. The present study used a simple recommendation formula from Post-Tensioning Institute PTI (Poulin and Larsen 2007) on the relation of drag coefficient against the inclined angle as:

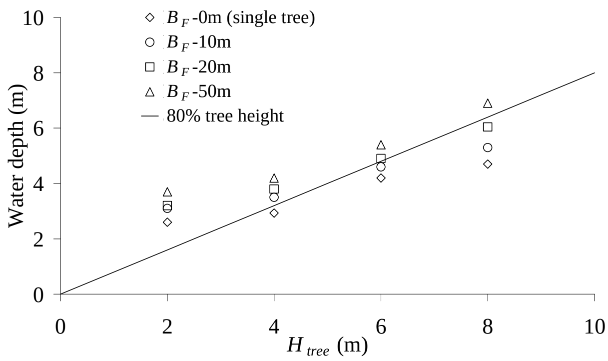
$$C_D = C_{D0} \sin^3 \varphi \qquad (12)$$

Where, C_{D0} is the drag coefficient for the case the flow has direction perpendicular to the trunk, corresponding to V_0 (velocity component perpendicular to the trunk). The project width of vegetation was also changed and depends on the inclined angle.

Figure 7 shows the reduction rate of tsunami force with incident tsunami water depth for three cases of tree growth stage corresponding to trunk diameters of 0.07, 0.1 and 0.15 m, where the forest width, tree density and inclined angle (if breaking occurs) are kept as 100 m and 0.2 trees/m^2 and 30º. The initial breaking tsunami water depth for the tree diameter of 0.07, 0.1 and 0.15 m are 4.9(5.5), 6.1(7.3) and 7.8(9.9) respectively. The value in brackets indicates the height of water depth including the reflection by the vegetation. According to the result, *C. equisetifolia* is stronger than *P. odoratissimus* against tsunami action. The tree with diameter of 0.07 and 0.1 m was broken by 5.5 and 7.3 m tsunami height. Tanaka et al. (2007) also found the same trunk diameter can be broken by the tsunami height of 5 m (for 0.07 m trunk diameter at Laem Son National park- Thailand) and 10 m (for 0.1 m trunk diameter at Phra Thong Island-Thailand). For all cases the reduction rate of tsunami force increases suddenly as the



(a)



(b)

Figure 5: *Damage of P. odoratissimus (a) observed data in Java-Indonesia, (b) Variation of water depth (the threshold of tree broken) with tree height. The line presents the height of 80 % of tree height*

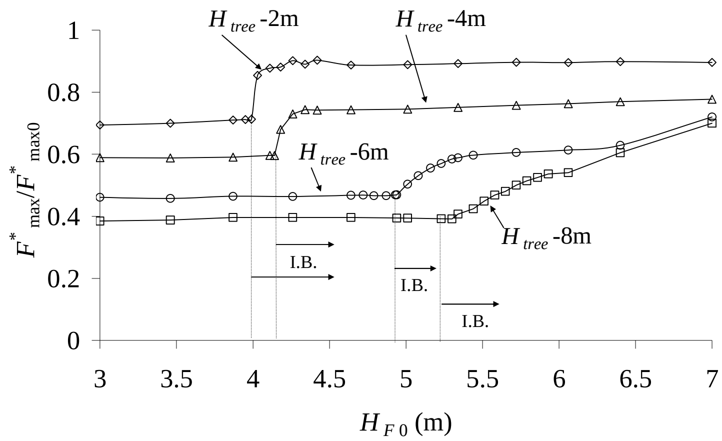


Figure 6: *Reduction of tsunami force (F^*_{max}/F^*_{max0}) with incident tsunami water depth, note that subscript 0 indicates the case of no vegetation*

incident tsunami water depths exceeds the threshold breaking values owing to the reduction in drag resistance after tree breaking. With the same forest conditions (B_F, γ), *P. odoratissimus* can reduce tsunami energy higher than *C.equisetifolia* due to the complex of aerial root, even if the breakage occurs. However, *P. odoratissimus* is not strong when the tsunami water depth greater than 80% of tree height. On the other hand, young *C. equisetifolia* trees (b_{ref}=0.15 m) remain intact by high tsunamis. In fact, young *C.equisetifolia* can grow densely in natural coastal area and its growth rate is higher than *P. odoratissimus*. Therefore, the combination of *P. odoratissimus* and young *C. equisetifolia* would be effective to protect tsunami (Tanaka et al., 2007, 2009). The present study recommends combined vegetation of *P. odoratissimus and C. equisetifolia* as a green belt to protect coastal area from tsunami hazard considering tree breakage phenomenon.

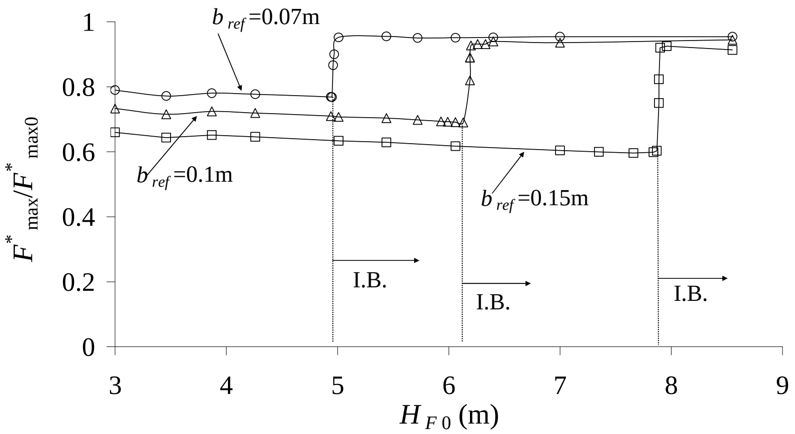


Figure 7: *Reduction rate of tsunami force (F^*_{max}/F^*_{max0}) with incident tsunami water depth in the front of forest, note that subscript 0 indicates the case of no vegetation*

4 Summary and conclusions

Numerical model for estimating tsunami bending moment on a tree and including tree breakage was developed, and the damage length of vegetation, and reduction of tsunami energy were discussed with tree growth stage of *P. odoratissimus* and *C. equisetifolia*, those are dominant in tropical countries. This study can be summarized as follows:

1. The threshold of water depths for starting tree trunk breakage is increased with increasing the forest width, and the analysis satisfies the field investigation results that the critical breaking tsunami water depth is around 80% of the tree height for *P. odoratissimus*.
2. The reduction in water depth and tsunami force decrease when the tsunami water depth exceeds the critical value for breaking. The previous numerical models that do not include the breaking phenomena have a possibility to overestimate the vegetation effect for reducing tsunami force.
3. *C. equisetifolia* is stronger than *P. odoratissimus* against tsunami action. *P. odoratissimus* can reduce tsunami energy higher than *C .equisetifolia* due to the complex of aerial root structures. The Combined vegetation of *P. odoratissimus* and *C. equisetifolia* can be recommended as a green belt to mitigate tsunami hazard considering tree breakage phenomenon.

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Acknowledgements

This work was supported in part by JSPS AA Science Platform Program. The authors acknowledge emeritus Prof. Tanimoto, Saitama University for his advice.

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THE ROLE OF HUMAN ACTIVITIES FOR THE WETLAND ECOSYSTEM AND WATER QUOLITIES, IN CASE OF JAPANESE WETLAND

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Abstract: Wetland ecosystems and water quality are largely changing due to human activities. A large amount of nutrients are accumulated in wetland ecosystem in a lake, due to activities such as land reclamations, intensive agriculture and eutrophication. Some areas around the Biwa Lake (the biggest lake in Japan), are covered by snow in winter but many alien species including water hyacinth and water lettuce can survive, due to increasing temperature (average temperature increase about 2˚c). In the recent 20 years, it was concerned about global warming for vegetation. Japanese farmers, until today, control the nature by cutting grass and tree, burning, and collect water plants for fertilizing. During last 5 years, Japanese farmer's population has been decreased by 20 % and the farmer's average age was about 66 years old. Now, the same condition happens in the field of fishery and forestry. In near future, the lake area will become marsh, and wetland will become swamp forest and consequently, evaporation range will be increased. Thus we can not keep more water in small ponds and wetlands.

Keywords: land reclamation, eutrophication, global warming, Fushin system, Satoyama

1 Introduction

One of the Japanese mission in the twentieth century was to expand the paddy field for keep food production, like land reclamation of wetland. For example, at the largest Lake Biwa, the wetland surrounding the lake was decreased by 85%, and at the second largest Hachirou-Gata lagoon lake, about 88% of the water area was changed to the paddy field.

Figure 1: *Land reclamation of wetland at second large Hachirou –Gata lagoon lake,where Changed to paddy field about 88% (Akita,Japan)*

2 Japanese agricultural system

Japanese farmers were producing their own main crops and same times were using natural resources well. They also managed and controlled the nature to keep sustainable productions, like harvesting grasses, cutting trees for fire, burning, and collecting water plants for fertilizing, under some traditional rules.

Figure 2: *One of the Traditional utilization of common reed surrounds the Lake Biwa (Ohmi-Hachiman, Shiga).*

3 Japanese traditional civil engineering construction system "Fushin"

Japanese people had a traditional civil engineering construction and maintenance system, called "Fusin".or "Bushin", because there were minimum institutions and facilities for the save of agricultural production to keep their life. Fusin was a traditional community work system of the local people's cooperated.The "Fusin" system had many varieties such as the river Fushin , canal Fushin , lake, pond or lagoon lake Fushin and also road Fushin, and bridge Fushin. The local people constructed irrigation canals, and bridges and maintained them in every years due to the Fushin system.

Figure 3: *Picture of canal Fushin (Left) and river Fushin (Right), worked community peoples cooperated (Sudou, 2004)*

4. Japanese traditional mutual support system

In the past, Japanese farmers had a large number of family mebers about 10 people including children. Even every family members worked, sometimes it needed more man power, specially when harvesting, constricting own houses, thatching new roofs etc. In that time, the community people supported each other. Such mutual support system was also called as "Fusin", for example, thatched roof Fushin, disaster Fushin, tempel or shrein Fushin, and sometimes employment opportunity Fushin.

Each families and communities were working long time by such human activities. In the farms in mountain areas and fishing villages were set up beautiful and functional landscape in harmony, called “Satoyama”.

Figure 4: *Picture of thatched roof Fushin,worked community peoples cooperated. (Sudou, 2004)*

Figure 5: *Picture of harvesting Fushin,worked community peoples cooperated (Sudou, 2004)*

5 Structural change of Japanese agricultural society

After the Second World War, the Japanese society changed remarkably with the advance of Japanese economy. Especially in recent time, Japanese farmer’s society is changed largely. The farmer’s population was decreased by 20% in last 5 years. There will not be any Japanese farmer by 2035 if similar conditions continue. And also, the average age of Japanese farmers is about 66 years old now, the 1% number of village has gone in last 7 years. Japanese traditional agriculture will be broken more quickly. Such decreasing of the farmer population means that nobody will manage and control their field and wetland further. By the last national census, the population of Japanese forester was decreased by 90% in recent 45 years. A similar condition happened in the field of Japanese fishery. Those are examples of advanced nation.

6 The change of the environmental conditions

Due to the intensive agriculture, the wetlands subjected to the conditions of eutrophication, and in the recent 20 years, vegetation influenced to the global warming effect largely.

6-1 Water quality

Water quality of the Lake Biwa was checked at 47 points in every months. Compared with 1979, the transparency and the suspended solids of the water was changed for the better. T-N and T-P was decreased little. But, COD rate is increased now It is about 2.7 mg/l in north part of lake) and 3.4 mg/l.in south part of the lake. On the other hand, yearly average temperature is increased by 1.2 ℃ and water surface temperature is going up about 1.0 ℃.

6-2 The expand of alien species

Some areas around the Lake Biwa (the biggest lake in Japan) are covered by snow in winter but many alien species including water hyacinth and water lettuce can survive, because of increasing temperature (average temperature and water temperature increase 2˚c). In the recent 20 years, it is concerned about global warming for the vegetation. Many alien species from North and South America, from tropical Asia are as follows,

Floating aquatics; *Echhornia crassipes(*water hyacinth), *Pitia stratiote*(water lettuce), *Azolla cristata*
Emergent aquatics; *Alternanthera nodifera Paspalum distichum*
Submerged aquatics; *Elodea nuttallii, Myriophyllum brasilens, Egeria densa*
Terrestrial plants;
Graminae, *Poa, Festuca,Bromus vena, Briza, Eragrostis Paspalum, Sorghum, Vulpia, Lolium, Aira, Andropogon*
Compositae; *Bidens, Eclipta, Taraxacum Gnaphalium, Conyza, Sonchus Helianthus,Erigeron, Solidago Lactuca, Senecio, Galinsogo Stenactis, Aster, Crossocephalum*

7 Conference of the Parties; COP10 in Nagoya, Nagoya Protocol 2010 can assist us ?

The main theme of the conference “the saving efficiency and utilization of genetic resources” is very important. However, in the same time almost local people of the world need general resources of nature sustainably, especially for local peoples depend on the natural resources in the developing countries.

Since techniques and funds for saving natural resources is incompleted, international protocols like Ramsar convention, World Heritage convention, or Biological Diversity convention can not assist such urgent tasks now.

The destruction of the farmer society and creation of aging society means that nobody will take care and control the nature. If Trans Pacific Partnership (TPP) will start, Japanese agriculture will be broken soon probably. In near future, the lake area will be changed to marsh and wetland will be changed swamp forest. Consequently, the evaporation rate will be increased and therefore we can not keep more water in small ponds and wetlands.

Figure 6: *Even Ramsar site ,it can not keep and control wetland condition, full covers aquatiplants,*

8 New Cooperation Work for keeping our Life and Bio-Diversity

After losing the traditional community works, a problem to be solved is that who controls the nature to keep biological diversity and to keep human life in harmony into the future. The alternative works include public office works and volunteer activities.

8-1 : Volunteer activity

Volunteer activities are very important, but the number of volunteer and the groups that interested in nature are still limited in Japan. They don’t have enough powers for control the nature and don’t have sustainability.

Figure 7: *Volunteer activity of harvesting common reed and picked out over grow aquatic plants (Lake Biwa in Sjiga and Sakata lagoon lake in Niigata)*

8-2. Public office work

Public office works are always depended on the budget. Therefore it is not sustainable. And sometimes it has missed the good opportunity of actions by the officials.

Figure 8: *Works of the public office for harvesting of over grow, aquatic plants, (Lake Biwa)*

9 Conclusions

Importance of maintaining the nature is the sustainability. Therefore the leading actor should be the local people who live in this region for managing and controlling the nature in each area, in any case. The government or some non government organizations (NGO) have to support them.

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Acknowledgements

The research staffs of the Institute of Environmental Research Center, Lake Biwa, Shiga Prefecture, Japan. Y.Kaneko, M Nishino and Y.Murakami in Japanese Center for International Studies in Ecology, assisted this project.

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ZINC ADSORPTION BY LOWCOST SORBENT MATERIALS: CLAY TILE, BRICK, SAWDUST AND RICE HUSK

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Abstract: It has been found over the past couple of years rapid growth of population, industrialization and urbanization has first and foremost contributed to the severe water pollution in both surface and ground water. The health hazards associated with heavy metals have been on the rise, particularly the chronic diseases. Lack of tertiary treatment of wastewater may have contributed to this emergent problem, adsorption process is considered as the best available water treatment method and activated carbon has proven to be the best sorbent material which can be used in removing wide variety of pollutants. However, usage of this activated carbon becomes restrict due to its high cost and regeneration cost. Therefore, the present study focuses on low-cost sorbent materials: viz., clay tile, brick, sawdust and rice husks. Laboratory-scale experiments were performed with a synthetic Zinc solution. Results revealed that clay tile material has the highest adsorption capacity (47.6 mg/g) and removal efficiency, (98%), while brick (37.0 mg/g, 86%), sawdust (20.4 mg/g, 80%) and rice husks (15.8 mg/g, 64%) have relatively low adsorption capacities and removal efficiencies, respectively. The separation factor of equilibrium (R_L) indicates favourable isotherms ($0< R_L<1$) for all tested sorbent materials. Among the studied materials clay tile, brick and rice husks are good adsorbent for Zinc (n>2) while sawdust is a moderately difficult material for adsorption of Zinc (n <2).

Keywords: adsorption capacity, low cost sorbent materials**,** Zinc

1 Introduction

Rapid growth of population, industrialization and urbanization has first and foremost contributed to the severe water pollution in both surface and ground water. The main sources of freshwater pollution can be attributed to discharge of untreated sanitary and toxic industrial wastes, dumping of industrial effluents, and runoff from agricultural fields (Bhatnagar and Sillanpa, 2010). Heavy metal contamination has become an increasingly serious problem in recent years. Industrial and municipal wastewaters frequently contain heavy metal ions (Demirbas et al., 2008) such as lead, copper, cadmium, zinc, and nickel, which are amongst the most common pollutants found in industrial effluents (Djeribi and Hamdaoui, 2008). Heavy metal ions are reported as priority pollutants due to their mobility in natural water ecosystems and due to their toxicity. The heavy metal ions are stable and persistent environmental contaminants since they neither be degraded nor destroyed (Bozic et al., 2009). However, selective removal of metal ions in dilute solutions is very difficult by conventional wastewater treatment methods. Therefore, in order to safeguard public health, the social security and accomplish environmental integrity through the application of reliable but low-cost technologies particularly in developing countries.

However, activated carbon has been extensively used for decades, as a good candidate for adsorbing pollutants because porous carbons have a large specific area and a high adsorption capacity, compared with other sorbent materials (Kurniawan et al., 2006). On the other hand, varieties of activated carbon they are expensive and cannot regenerate easily. Later on, there has been a growing demand for an efficient and cost-effective sorbent material to be used as an alternative for activated carbon.

Therefore, the present work investigates the Zinc adsorption capacity for low-cost sorbent materials. To accomplish this, two objectives were defined as:

1. Investigation adsorption behaviours of clay tile, brick, sawdust and rice husks by using Langmuir and Freundlich isotherms and
2. Compare the adsorption behaviour with activated carbon, the industry standard, for Zinc adsorption.

2 Materials and Methodology

The main objective is to develop a cost effective rainwater harvesting system that can be integrated with the central water supply to supplement part of the water used for domestic needs. The following methodology was used:

2.1 Adsorbent

The four low cost adsorbents used in this study were: clay tile, brick, sawdust and rice husks. Each sorbent material was obtained from local industries. They were used directly for adsorption experiments without any pre-treatment. Samples were washed thoroughly with distilled water, dried and ground to obtain a fine powder. Then the powder was washed several times with distilled water till clear water was obtained. Thereafter, it was dried in an oven at 105ºC for 24 hrs. The dried powder was then sieved to separate particles less than 415µm in order to obtain a uniform particle size. The materials were placed in vacuum desiccators for further use.

2.2 Adsorbate

Synthetic Zn solution was used for both the preliminary study and batch experiment. The stock solution of 500 mg/L Zn was prepared using Zinc Sulphate ($ZnSO_4.7H_2O$, analytical grade). Test solutions were prepared from stock solutions with desired dilution with de-ionized water.

2.3 Batch experiments and isotherm studies

Batch experiments were carried out in 1L beakers with 250 ml test solution agitated on a horizontal shaker for 24 hrs at 100 rpm at room temperature (28 ± 3 ºC). For each run, 1.000 g of each adsorbent (clay tile, brick, and sawdust and rice husks) was used. The samples were taken at predetermined intervals. At the end of desired contact time, a beaker was removed from the shaker and allowed for settling the adsorbent. Then, samples were centrifuged and the supernatant was analyzed for residual metal Zn concentration using AAS method, as described in the Standard Methods of Examination of Water and Wastewater (APHA, 1999). Blank runs, with only the adsorbent in 250 ml of deionized water were conducted simultaneously under similar conditions. The amount of metal adsorbed into each adsorbent was calculated by a mass balance equation:

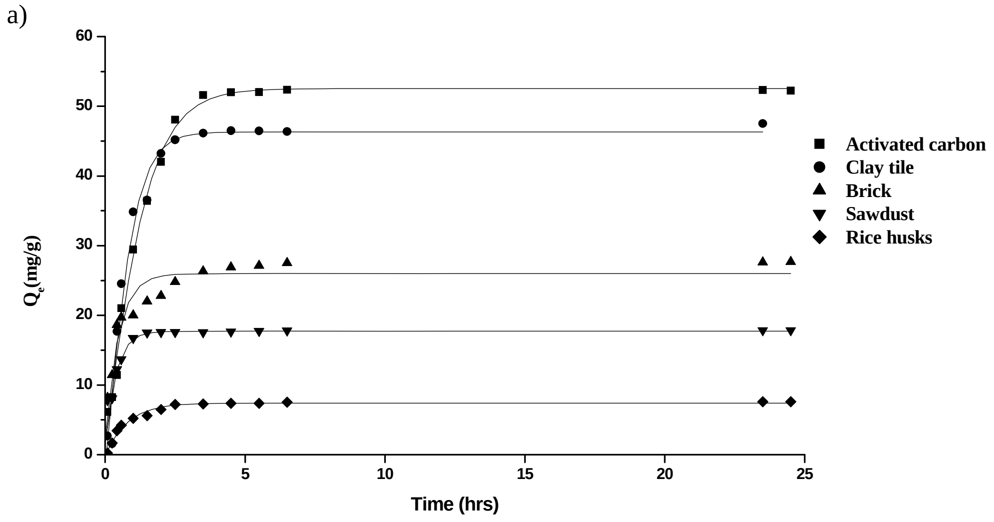
$$Q_e = (C_o - C_e)V/W \qquad (1)$$

where C_o and C_e are the initial and equilibrium liquid phase concentrations of the Zn metal (mg/L) respectively, V the volume of the test solution (L) and W the weight of the dry adsorbent (g).
The data for the sorption of Zinc were modelled using Langmuir and Freundlich isotherms.

3 Results and discussion

3.1 Equilibrium studies and removal efficiency

Adsorption isotherms are in general determined under equilibrium conditions. The amount of the metal adsorbed into four different adsorbents increased with time (Fig. 1) and reached saturation where no more removal was observed from the solution. At this point, the amount of Zinc being adsorbed onto adsorbent is in a state of dynamic equilibrium with the amount of Zinc desorbing from the adsorbent. The time required to attain half saturation for clay tile, brick, sawdust and rice husks were 75 min, 21min,49.2 min and 66.6 min respectively. However, adsorption capacities and the removal efficiencies were different: tile material has the highest adsorption capacity (47.6 mg/g) and removal efficiency, (98%) while brick (37.0 mg/g, 86%), sawdust (20.4 mg/g, 80%) and rice husks (15.8 mg/g, 64%) have relatively low adsorption capacities and removal efficiencies, respectively.



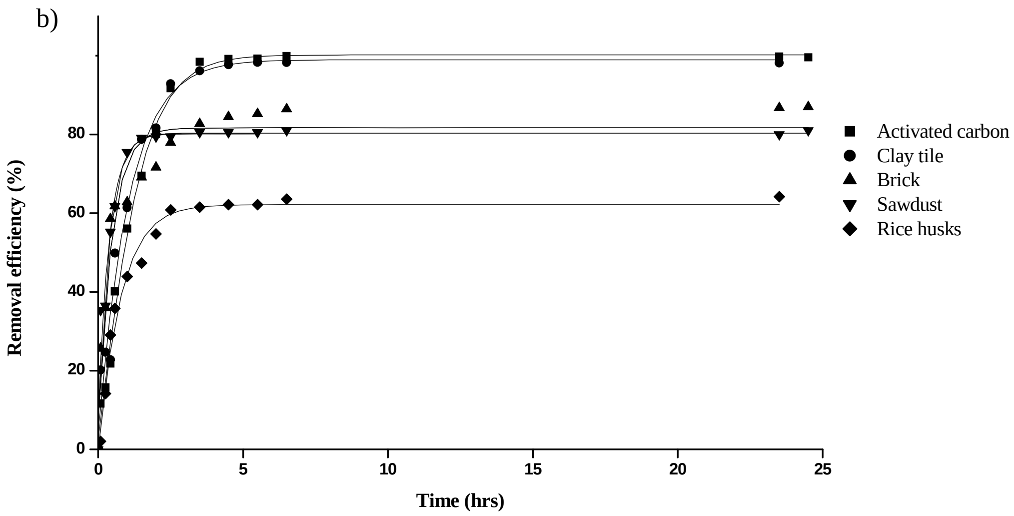


Figure 1: *The effect of contact time on amount adsorbed a) and removal efficiency b) (Initial concentration - 100 mg/l of Zn, particle size - 415 um, dose - 1 g/100 ml, pH - 6.5)*

3.2 Isotherm Studies

The adsorption equilibrium was described by isotherm equations which often provide some insights into sorption mechanism, surface properties and affinity to sorbent. The Langmuir and Freundlich equations are commonly used in describing adsorption isotherms at a constant temperature for water and waste water treatment applications. Therefore, following two widely used isotherms were applied: Langmuir adsorption isotherms: A basic assumption of this theory is homogeneous sites within the adsorbent and monolayer adsorption. The Langmuir model is given by the following equation:

$$q_e = QbC_e/1+bC_e \qquad (2)$$

and its linearized expression is:

$$C_e/q_e = 1/(bq_m)+(1/q_m)C_e \qquad (3)$$

where q_e amount of Zinc adsorbed per unit weight of adsorbate (mg/g), C_e is the equilibrium concentration of the solution (mg/L). The b and q_m are Langmuir coefficients representing the equilibrium constant for the adsorbate-adsorbent equilibrium and monolayer capacity of the solid.
The values of maximum adsorption capacity determined using linear transformation of the Langmuir equation are higher than the experimental adsorbed amount at the equilibrium and correspond to the adsorption isotherm plateau (Table 1).
The Langmuir equation is also used to obtain R_L, the separation factor of equilibrium:

$$R_L = 1/ (1+bC_0) \qquad (4)$$

where C_0 is the initial concentration of the adsorbate.

The values of R_L indicates the type of isotherm to be irreversible ($R_L = 0$), favourable ($0< R_L<1$), linear ($R_L = 1$) or unfavourable ($R_L> 1$).

Freundlich equation based on heterogeneous surface:

$$\text{Freundlich isotherm: } q_e = K_F C_e^{1/n} \qquad (5)$$

where K_F is the Freundlich constant and n is the Freundlich exponent. A linear form of Freundlich equation is given by :

$$\text{Log } q_e = \text{Log } K_F + 1/n \log C_e \qquad (6)$$

Based on the correlation coefficient (R^2) shown in Table 1, the equilibrium data were correlated with both Langmuir and Freundlich isotherms. However, adsorption isotherms are well-described by Langmuir isotherms. The separation factor of equilibrium (R_L) indicates favourable isotherms ($0< R_L <1$) for all tested sorbent materials. This further describes that monolayer adsorption of Zinc.

a)

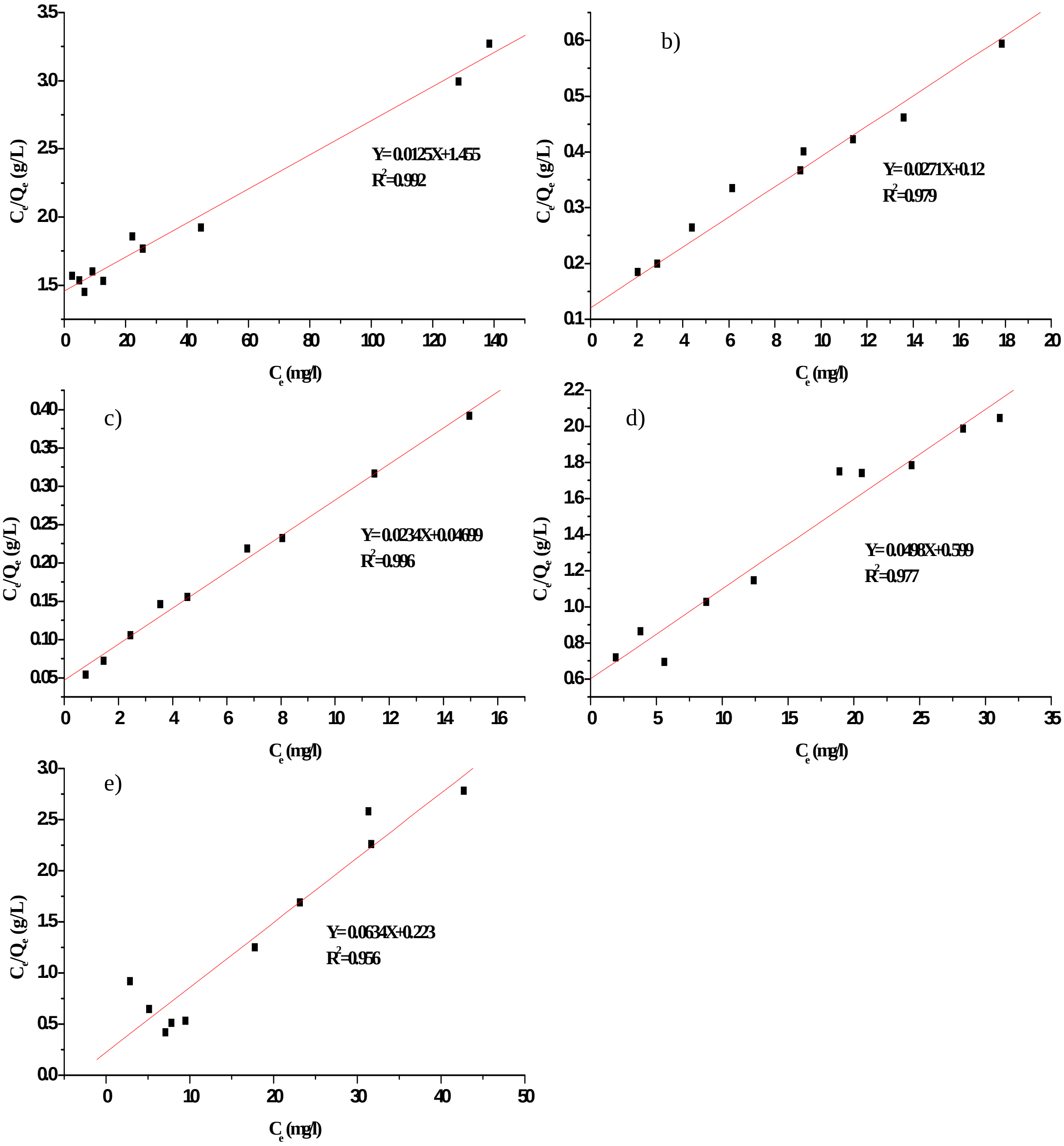


Figure 2: *a) Langmuir Isotherms for a)clay tile, b)brick , c)sawdust d)rice husks and e) activated carbon at room temperature (28 ± 3 ºC).*

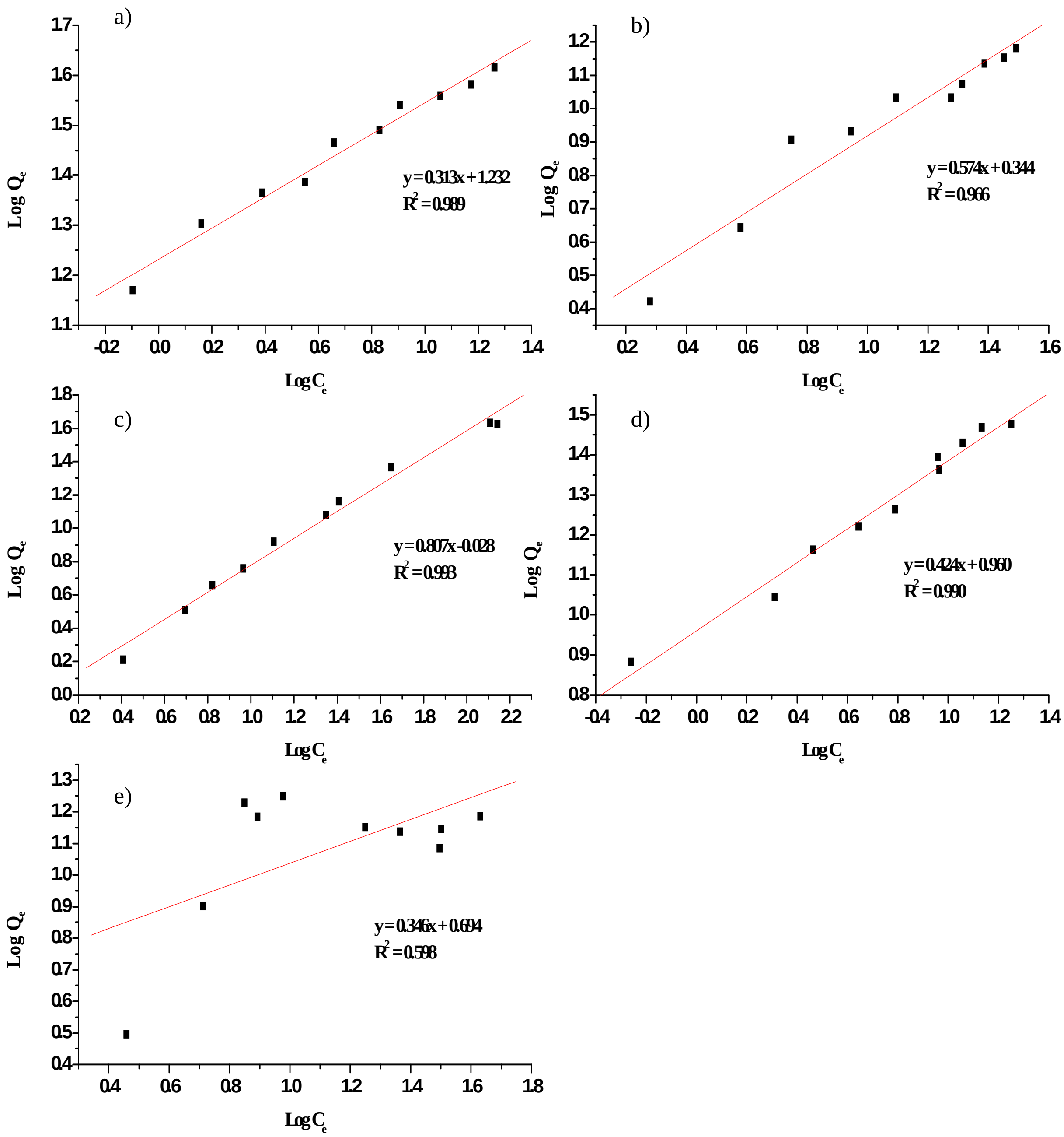


Figure 4: *a) Freundlich Isotherms for a) clay tile, b)brick, c) sawdust d)rice husks and e)activated carbon at room temperature (28 ± 3 ºC).*

Table 1: *Langmuir and Freundlich isotherm constant for clay tile, brick, sawdust and rice husks in Zinc solution*

Material	Langmuir constant			R_L	Freundlich constant		
	$Q_{max(mg/g)}$	b (1/mg)	R^2		K_F	n	R^2
Clay tile	47.6	0.403	0.996	0.113	16.98	3.19	0.989
Brick	37.0	0.225	0.979	0.305	9.12	2.35	0.990
Sawdust	20.4	0.081	0.977	0.701	2.18	1.74	0.966
Rice husks	15.8	0.022	0.986	0.342	4.26	2.89	0.598
Activated carbon	80. 0	0.008	0.992	0.952	22.14	4.24	0.993

However, using the Freundlich model similar results can be reported for the sorption of Zinc. The magnitude of the exponent *n* gives an indication of favourability of adsorption. It is stated that *n* in the range between 2-10 represent good, 1-2 moderately difficult and less than 1 poor adsorption characteristics. Among the studied materials, clay tile, brick and rice husks are good adsorbent for Zinc (n>2) while sawdust is a moderately difficult material for adsorption of Zinc (n <2).
Selection and identification of appropriate low cost adsorbent may rely on maximum adsorption of pollutant to the adsorbent. From the present study (Table 2), these low cost materials have shown outstanding adsorption capacity. It is evident that the cost effectiveness of an adsorbent is one of the important factors that needs to be compared with commercially available activated carbon.

Table 2: *Zn removal capacities of different low-cost sorbent materials and commercial activated carbon*

Adsorbent	Adsorption capacity(mg/g)	References
Mango peel	28.2	Iqbal et al., 2009
Sugar cane baggase	31.1	Mohan et al., 2002
Blast furnace slag	103.3	Dimitrova (1996)
Green sand	32.4	Lee et al., (2004)
Natural zeolite	13.0	Peric et al., (2004)
HCL treated clay	63.2	Vengris et al., (2001)
Clay tile	47.6	Present study
Brick	37.0	Present study
Sawdust	20.4	Present study
Rice husks	15.8	Present study
Type of commercially available activated carbon		
GAC type carbon	20.0	Leyva-Romes et al., (2002)
GAC type	0.29	Bansode et al., (2003)

4 Conclusion

Results revealed that clay tile material has the highest adsorption capacity (47.6 mg/g) and removal efficiency, (98%) while brick (37.0 mg/g, 86%), sawdust (20.4 mg/g, 80%) and rice husks (15.8 mg/g, 64%) have relatively low adsorption capacities and removal efficiencies respectively. The separation factor of equilibrium (R_L) indicates favourable isotherms (0< R_L<1) for all tested sorbent materials. Among the studied materials clay tile, brick and rice husks are good adsorbent for Zinc (n>2) while sawdust is a moderately difficult material for adsorption of Zinc (n <2).

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EFFECT OF PHYSICAL TREE CHARACTERISITCS AND SUBSTRATE CONDITION ON MAXIMUM OVERTURNING MOMENT

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Abstract: Effects of physical tree characteristics and soil shear strength on overturning moment due to flooding were investigated using *Salix babylonica* and *Juglans ailanthifolia*, exotic and invasive plants in Japanese rivers. Tree pulling experiments were conducted, and the resulting damage was examined in order to assess the effects of physical tree characteristics on the maximum overturning moment (M_{max}). In situ soil shear strength tests were conducted in order to measure soil strength parameters. The effects of species differences on the $M_{\max}$ were examined by analysis of the root architecture. *S. babylonica* has a heart-root system that produces a greater overturning moment due to the strong root anchorage and the large amount of substrate that must be mobilized during overturning. *J. ailanthifolia* has a plate-root system that produces a smaller overturning moment. However, trees with the plate-root system may withstand overturning better due to an increased root:shoot ratio. Considering the strategy of *J. ailanthifolia* to increase the root:shoot ratio for anchoring in the substrate, the trunk volume index (height*D_{bh}^2) is a better parameter than D_{bh}^2 because it indirectly involves the difference in belowground volume and surface area. Different soil cohesion values were found at different experimental sites, and the average $M_{\max}$ for overturning each species decreased linearly with increasing soil cohesion.

Keywords: Tree pulling test, Root architecture, Soil shear strength, Maximum overturning moment, *Salix babylonica, Juglans ailanthifoila.*

1 Introduction

Tree damage due to flooding causes serious problems in managed floodplain forests, where trees produce large amounts of debris and sometimes affect on the structures in river, e.g., gates, bridge piers, and weirs. Flood damage also results in a loss of the balance of the floodplain ecosystem. Researchers have investigated direct and indirect effects on floodplain trees due to flooding.

Previous studies of tree-root systems showed that the strength of a tree-root anchorage is governed by several factors, including the root architecture (Dupuy et al. 2005); physical and analytical properties of the soil (Dupuy et al. 2005); depth, shape, and weight of the soil-root plate (Coutts 1986); and location of the rotational axis during overturning (Mickovski and Ennos 2002). Species characteristics, such as the root architecture (Dupuy et al. 2005), are important parameters in determining the overturning moment. Dupuy et al. (2005) studied different root architectures, including the heart-root system, tap-root system, and plate-root system, and found that the heart-root system was the most effective and plate-root system was the least effective against overturning a tree. The Technology Research Center for Riverfront Development (TRCRD) (1994) has developed guidelines for the management of trees in rivers in Japan. The guidelines proposed a model to calculate the maximum resistive bending moment

(M_{max}) of a tree in terms of the square of the breast height diameter. However, they did not elucidate a species difference for the trees in Japanese rivers. Further, researchers have found that the stability of a tree under external forces is mainly governed by physical characteristics such as tree height (H), diameter at breast height (D_{bh}), tree weight, and root-soil plate depth and radius (Peltola et al. 2000). In addition, TRCRD (1994) proposed the overturning moment of a tree as a function of D_{bh}^2. However, this method of calculating the M_{max} neglects several important parameters, such as tree weight and trunk volume.

In addition, the stability of a tree is also governed by the shear strength of the soil at the base of the root-soil plate (Peltola et al. 2000). Rahardjo et al. (2009) found that the resistance to overturning is increased by increasing the soil shear strength. Nevertheless, the effects of soil shear strength on the M_{max} for trees in Japanese rivers have not been investigated yet.

Thus, the objectives of this study were to (1) elucidate the effects of species differences on M_{max} by considering the root architecture, (2) develop a model of the relationship between the M_{max} and important tree characteristics to determine the M_{max} for overturning trees, and (3) clarify the effects of shear strength of soil on the M_{max} for overturning. The tree species weeping willow (*Salix babylonica Linn*.) and Japanese walnut (*Juglans ailanthifolia Carr*.) were selected because they had been affected by earlier flooding conditions, and they were widely distributed on the investigation sites.

2 Material and Method

2.1 Site information and tree pulling tests

The tree-pulling experiments were carried out in August 2009 at three sites located on the floodplains (35°49′38.8″ N, 139°39′37.1″ E) of the Arakawa River in the Kanto area of Japan. The three selected sites were located close to each other (sites 1 and 2 were on the same side of the river about 300 m apart, and site 3 was on the opposite side of the river) (Fig. 1). All sites were approximately the same relative height above the normal water level (about 2.0 m) and had the same flood frequencies. There were two severe flooding events from 1995 to 2004 on these floodplains due to typhoons. The condition of soil at each experimental site was investigated by using a softness test. In site 1, the top 1.05 m from the ground surface was fine sand (0.10-0.25 mm), and the next 0.90 m was silt (0.002 -0.05 mm). The top soil layer of site 2 consisted of clayey fine sand (0.05-0.10 mm) up to 1 m deep, and the next 1 m was sand mixed with clayey silt (0.0001-0.001 mm). In site 3, the top 0.65 m from the ground surface was fine sand (0.10-0.25 mm), and the next 1.3 m was sandy silt (0.001-0.002 mm). All the soil diameters are defined according to the USDA soil textural classification system. Stands of *S. babylonica* and *J.ailanthifolia* growing on sandy soils were tested at each site. Tree trunks with apparent defects such as decay, damage, and obvious fungus infection were avoided in order to limit the number of interacting factors that could not be distinguished in the analysis. Trees in the range of D_{bh} ($3 < D_{bh} < 40$ cm) were selected in order to evaluate the effect of D_{bh} on maximum resistive bending moment.

For elucidating the maximum resistive bending moment, the tree pulling tests were carried out using a method previously used and described by many researchers (Peltola et al. 2000). The force required to

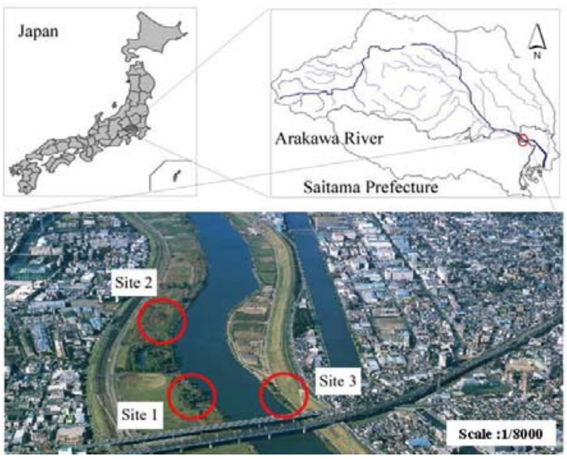

Fig.1 Experimental sites on floodplains of the Arakawa River

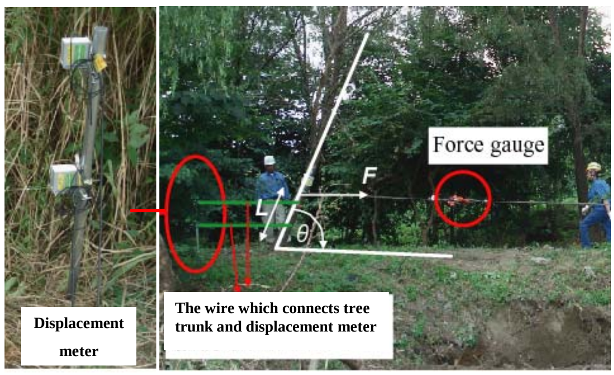

Fig.2 Layout of tree-pulling system
L: The distance from the base to the cable attachment point, F: The force applied via the rope,
θ: The angle of the trunk to the horizontal at the

pull down the trees was applied by the arm of an excavator with a system (Fig. 2) comprising a double rope and a load cell (type TLP-108, Tokyo Sokki Kenkyujo Co., Ltd.). The load values measured by load cell were recorded every second by a data logger that was connected to the load cell. The cable attachment point was kept at a constant height of 1.2 m (10-30% of tree height) above the ground because the tree height is usually higher than the flood water depths and the fluid forces of the flood act only on the submerged part. The angle of the trunk to the horizontal at the point of failure was determined from two displacement gauges as shown in Fig. 2. The displacement gauges were connected to the trunk using two parallel ropes. The displacement gauges and data logger were synchronized to each other, and hence the load data could be easily linked with the positions of the tree during the pulling period. The angle of the trunk to the horizontal at maximum load was derived using the information recorded by the data logger and displacement gauges.

The maximum resistive bending moment at the trunk base was calculated from the following equation:

$$M_{\max} = FL\sin\theta \tag{1}$$

where M_{max} is the maximum resistive bending moment at the trunk base (kNm), F is the force applied via the rope (kN), L is the distance from the base to the cable attachment point along the trunk (m), and θ is the angle of the trunk to the horizontal at the time of maximum load (deg). The bending moment due to the weight of the offset trunk and the crown itself was not considered in this study. The maximum applied bending moment was expected to equal the maximum resistive bending moment.

2.2 Measurements of tree characteristics

The following characteristics were measured on all the trees pulled over: trunk diameter at breast height D_{bh} (cm), tree height H (m), root-soil plate depth (R_d), and root-soil plate radius (R_r). The root-soil plates were separated from the trunk after overturning and brought to Saitama University. The R_r was measured by taking the average of four perpendicular measurements parallel to the ground. In every measurement, the radius was measured as the length from the center of the tree trunk to the outer margin of the central mass of roots and soil. In addition, the R_d was measured as the average length of roots in the root-soil plate. Table 1 summarizes the basic characteristics of the trees pulled out.

2.3 In situ soil shear strength analysis

In situ shear tests were conducted after the tree-pulling experiments to measure the soil strength characteristics (cohesion c and angle of internal friction ø) at each site in order to evaluate the effects of soil parameters on overturning moments. Soil samples were tested in dry soil conditions (soil moisture content = 12–15%). The size of the shear box was 24 cm x 24 cm x 15 cm. The shearing force was applied manually perpendicular to one of the edges of the box to avoid the rotation of the specimen that occurs during the application of a shearing force. Because some of the roots tend to be concentrated at great depth, the normal stress on the shear plane is considerably high. Thus, vertical loads on top of the soil specimen were applied in the in situ shear tests conducted at each site.

Table 1 Summary statistics from tree-pulling database for two tree species

Variable	Notation	Unit	Tree species	
			S. babylonica 17[a]	*J. ailanthifolia* 6[a]
Tree Height	H	m	9.5 (2.2)[b]	6.3 (1.7)
Trunk diameter at breast height	D_{bh}	m	23.7 (9.6)	11.0 (5.5)
Crown width	C_w	m	7.0 (2.0)	6.3 (1.6)
Crown depth	C_h	m	7.0 (1.7)	4.5 (1.5)
Lowest branch height	B_h	m	2.5 (0.7)	1.8 (0.5)
Maximum resistive bending moment	M_{max}	kNm	53.0 (41.5)	17.0 (13.9)
Angle of trunk at M_{max}	θ	°	12.7 (8.5)	23.0 (17.2)

[a] Number of observations relative to each tree species

[b] Means with standard deviations are presented for each variable

3 Results

3.1 Mode of failure

All the trees, i.e., 17 *S. babylonica*, and 6 *J. ailanthifolia*, were uprooted during the pulling experiments. The number of trees of one species selected depended on the availability of such trees within the boundaries of the sites. Uprooting failures were characterized by the lifting of the intact root plate with the tree falling under its own weight. Trunk failures were not observed for any of the trees subjected to the pulling tests. The angle of the trunk to the vertical at M_{max} showed a significant inverse correlation with the tree height for each species. A similar variation was seen among the tree species where the average tree heights of 9.5 m and 6.3 m for *S. babylonica* and *J. ailanthifolia*, respectively, provided the maximum resistance on average when the trunk was deflected by ≈13° and ≈23° to the vertical, in sequence. Two types of root systems were observed on all the trees tested: *S. babylonica* had a heart-root system while *J. ailanthifolia* had a plate-root system (Fig. 3).The more effective root architecture to withstand overturning was the heart-root system (average M_{max}= 52.97 kNm for average root-soil plate depth = 89.4 cm). This root system was composed of lateral, oblique, and vertical roots that originate from the trunk bole. This structure was densely branched, and the secondary lateral roots were oriented randomly between the horizontal and vertical directions. The plate-root system was the less effective (average M_{max}= 16.96 kNm for average root-soil plate depth = 65 cm). This system did not have a tap root but only main lateral roots, which were attached to the stump.

3.2 Variation of Mmax with tree characteristics

The variations of M_{max} against D_{bh} for *S. babylonica* and *J. ailanthifolia* at different experimental sites are shown in Fig. 4(a) and (b), respectively. Fig. 4(a) depicts the variation of M_{max} with D_{bh} for *S. babylonica*, and it indicates that the M_{max} of trees that have nearly same D_{bh} but grow at different sites are not equal. A similar variation could be seen for the case of *J. ailanthifolia* (Fig. 4(b)). Thus, trees belonging to one species, distributed at different sites were not analyzed together. Therefore, the following analyses were done on the *S. babylonica* at study site 1 and *J. ailanthifolia* at study site 3.

Fig.3 Different types of root architectures for (a) hear-root system, (b) plate-root system

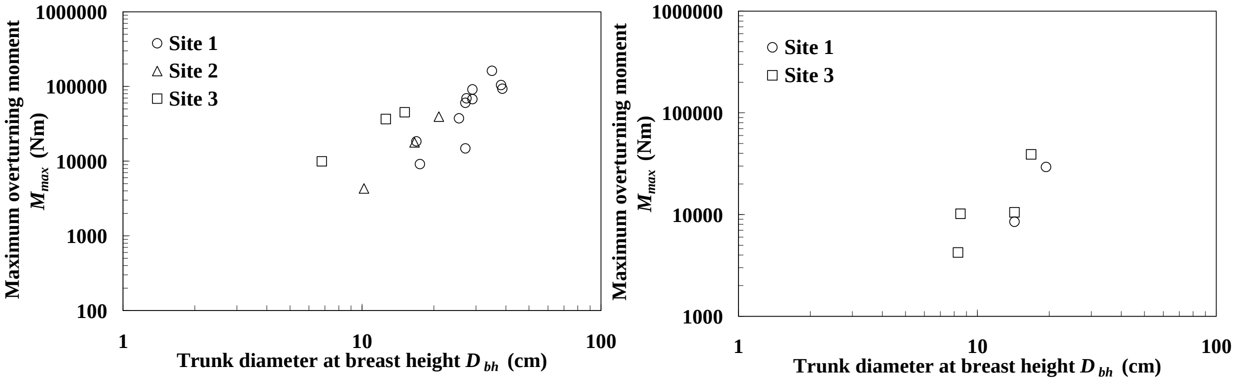

Fig.4 The variation of Mmax against D_{bh} in different experimental sites for
(a) *Salix babylonica*, (b) *Juglans ailanthifolia*

Table 2 Correlation coefficients for relationships between tree characteristics and M_{max} for *S. babylonica*

	M_{max}	D_{bh}	D_{bh}^2	H	$H*D_{bh}^2$	R_d	R_r
M_{max}	**1**	-	-	-	-	-	-
D_{bh}	**0.70**	**1**	-	-	-	-	-
D_{bh}^2	**0.70**	**1**	**1**	-	-	-	-
H	**0.61**	**0.29**	**0.29**	**1**	-	-	-
$H*D_{bh}^2$	**0.83**	**0.94**	**0.94**	**0.54**	**1**	-	-
R_d	**0.06**	**0.01**	**0.01**	**0.39**	**0.07**	**1**	-
R_r	**0.51**	**0.88**	**0.88**	**0.17**	**0.78**	**0.002**	**1**

Table 3 Correlation coefficients for relationships between tree characteristics and M_{max} for *J. ailanthifolia*

	M_{max}	D_{bh}	D_{bh}^2	H	$H*D_{bh}^2$	R_d	R_r
M_{max}	**1**	-	-	-	-	-	-
D_{bh}	**0.66**	**1**	-	-	-	-	-
D_{bh}^2	**0.66**	**1**	**1**	-	-	-	-
H	**0.83**	**0.8**	**0.8**	**1**	-	-	-
$H*D_{bh}^2$	**0.84**	**0.99**	**0.99**	**0.86**	**1**	-	-
R_d	**0.71**	**0.89**	**0.89**	**0.62**	**0.86**	**1**	-
R_r	**0.24**	**0.001**	**0.001**	**0.22**	**0.01**	**0.003**	**1**

There were significant correlations between the M_{max} and various tree characteristics, such as the tree height, D_{bh}, D_{bh}^2, $H*D_{bh}^2$, and root-soil plate depth and radius ($p<0.05$), with $H*D_{bh}^2$ explaining the greatest proportion of the variation in M_{max} for all trees tested. However, D_{bh}^2 also had a good correlation with M_{max}. Tree height showed rather weak correlations with M_{max} and other tree characteristics, especially for *S. babylonica*. The correlation between M_{max} and root-soil plate depth for *S. babylonica* was significant, whereas the correlation coefficient was very weak (R^2=0.06). On the other hand, while the correlation between M_{max} and root-soil plate radius for *J. ailanthifolia* was significant, the correlation coefficient was quite law (R^2=0.24). The best regressions also show that the M_{max} required to uproot a tree increases with increasing height multiplied by the second power of D_{bh} for a fixed height and D_{bh}. Similarly, the M_{max} required for uprooting a tree increased with increasing tree height for a fixed taper or with increasing D_{bh} for a fixed tree height. The correlation coefficients of relationships between M_{max} and tree characteristics and tree characteristics themselves for *S. babylonica* and *J. ailanthifolia* are presented in Table 2 and Table 3, respectively. The correlations between tree characteristics themselves were strong except in the cases of soil-root plate depth for *S. babylonica* and soil-root plate radius for *J. ailanthifolia*.

The data showed that tree height multiplied by the square of D_{bh} explained the greatest proportion of the variation in M_{max} for all the trees tested. Hence, M_{max} could be written in terms of D_{bh} and tree height. The following equations show the corresponding relationships.

$$M_{\max} = 0.81(H * D_{bh}^2)^{1.23} \quad \textit{S. babylonica} \quad (2)$$

$$M_{\max} = 44.49(H * D_{bh}^2)^{0.79} \quad \textit{J. ailanthifolia} \quad (3)$$

where M_{max} is in Nm, H is in m, and D_{bh} is in cm. However, the Technology Research Center for Riverfront Development (TRCRD) of Japan proposed the overturning moment of a tree as a function of D_{bh}^2 (TRCRD, 1994) as follows.

$$M_{turnc} = 78.8 d_{BH}^2 \quad (4)$$

where M_{turnc} is the critical overturning moment of a tree in rivers (Nm), and d_{BH} is the diameter of a tree trunk at breast height (cm). Hence, the following models were also developed between M_{max} and D_{bh}^2 to compare the equation of overturning moment with that by TRCRD (1994).

$$M_{\max} = 87.59 D_{bh}^2 \quad \textit{S. babylonica} \quad (5)$$

$$M_{\max} = 85.61 D_{bh}^2 \quad \textit{J. ailanthifolia} \quad (6)$$

where M_{max} is in Nm and D_{bh} is in cm. The models (Eq (5) and (6)) were validated for all the trees pulled down at experimental sites 1, 2, and 3. It can be seen that the correlations coefficients are fairly strong (0.43-0.97), and thus the models are applicable to determine the M_{max} of both tree species before overturning due to a severe flooding condition.

Table 4 Peak strength characteristics of soil obtained by in situ shear test and average M_{max} of two tree species in different site

Parameter	species	Notation	Unit	Site location		
				Site 1	Site 2	Site 3
Cohesion	—	c	kN/m^2	1.3	3.2	2.7
Angle of internal friction	—	φ	°	60.9	35.0	39.6
Average maximum overtuning moment	*S. babylonica*	M_{max}	kNm	66.1	20.5	30.5
	J. ailanthifolia			18.9	—	16.0
Average root-soil plate depth	*S. babylonica*	R_d	m	99.4	71.7	74.0
	J. ailanthifolia			68.0	—	63.5

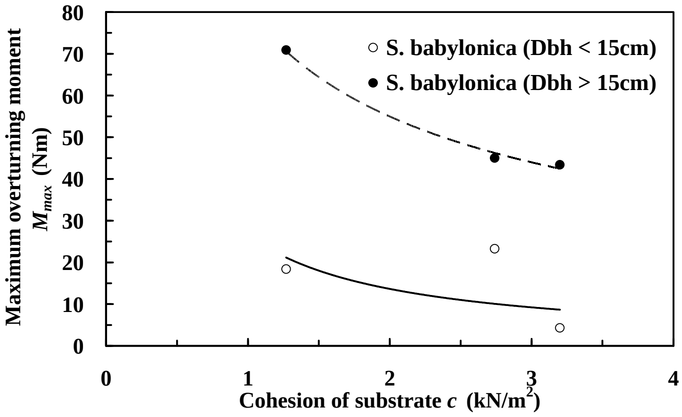

Fig.5 Variation of M_{max} against soil cohesion at each experimental site

The models developed in this study take a pattern similar to equation (4), although the coefficients are different. The reason why the coefficients of equations (5) and (6) have similar values, even though the two tree species have different root architectures, will be explained in the Discussion.

3.3 Effects of soil shear strength on M_{max}

Soil shear strength is one of the key factors that govern the strength of the tree-root anchorage. The shear strength of a soil is governed by effective cohesion and the effective angle of internal friction as given by the Mohr-Coulomb equation. Therefore, in situ shear tests were conducted after the tree-pulling experiments at each site in order to determine the soil shear strength parameters. The peak strength characteristics of soil obtained through in situ shear tests in dry conditions (soil moisture content = 12–15%), the average root-soil plate depth of each tree species at each site, and the average M_{max} of tree species at different sites are shown in Table 4. The effects of soil cohesion on the size of the root-soil plate and M_{max} for overturning were examined among the trees of the same species at different sites. The depth of the root-soil plate decreased with increasing soil cohesion for both tree species. Fig.5 shows the variation of average M_{max} against soil cohesion. The corresponding equations are as follows.

$$M_{\max} = 26.7c^{-0.97} \qquad \textit{S. babylonica}, \quad D_{bh} < 15 \text{ cm} \qquad (7)$$

$$M_{\max} = 80.5c^{-0.55} \qquad \textit{S. babylonica}, \quad D_{bh} > 15 \text{ cm} \qquad (8)$$

where c is soil cohesion (kN/m^2). Fig.5 and comparison of the coefficients of the above equations demonstrate that the average M_{max} decreased linearly with increasing soil cohesion for both tree species.

4 Discussion

4.1 Variation of M_{max} with root architecture

In this study, we have observed two types of root systems: a heart-root system and a plate-root system. Many previous investigations have reported that the heart-root system generally afforded the most efficient anchorage (Stokes et al. 2005). These root systems possess large lateral roots originating from the centre of the bole, which then rapidly branch into smaller roots. Wu et al. (1988) reported that the heart-root architecture improves soil shear resistance by combining stiffness close to the trunk and

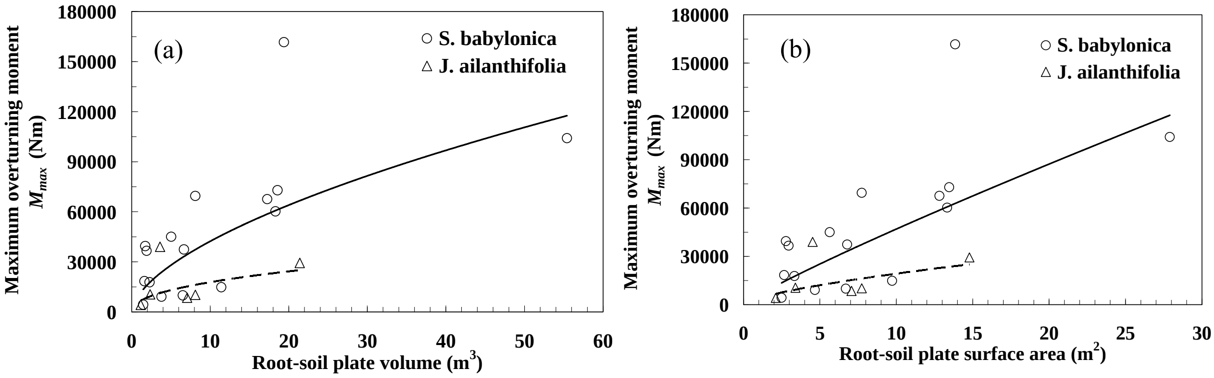

Fig.6 Variation of M_{max} against root-soil plate dimensions for
(a) root-soil plate volume, (b) root-soil plate surface area

dense fibrous networks further away. When forked roots are lifted up out of the soil, they also carry soil upwards with them in the crux of the fork, the weight of which helps to increase overturning resistance.

In the case of a plate-root system, many roots have penetrated only the top soil layer, and thus, a small amount of soil is mobilized during uprooting. The soil/root cohesion will be decreased and anchorage strength reduced when few vertical roots are embedded in the soil. Therefore, when a plate-root system is overturned, the entire root-soil plate is lifted upwards.

Nevertheless, the coefficients in the equations (5) and (6) are not very different. The equations gave relatively identical M_{max} values for both species with similar D_{bh}. However, we have observed that *S. babylonica* and *J. ailanthifolia* have different root systems, which gave different M_{max} values even for the trees with similar D_{bh}. The root:shoot ratio of *J. ailanthifolia* was found to be greater than that of *S. babylonica* for approximately identical D_{bh} (the root:shoot ratios of both *J. ailanthifolia* and *S. babylonica* were 0.19 and 0.05 for trees with D_{bh} of 10.3 and 10.2 cm, respectively). Thus, D_{bh} itself does not explain the overturning moment of *S. babylonica* and *J. ailanthifolia*. The effect of different root systems is also significant in determining the overturning moment. To verify this, the relationships between M_{max} and root-soil plate volume and surface area were analyzed. Figure 6(a) and (b) show the variation of M_{max} with root-soil plate volume and surface area. The figures demonstrate that for a certain value of both volume and surface area of the root-soil plate, the moment required for overturning *S. babylonica* was considerably greater than that for overturning *J. ailanthifolia*. Further, the difference increased with increasing root-soil plate volume and surface area. This indicates a similar conclusion that a heart-root system is stronger than a plate-root system. It also implies why equations (2) and (3) explain the difference of root volume or surface area indirectly because they are functions of the aboveground part, but equations (5) and (6), which are only functions of trunk area, do not.

4.2 Effects of soil shear strength on M_{max}

The failure mode of trees is closely linked to soil type. All the trees tested were overturned with an intact root-soil plate. The trees grew on periodically flooded river floodplains consisting of sandy soils in the top layer of the ground (about 1 m). Normally, the distribution and anchoring ability of tree roots are affected by soil texture and consistency (Mergen 1954). The factors determining the consistency are cohesive and adhesive strength and the angle of internal friction. A cohesive soil is described as one where the particles adhere after wetting and subsequent drying and which requires significant force to crumble the soil (Craig 1990). Usually, the cohesion of sandy soils is rather low. Therefore, the trees grown in less cohesive sandy soils are more likely to be overturned when external forces are applied.

In this study the average M_{max} for overturning trees of the same species decreased with increasing soil cohesion. The ability of roots to grow in a soil is an important factor that determines the rate of tree growth. The rate of roots growth is determined by the mechanical impedance that roots experience when they elongate through soil. As soil shear strength increases, the root elongation rate decreases due to the increasing resistance of the soil particles to displacement. Thus, roots easily penetrate the soil more deeply when the shear strength is smaller. Further studies are needed to explain the relationship between the overturning moment of a tree and the shear strength of the soil.

5 Conclusions

Threshold overturning moments were investigated for two tree species with two types of root architectures: the heart-root and plate-root systems. The heart-root system (*S. babylonica*) had a greater M_{max} than the plate-root system (*J. ailanthifolia*) with the same below-ground volume or surface area because the heart-root system affords a stronger anchorage and a large amount of substrate must be mobilized during overturning. However, the plate-root system can withstand overturning by improving the root:shoot ratio. The results of the study show that the M_{max} for overturning a tree has close correlations with the tree's physical characteristics. The trunk volume index explained the greatest proportion of the variation in M_{max} for all trees tested. The trunk volume index explained the above-ground volume of a tree that is related to the root:shoot ratio. Thus, the correlation between the M_{max} and trunk volume index is an indirect method of describing the correlation between the M_{max} and root:shoot ratio. In addition, the overturning moment of a tree is largely affected by the cohesion of the soil. The study found that the average M_{max} for overturning of *S. babylonica* decreased with increasing cohesion of soil.

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Acknowledgements

This study was supported in part by JSPS AA Science Platform Program. This study was partly funded by JSPS Grant in Aid for Scientific Research (ID No. P 09081 and ID No. 21860013). The experiments were conducted jointly with the Kanto Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism of Japan, and the ECOH Corporation. Prof. Yasushi Sasaki, Saitama University, is acknowledged for his useful suggestions.

WATER BALANCE AND RENEWAL TIME OF REKAWA LAGOON, SRI LANKA; A RESTORATIVE APPROACH

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Abstract: Rekawa Lagoon is a chocked and shallow coastal water body located in the southern coast of Sri Lanka. It is relatively unusual in that the major freshwater input, Kirama-oya river connects through the constricted channel much closer to the inlet at seaward end. A causeway was constructed, around 700 m from the lagoon inlet to the inland, across the constricted channel with an effort to link a secluded Kapuhenwala village with the rest of the area which in turn greatly reduced the volume and speed of water entering and leaving the lagoon system. Construction of the causeway led to many environmental problems with poor flushing efficiency and hampering to and fro movement of the prawns in the lagoon. The aim of this study was to evaluate the present situation and propose alternative management scenarios for improvement of water flow and lagoon ecosystem. The implications of different development stages of the causeway were discussed in terms of field measurements supported by modeling to describe the water balance and the water renewal time. The alternative of modifying the existing causeway was proposed to increase the free water flow at the inlet that favors recruitment of juvenile shrimp species.

Keywords: Lagoon hydrology, Lagoon restoration; Shrimp fishery management

1 Introduction

Coastal lagoons are defined as shallow inland marine water bodies, usually oriented parallel to the coast, separated from the ocean by a barrier, connected to the ocean by one or more restricted inlets (Phleger, 1969; Kjerfve and Magill, 1989). They are mainly important for fisheries and aquaculture in many areas of the world, since marine shrimp and fish species migrate towards the lagoons, which provide favorable conditions for feeding and shelter (Colombo, 1977). Many coastal lagoons have been affected over the decades by natural and mostly anthropogenic influences, including environmental degradation from hydrologic alterations (Tsihrintzis et al, 1996; Gunaratne et al, 2010b; Gunaratne et al, 2010c) and point and non-point sources of pollution (Miller et al., 1990). Physiochemical and biological parameters in a coastal lagoon may affect directly fish production and ecosystem dynamics (Corsi and Ardizzone, 1985) and these parameters are generally dependent on seawater circulation and water renewal time, in addition to inflowing freshwater and seawater quality (Tsihrintzis et al, 2007). Coastal lagoons are important for fisheries and extensive aquaculture, and contribute notably to the fishery economies in many countries. Sri Lankan coastline circles along about 1,585 km of sandy beaches, extensive lagoons, estuaries, mangroves, coastal marshes and dunes (Baldwin, 1991). In Sri Lanka many water bodies are usually named as lagoons that are really estuaries and Rekawa lagoon has been identified as a true lagoon (Baldwin, 1991).

The scope of this study is to present a comparative approach on hydrology and renewal time for different scenarios of inlet causeway changes, aiming at reaching better decisions with regards to lagoon restoration design and management actions for improvement of environmental conditions and shrimp fishery exploitation. Hydrology, including quantity, distribution and flow patterns, and quality of water, is possibly the most important factor affecting lagoon successful operation, management and/or restoration design. Several studies have been undertaken in this system over the last two decades (e.g.

Jayakody and Jayasinghe, 1992; Priyadarshana, 1998; Rathnaweera, 2005) but none investigates the changes in hydrology and flushing properties comprehensively. This study is performed through the analysis of recent meteorological, bathymetric, morphometric and tidal elevation data combined with mathematical models aiming at reaching better decisions with regard to design of the restoration interventions and management actions for improvement of environmental conditions and aquaculture.
The detail objectives of the work are 1) to determine the annual water balance of the lagoon; 2) to investigate the renewal time of the lagoon for different scenarios of inlet causeway changes; 3) to discuss the implications of the proposed scenario on the lagoon's shrimp fishery management. Annual water balance and renewal time were investigated for two or more scenarios of the lagoon and they are a) Before the construction of causeway or time period before year 1984 (Rekawa Scenario 1 - RS1); b) Existing situation or time period after year 2000 (Rekawa Scenario 2 – RS2) and c) Future scenario with respect to proposed box culvert introduction (Rekawa Scenario 3 – RS3)

2 Methodology

2.1. Study site description

Rekawa is located in Hambantota District in the Southern Province of Sri Lanka and it is 200 km from Colombo to the south. It is a comparatively small coastal lagoon, having connected to the sea with a 3 km narrow inland waterway (Figure 1). Rekawa lagoon is shallow with a depth of averaging 1.4 meters and the widest point is approximately 2.5 km (Jayakody and Jayasinghe, 1992). The water surface area of the lagoon is 2.4 km^2 (Priyadarshana, 1998). Most parts of the lagoon are encircled with a mangrove belt. Winds and constant waves on the shoreline give rise to dispositional sand dunes along the coast. Such accumulation results in periodic closure of the lagoon mouth to the sea as very little sand is supplied by river deposits. Kirama-oya river (Tangalu-oya river) that enters the lagoon at the sea ward end of the inlet canal is the main freshwater supply (Figure 1). Apart from the main freshwater inflow, there are two small freshwater streams function only in rainy season and provide surface runoff from the suburb. The total hydro-catchment of the lagoon outlet is about 225 km^2 (Priyadarshana, 1998). Rekawa Lagoon is a unique natural resource and one of the most significant aquatic habitats in southern Sri Lanka. Shrimp fishery is highly seasonal and extends from October to April of the following year (fishermen information). The most abundant shrimp specie in Rekawa lagoon and commercially most important shrimp species is *Penaeus indicus* (White shrimp).

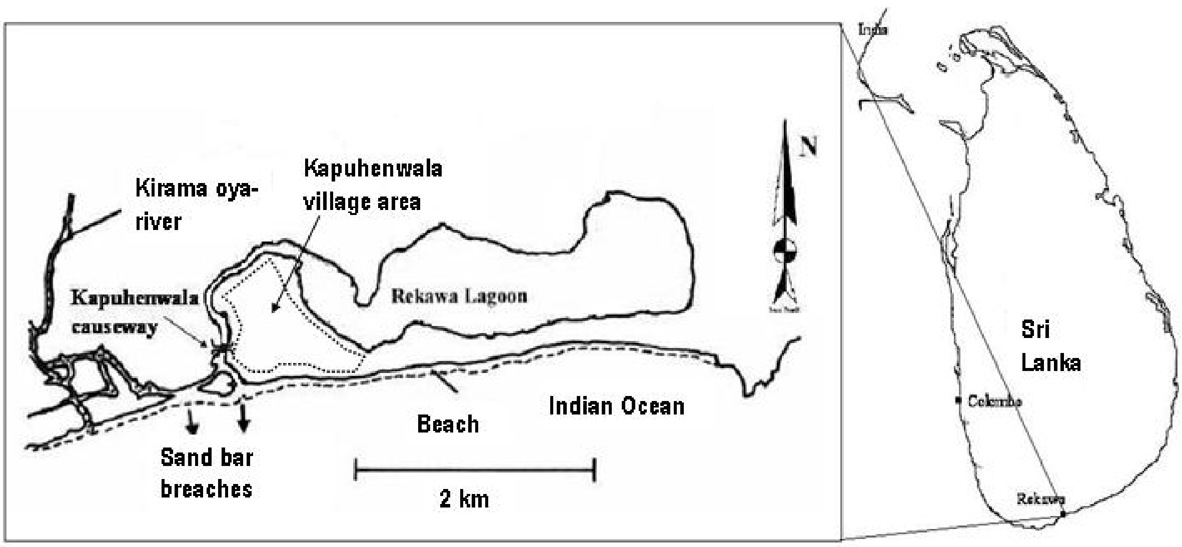

Figure 1: *Map of Rekawa Lagoon, Sri Lanka with the locations of major freshwater inflow (Kirama-oya river) and Kapuhewala causeway*

2.2 Chronology of causeway development process

The Road Development Authority of Tangalle in1984 built a causeway called Kapuhenwela across the outlet canal; around 700 m from the lagoon mouth to the inland (Rathnaweera, 2005) (Fig.1). Water passes under the causeway through twenty three, 23 cm diameter pipes which greatly reduce the volume and speed of water entering and leaving the lagoon system. This causeway has prevented flushing of the lagoon by natural water flow, causing continues sedimentation in the lagoon. In 1999 a bridge of 6.2m in length was constructed in place of the part of the causeway in order to improve free water flow. After the Indian Ocean Tsunami in 2004, minor damage inflicted on the causeway and it was renovated and replaced with 8 cylindrical culverts with an average diameter of 79 cm in 2005. This modification remains to be changed until today in 2010(Fig. 2). Causeway itself and its modifications provoked concern over local resource users and environmentalists as the lagoon hydrology, salinity and there by the ecology showed drastic changes and variations. Figure 3 is a schematic representation of channel cross sections at the causeway before and after the construction of the causeway. Before the construction of causeway, effective channel cross section was 87m^2 and it reduced upto 25m^2 with the introduction of existing causeway structure with the bridge and it's a drop of 71% of effective channel cross section.

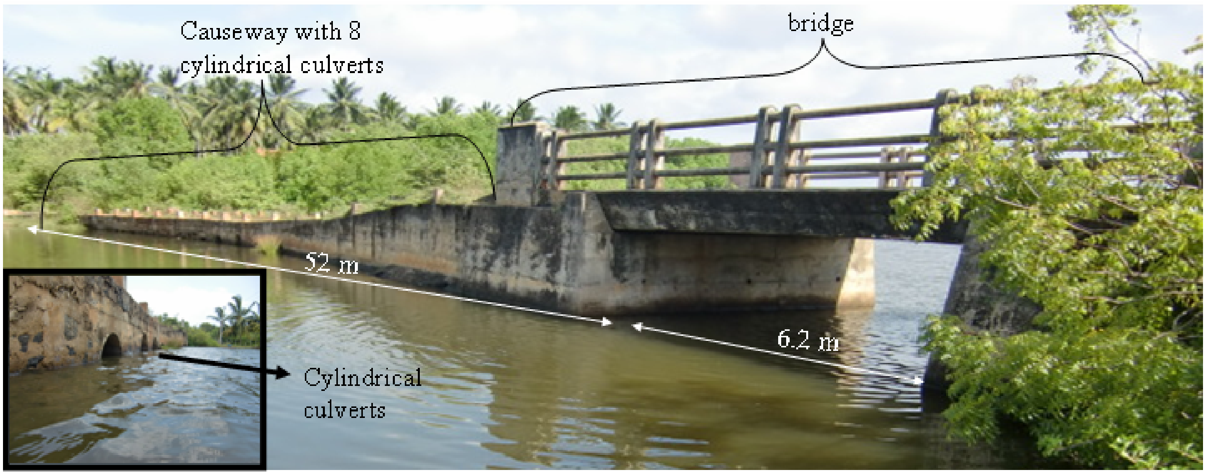

Fig. 2: *Existing situation of the causeway with 8 cylindrical culverts and the partial bridge at Kapuhenwala, Rekawa Lagoon*

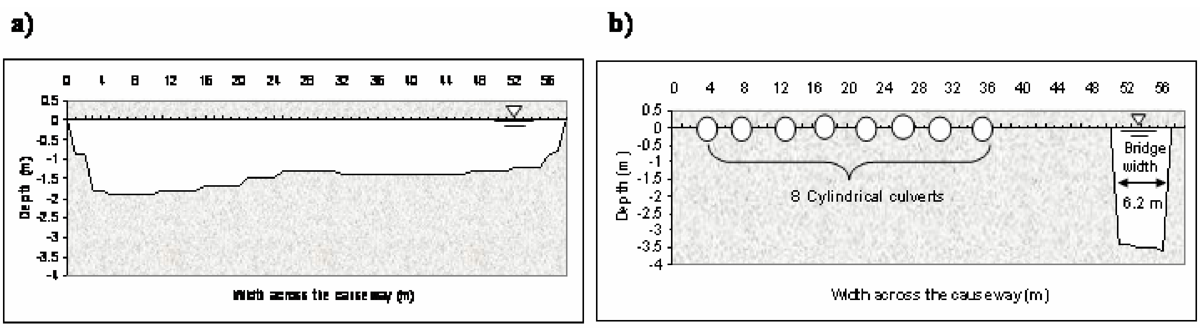

Figure 3: *Schematic representation of a) channel cross section at the causeway before the construction of causeway (Before 1984); b) channel cross section at the causeway after the construction of causeway and the bridge (After 2005)*

2.3 An Engineering solution

To improve the flushing efficiency it is essential to create a modification where ebb flow is dominant, which will also increase the amount of seawater entering the lagoon. An ideal engineering solution would be a complete bridge across the channel instead of the causeway with the partial bridge. This improves the free water flow which in turn increases the flushing efficiency which is poor in existing situation. Further, a complete bridge will have no adverse impacts on the adjoining banks or to the lagoon itself. However, though this option is technically highly feasible and capital costs are well-above the long term intended benefits.

Therefore, a relatively 'soft' solution is proposed in this report which is based on the concept of expanding the existing culvert cross sections. Box culverts would be introduced instead of existing cylindrical culverts.
An engineering solution was proposed with a redesign of existing causeway structure with more room for freeware flow introducing box culverts (Fig. 4). With the modification, effective channel cross section is expanded introducing 10 box culverts, each with 2m X 2m cross sectional dimensions.
The effectiveness of the solution was determined after the comprehensive study of the water balance and renewal time.

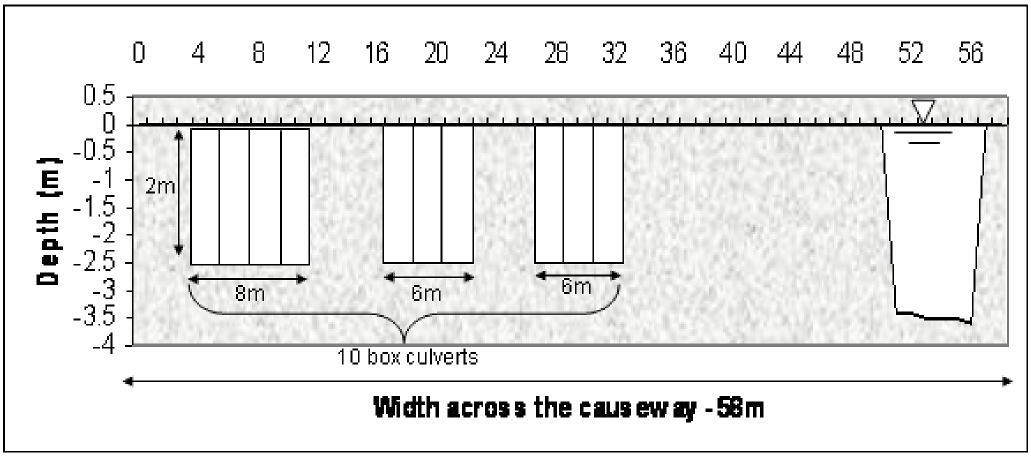

Figure 4: *Schematic representation of proposed modifications to the causeway with 10 box culverts each of 2mx2m replacing existing 8 cylindrical culverts. Box culverts are placed 0.5m below of the causeway top surface.*

2.4 Water Balance

The net water balance contributors for Rekawa lagoon for two scenarios (RS1 and RS2) were analyzed, in order to investigate the order of magnitude of the hydrologic processes responsible for maintaining steady-state conditions. This methodology has also been described by LOICZ Biogeochemical Modeling Guidelines (Gordon et al., 1996) for the application of simple budget models in coastal water bodies. These budget models are generally defined as mass balance calculations of specific variables (water, salt, sediment, carbon, nitrogen, phosphorus, etc.) for a defined geographical area and time period. Thus, the net water balance can be written as:

$$\frac{\Delta V}{\Delta t} = Q_P + Q_E + Q_G + Q_R + Q_O \qquad (1)$$

where V is the lagoon water volume (m^3), Q_P is mean monthly precipitation rate (m^{3}s^{-1}), calculated as the sum of products of daily rainfall depths times the lagoon surface area, Q_E is mean monthly evaporation rate (m^{3}s^{-1}), computed as the sum of the products of daily evaporation depth times the lagoon surface area. Mean monthly precipitation and evaporation data for past 10 years at Bataatha and Angunakolapelessa stations respectively were used for calculations (DOMSL, 2010). Q_G represents the groundwater inflow into the lagoon, which should be at least an order of magnitude lower than the other parameters, thus it can be ignored, since no measured data were available. However, inclusion of real data would probably slightly modify the water balance. The term Q_R represents the surface runoff discharge rate (m^{3}s^{-1}) from the surrounding drainage basin. Q_R was calculated using simple tidal prism considerations and salinity data. For a lagoon basin with constant salinity over time, the amount of salt entering and leaving the basin within a tidal cycle must be zero. If V_R is the volume of fresh water entering each lagoon basin from the drainage basin and V_P the volume of saline water entering (during flood) or leaving (during ebb) the lagoon basin through its mouth, according to tidal phase, then salt balance requires:

$$\frac{V_R}{2}S_R - \left(\frac{V_R}{2} + V_P\right)S_L + \frac{V_R}{2}S_R + \left(V_P - \frac{V_R}{2}\right)S_O = 0 \qquad (2)$$

where S_R, S_L and S_O the salinity at the river, the lagoon and the coastal sea water, respectively. Salinity data were obtained from filed study in May to Sep 2010 and from existing literature. Since monthly salinity values are available for each lagoon and V_P can be estimated from the lagoon area and mean tidal range. Mean tidal range in the sea, 0.34m was adapted from Gunaratne (2010a) and mean tidal range in the lagoon for RS1, RS2 and RS3 scenarios were computed using repletion factors as explained by Kjerfve and Magill (1989). Equation (2) can be used to quantify V_R, which represents the monthly average volume of fresh water entering each lagoon basin. The magnitude of the monthly Q_R -term was calculated as $Q_R = V_R T^{-1}$, where T the duration of a tidal cycle. These monthly Q_R values were used to calculate the mean monthly freshwater discharge flowing into the lagoon. The term Q_O represents the residual water exchange between the inflow of saline coastal water and the outflow of lagoon brackish water on tidal, meteorological and longer time scales. On the assumption that the lagoon volume remains constant within the period of observation, Q_O was estimated from Equation (1). Over the period of study (Δt = one month), there are no indications that the mean water level changed; thus, the term dV/dt can safely be assumed equal to zero.

2.5 Water renewal time

Water renewal time or flushing time for a lagoon is defined by Officer (1980) as the mean time a particle of a conservative substance spends in a given volume. Salt and fresh water are usually considered conservative substances in estuarine hydrodynamics. In quantifying the flushing of Rekawa lagoon, the concept of flushing half-life ($T_{50\%}$ hours) was adapted as the optimum measure of flushing time. Flushing half-life defines as the time that it takes to replace half of the lagoon water volume and this definition is based on a rather restrictive assumption, i.e. it is assumed that complete mixing occurs rapidly compared to flushing half time (Knoppers et al. 1991). Assuming first order kinetics, if *V* denotes the volume of water in the lagoon, *t* time, and *k* a rate constant, it is expressed

$$\frac{dV}{dt} = -kV \qquad (3)$$

(Pritchard, 1961) which can be integrated from $t = 0$ when the lagoon volume was V_0, to a new time, $T_{50\%}$, when the total water volume is the same but only 50% of the original water parcels remain inside the lagoon, or when $V_{new}/V_0 = 0.50$. It follows that

$$T_{50\%} = 0.69/k \qquad (4)$$

where k is a rate constant calculated as the average fraction of lagoon water volume replaced each second by the sum of the water fluxes. Hence,

$$k = \frac{\left[Q_R + Q_P + Q_G + Q_O + |Q_T|\right]}{V} \qquad (5)$$

The term Q_T represents the tidal flushing rate (m^{3}s^{-1}); hence the absolute value sign was used. Since in both lagoon systems predominant tidal constituent is the semi-diurnal tide, Q_T, was expressed as the prism entering the lagoon system per tidal cycle, although in reality this transport occurs only during half a tidal cycle. Q_T was calculated by:

$$Q_T = \pm\frac{A_W \times \Delta h}{T} \qquad (6)$$

where Δh is the mean tidal range and A_W is the waterway area of the lagoon. A_W does not change appreciably between high and low tides because of the small tidal ranges, but are often appreciably different seasonally as a result of the runoff conditions. A_W was adapted from existing literature. *T* is the period of the semi-diurnal tide (*T* = 12.42 hr = 44714 s).

Flushing half-life was calculated for three scenarios of Rekawa lagoon; 1) Before the construction of causeway or time period before year 1984 (Rekawa Scenario 1 - RS1); 2) Existing situation or time period after year 2000 (Rekawa Scenario 2 – RS2) and 3) Future scenario with respect to proposed box culvert introduction (Rekawa Scenario 3 – RS3).

3 Results and discussion

3.1 Water Balance

Table 1 illustrates the summary of the estimated average monthly water budget contributors for Rekawa lagoon for RS1 and RS2 scenarios based on rainfall and evaporation data for past 10 years (from 2000 to 2010 Sep.). According to the Table 1 tidal net water discharge (Q_O) through out the year was negative and that means the total outflow runs towards the sea. February has the highest Q_O despite of low freshwater inflow due to increasing seawater inflow. December has the second highest Q_O and that is due to the increment of freshwater inflow. Comparatively Q_O for RS1 scenario is larger than Q_O for RS2 scenario due to the tidal chocking caused by the causeway. These water budget contributors are expressed in m^3s^{-1} with the sign convention that water gain is positive and water loss is negative.

Table 1: *Summary of the estimated average monthly water budget contributors for Rekawa lagoon fro RS1 and RS2 scenarios based on rainfall and evaporation data for past 10 years (from 2000 to 2010 Sep.)*

Month	Q_P (m^3s^{-1})	Q_E (m^3s^{-1})	Q_R-*RS1*(m^3s^{-1})	Q_O-*RS2*(m^3s^{-1})	Q_R-*RS2*(m^3s^{-1})	Q_O-*RS2*(m^3s^{-1})
Jan	0.075	-0.003	23.488	-23.559	9.430	-9.501
Feb	0.016	-0.004	24.675	-24.687	9.906	-9.918
Mar	0.085	-0.004	22.592	-22.673	9.070	-9.151
Apr	0.092	-0.004	22.196	-22.283	8.911	-8.999
May	0.065	-0.004	18.891	-18.951	7.584	-7.644
Jun	0.041	-0.004	18.777	-18.813	7.538	-7.575
Jul	0.032	-0.005	18.663	-18.690	7.493	-7.520
Aug	0.063	-0.005	15.807	-15.865	6.346	-6.404
Sep	0.093	-0.004	18.243	-18.332	7.324	-7.413
Oct	0.101	-0.004	18.421	-18.518	7.396	-7.493
Nov	0.139	-0.003	23.261	-23.397	9.339	-9.474
Dec	0.104	-0.003	24.032	-24.133	9.648	-9.749

Q_P - mean monthly precipitation rate; Q_E - mean monthly evaporation rate; Q_R –estimated monthly surface runoff discharge rate; Q_O – estimated monthly tidal net water discharge rate

Results on water balance suggest the causeway has prevented flushing of the lagoon by natural water flow, causing continuous sedimentation in the lagoon. Consequently, the invading mangrove encroachment takes it toll resulting in the loss of the water surface area. Priyadarshana (1998) found nearly 2.38km^2 of water surface in 1998 whereas the Hambantota District profile completed in 1983 indicated 3.30 km^2 of water surface area (Samaranayake, 1983). It proves to be of significant evidence on gradual shrinkage of the lagoon area due to sedimentation with mangrove encroachment.

3.2 Water Renewal time

Estimated mean monthly flushing half-life and tidal flushing rate for Rekawa lagoon for three scenarios RS1, RS2 and RS3 for past ten years (from 2000 to 2010 Sep.) are illustrated in Fig. 5.

For RS1 flushing half-life ranges from 15hours to 20hours while it ranges from 39hours to 50hours for RS2. For RS3 it fluctuates from 25hours to 29 hours. For RS1, RS2 and RS3 scenarios tidal flushing rates (Q_T) were 13.6m^3s^{-1}, 5.5m^3s^{-1} and 14.1m^3s^{-1} respectively. Results depict renewal time increase with decreasing tidal flushing rates while decreases with increasing tidal flushing rates. Proposed modifications to the causeway (RS3) have positively effected to improve the flushing efficiency with respect to existing scenario (RS2) while providing more openings for increment of seawater. Flushing half-life was presented in hours in order identify its variation noticeably with its minute magnitudes.

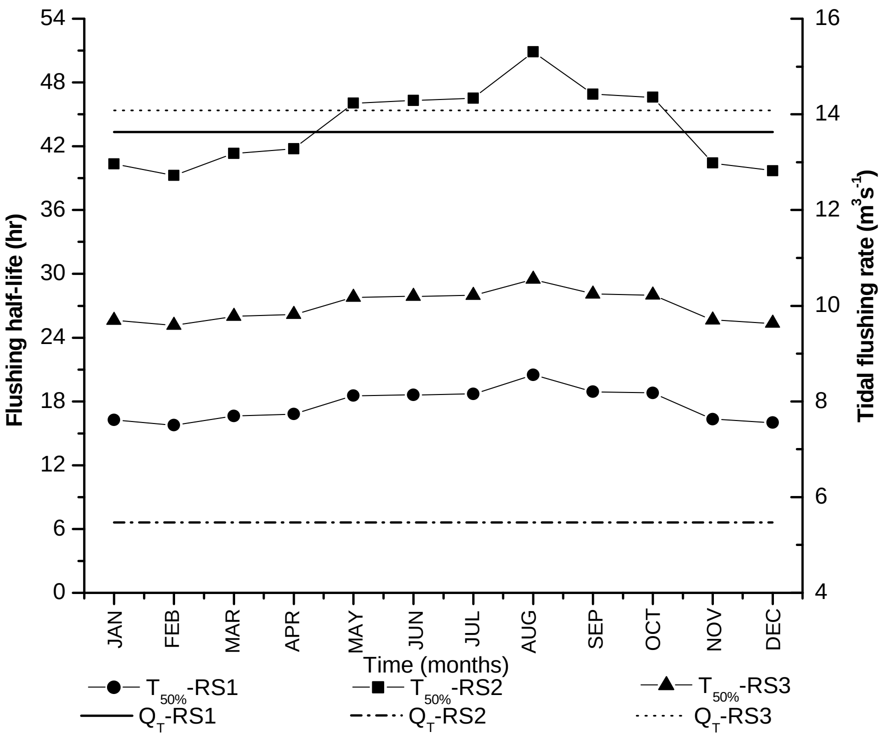

Figure 5: *Estimated mean monthly flushing half-life and estimated tidal flushing rate for Rekawa lagoon for three scenarios RS1, RS2 and RS3 for past ten years (from 2000 to 2010 Sep.)*

Reduction of total outflow and tidal flushing of the lagoon with the construction of the causeway indicates the impedance of free water flow due to causeway which in turn negatively affects on the shrimp growth because it needs around 8pH level and sandy bottom for better growth. Due to poor flushing and exchanging water, the pH level and salt contain of the lagoon water drop considerably, resulting in an unsuitable and unfriendly environment for the shrimp growth and production. Moreover, shrimps travel on the floor of the lagoon and since the water passing cylindrical culverts are placed on approximately 1m higher elevation than the lagoon floor, the shrimps do not go over it, as it becomes a barrier; it in turn stops the number of shrimps coming into the lagoon from sea.

4 Conclusions and management proposals

The comparative water budget and water renewal time have been studied in this paper for three scenarios (RS1,RS2 and RS3) of Rekawa lagoon, one of the most significant lagoonal system in Southern Sri Lanka. Results of water balance and flushing time reveal the impedance of free water flow due to causeway which in turn negatively affects on the recruitment of juvenile shrimp species. All the problems related to existing causeway were analyzed in redesigning the proposed causeway with box culverts. With the modification effective cross sectional area will be enhanced up to 74% from 28% in the existing situation which provides more allowance for free water flow. It is recommended that further dredging is required in either sides of the existing causeway as it still accumulated with some debris generated on last Tsunami disaster. Study can be concluded that the introduction of 10 box culverts will help to improve free water flow across the causeway there by it favors recruitment of juvenile shrimp species from the adjacent sea.

Water balance and water renewal time (Flushing half-life) can be used to support lagoon water resource planning and management. All the assessments can be a tool for restoration of Rekawa lagoon and can help the decision makers to take the correct decisions.

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Acknowledgements

We are grateful for financial support from Asia-Africa Science Platform Program, Japan. We extend our gratitude to villagers and local authorities in Rekawa, Sri Lanka for their fruitful collaboration and valuable assistance in this research project.

TSUNAMI HAZARDS: IMPACT MITIGATION CHARACTERISTICS OF COASTAL VEGETATION

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Abstract: In the aftermath of the Indian Ocean tsunami in 2004 the protection offered by coastal vegetation became evident in many countries affected and the role of coastal green belts in mitigating tsunami impacts has now been clearly recognized. Coastal green belts also attract attention as an environmental friendly and cost effective measure of impact mitigation. In this study, expanding the previous works conducted, further experiments were conducted to assess the energy dissipation and impact mitigation characteristics of coastal vegetation in detail. The resistance offered towards the flow which depends on the characteristics of individual plants and characteristics of the vegetation as a whole were assessed. Tests were conducted in a hydraulic flume in which vegetation was represented by geometrically similar small scale models. The energy dissipation of flow through vegetation was determined under steady flow conditions and reduction in inundation extent was assessed under unsteady flow conditions. Energy dissipation levels up to 48 % and inundation reduction levels up to 35 % were obtained in the experiments which clearly indicate the effectiveness of coastal green belts in tsunami impact mitigation. The dependence of the level of inundation reduction on the level of energy dissipation was also investigated.

Keywords: Tsunami, Hazards, Mitigation, Coastal, Vegetation

1 Introduction

Sri Lanka was unfamiliar with major natural hazards such as tsunamis until the Indian Ocean Tsunami (IOT) in 2004 which severely damaged the coastal areas causing a large number of casualties and property damage. Although tsunamis affecting the country have been rare, the IOT in 2004, subsequent tsunami alerts in 2005 and 2007 as well as the historical records of tsunami events in the past have highlighted the exposure of Sri Lanka to such hazards and the need of developing appropriate impact mitigation measures has clearly been identified.

Following the IOT disaster, the protection offered by coastal vegetation became evident in many countries affected (Kathiresan and Rajendran, 2005 and Tanaka et al, 2007) and the role of coastal green belts in mitigating tsunami impacts has now been clearly recognized. Coastal vegetation also attracts attention as an environmental friendly and cost effective measure of impact mitigation. The development and utilization of coastal green belts would thus be effective as an impact mitigation measure for such infrequent hazards affecting a widespread area.

In this research, the preliminary experimental studies on the resistance offered by coastal vegetation to tsunami overland flow were expanded to determine the energy dissipation characteristics and reduction in inundation extent in detail, in order to assess the effectiveness of coastal green belts in tsunami impact mitigation.

2 Resistance Offered by Coastal Vegetation

The flow through vegetation can be considered as a flow around non-streamlined solid bodies from a hydraulic engineering point of view. In such flow, both drag and inertia forces contribute to the resistance offered by solid bodies. In the tsunami induced overland flow caused by long waves of large periods, the drag force is dominant in comparison to the inertia force (Tanaka et al, 2007) and it can be considered that the energy dissipation of flow through vegetation is mainly caused by drag resistance.

The drag resistance *F* can be defined as,

$$F = \frac{1}{2}\rho C_D A U^2 \tag{1}$$

Where, ρ = Density of fluid
C_D = Drag coefficient
A = Projected area of solid body
U = Velocity of flow

The drag coefficient depends on the shape of the body and the characteristics of the wake formed by the separation of flow around the solid body. The variation of drag coefficient can be expressed in terms of the Reynolds number Re, which for a circular body can be expressed as,

$$\mathrm{Re} = \frac{UD}{v} \tag{2}$$

Where, D = Diameter
v = Coefficient of kinematic viscosity of fluid

3 Drag Resistance and Vegetation Characteristics

In a flow through group of solid bodies, as the wakes formed by upstream bodies are disturbed by downstream bodies, the total resistance would be influenced by the number of bodies and the distribution of such bodies. Thus the drag resistance offered by vegetation would likely to depend on the characteristics of individual plants as well as the characteristics of vegetation as a whole, namely density/spacing, extent and distribution pattern.

Based on field studies, three main components of a plant structure, aerial root system, stem and branch structure that may offer varing degree of resistance have been identified (Ratnasooriya et al, 2008). The influence of these three components has been considered together with depth of inundation, by identifying four categories of vegetation as indicated in Table 1.

Table 1: *Categories of Vegetation*

Category	Inundation		
	Aerial root system	Stem	Branch Structure
I	No	Yes	No
II	No	Yes	Yes
III	Yes	Yes	No
IV	Yes	Yes	Yes

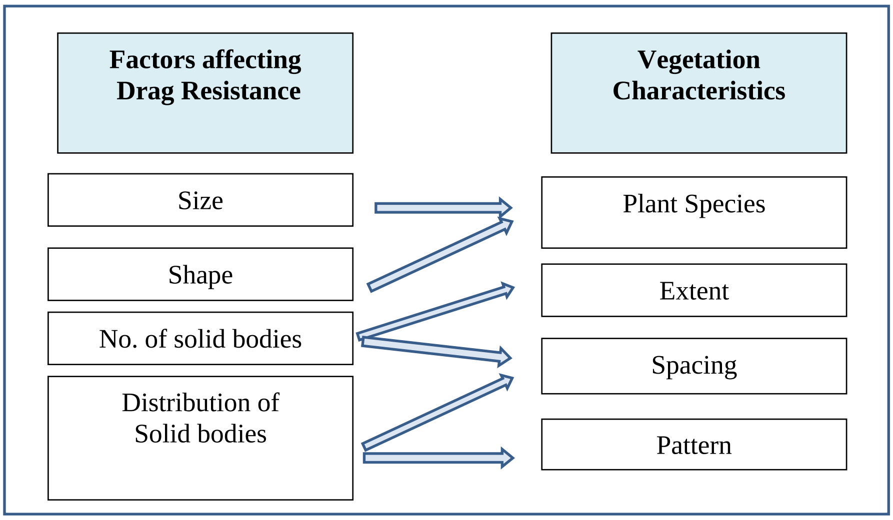

Figure 1: *Drag resistance and vegetation characteristics*

4 Physical Model Study

Detailed experimental studies were conducted to assess energy dissipation characteristics and to determine the reduction in inundation distance in which the vegetation was represented by geometrically similar small scale (approximately 1:100) models. Similar to preliminary studies (Ratnasooriya et al, 2008); this study was conducted in a hydraulic flume of length 10 m, width 30 cm and depth 30 cm.

The energy dissipation of flow through vegetation was determined under steady flow conditions. The experimental set up is shown in Figure 2(a) and Figure 2(b).

Figure 2(a): *Experimental set-up*

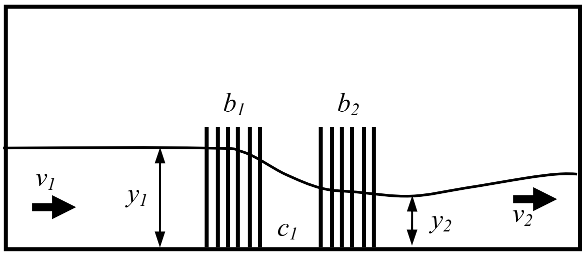

Figure 2(b): *Experimental set-up*

For the steady flow shown in Figure 2(b), neglecting frictional head loss and the bed slope over the short length through vegetation, the head loss due to the presence of vegetation *dH* can be expressed as:

$$dH = H_1 - H_2 = (y_1 - y_2) + \frac{1}{2}(V_1^2 - V_2^2) \qquad (3)$$

Where, H_1 = total head upstream of vegetation
H_2 = total head downstream of vegetation
y_1 = upstream depth of flow
y_2 = downstream depth of flow
V_1 = upstream velocity of flow
V_2 = downstream velocity of flow
g = acceleration of gravity

By replacing the velocity terms with discharge;

$$dH = (y_1 - y_2) + \frac{Q^2}{2gB^2}\left[\frac{1}{y_1^2} - \frac{1}{y_2^2}\right] \tag{4}$$

Where, Q = rate of flow
B = width of the flume

Hence the energy loss can be determined by % head loss with respect to total head of incoming flow H_1, by depth and discharge measurements.

The reduction in inundation extent was assessed under unsteady flow conditions where mass of water was released over a sloping surface as in dam break problem. The experimental set up is shown in Figure 3(a) and Figure 3(b).

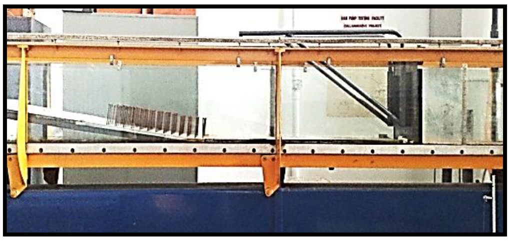

Figure 3(a): *Experimental set-up*

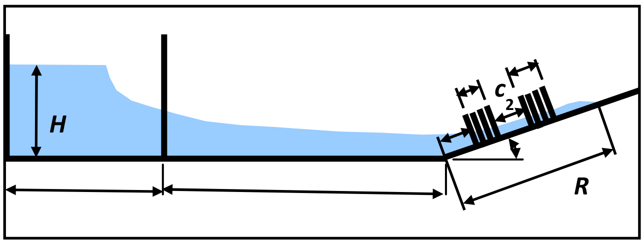

Figure 3(b): *Experimental set-up*

The reduction in inundation distance due to existence of vegetation, dR can be expressed as,

$$dR = \frac{(R - R_0)}{R_0} \tag{5}$$

Where, R_o = inundation distance without vegetation
R = inundation distance with vegetation

The inundation of the stem of plants without the aerial root system (Category I), perhaps representing the most common type of coastal vegetation, was considered in the tests. The plants were represented by nails and different diameters were used to represent variety of plant sizes. Parameters such as extent, density and grid pattern were varied to assess the influence on energy dissipation and impact mitigation.

5 Results and Analysis

Tests were considered for a number of vegetation configurations and the results are summarized in Table 2. The comparison of steady flow test results with unsteady flow test results for same vegetation configurations was presented where *dH/H %* represents the % head loss with the presence of vegetation and dR/R_0 % represents the % reduction in inundation distance over a sloping surface due to presence of vegetation.

Table 2: *Physical model test results*

Test No	Extent (cm)	Spacing (cm)	Diameter (mm)	Steady Flow		Unsteady Flow					
						θ = 1:7.5		θ = 1:10		θ = 1:12.5	
				S	**U**	**S**	**U**	**S**	**U**	**S**	**U**
				dH/H %	*dH/H %*	*dR/R %*	*dR/R %*	*dR/R %*	*dR/R %*	*dR/R %*	*dR/R %*
1			3	33.2	30.7	21.5	21.8	23.3	22.5	24.7	22.7
2		2	4	40.1	35.5	30.0	26.9	30.3	28.1	31.0	28.5
3			5	48.7	41.3	35.6	31.2	37.8	33.1	36.5	33.5
4			3	23.2	20.1	22.5	23.0	22.2	21.8	22.1	20.4
5	48	3	4	25.1	22.0	28.8	25.1	26.9	25.9	25.5	24.3
6			5	29.7	26.0	28.9	28.2	27.8	27.8	28.6	27.3
7			3	17.0	16.6	19.0	12.5	18.8	17.7	18.0	15.2
8		4	4	17.5	16.2	22.8	19.7	15.3	20.0	22.6	19.8
9			5	22.6	18.8	27.2	25.0	25.5	23.4	26.4	23.2
10			3	29.5	26.8	22.5	22.9	21.1	21.5	20.4	19.3
11		2	4	34.6	30.9	27.7	28.1	27.0	25.9	25.5	23.4
12			5	43.5	39.0	31.0	31.9	31.8	29.1	31.8	28.2
13			3	17.7	16.1	24.9	21.8	20.4	19.9	19.8	16.4
14	36	3	4	21.2	18.4	26.6	24.3	24.9	22.2	22.7	20.2
15			5	27.1	22.7	25.7	27.3	26.5	25.5	23.7	24.6
16			3	14.2	15.5	18.1	15.4	15.7	13.9	14.2	12.6
17		4	4	13.2	12.7	21.1	17.5	19.9	18.7	18.1	17.5
18			5	19.1	18.0	25.7	21.7	22.8	19.7	20.2	20.7
19			3	23.3	19.6	21.7	20.9	20.0	20.5	17.7	17.9
20		2	4	29.6	25.4	24.7	23.9	23.3	24.8	22.7	20.7
21			5	37.0	33.4	29.7	26.6	27.3	26.5	25.4	24.7
22			3	13.8	11.7	19.3	17.6	18.5	18.5	31.4	14.5
23	24	3	4	16.1	14.2	21.4	20.1	22.4	20.8	20.1	16.9
24			5	21.3	18.3	25.9	23.6	24.6	23.7	26.9	19.7
25			3	9.9	11.4	13.3	10.7	13.9	11.3	14.9	8.9
26		4	4	11.1	9.6	15.3	15.0	16.5	15.0	14.3	11.9
27			5	15.4	13.2	20.0	16.8	20.9	18.6	17.9	14.9
28	12		3	17.7	16.1	21.7	18.9	19.1	18.5	20.3	13.4
29		2	4	22.5	19.6	23.0	21.5	20.0	20.5	15.6	16.5
30			5	29.7	24.1	21.9	23.4	21.0	22.1	17.7	17.5
31			3	9.9	10.2	13.1	12.9	13.2	10.6	9.3	8.6
32		3	4	12.0	10.9	15.6	13.1	15.6	12.9	18.2	10.0
33			5	16.9	13.4	21.0	17.8	20.7	16.4	23.0	12.5

34			3	8.2	10.0	6.9	7.6	11.2	8.9	6.3	6.0
35		4	4	7.1	8.4	11.4	7.6	9.4	11.5	7.6	6.6
36			5	9.8	9.7	14.0	11.4	13.2	12.3	10.6	8.2

(Note: S: Staggered pattern, U: Uniform pattern)

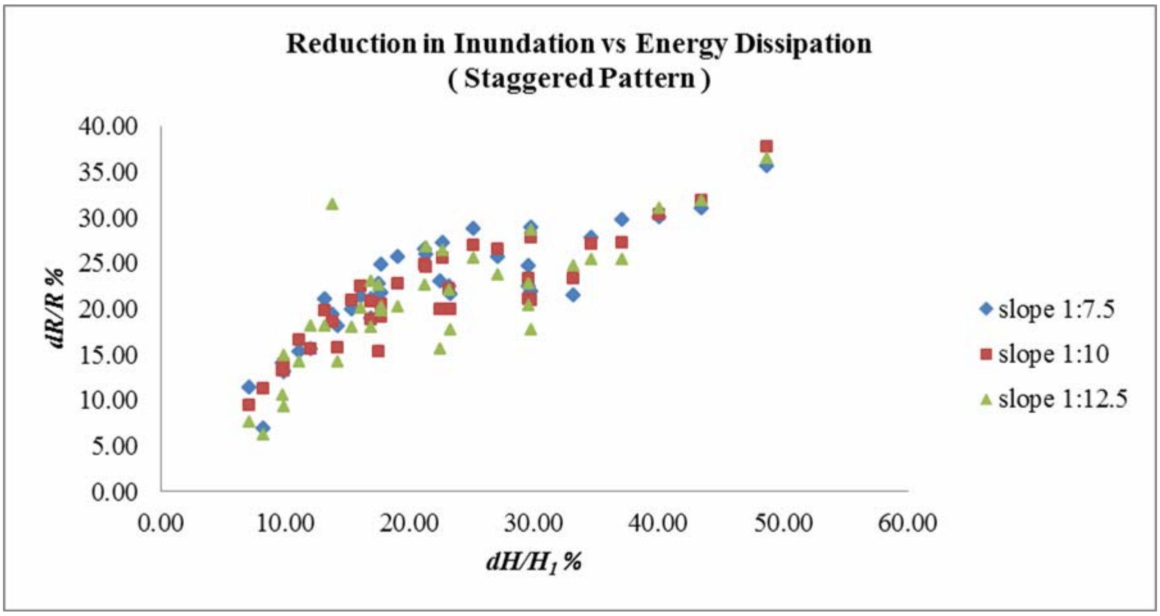

Figure 4(a): *Levels of Impact mitigation and Energy dissipation*

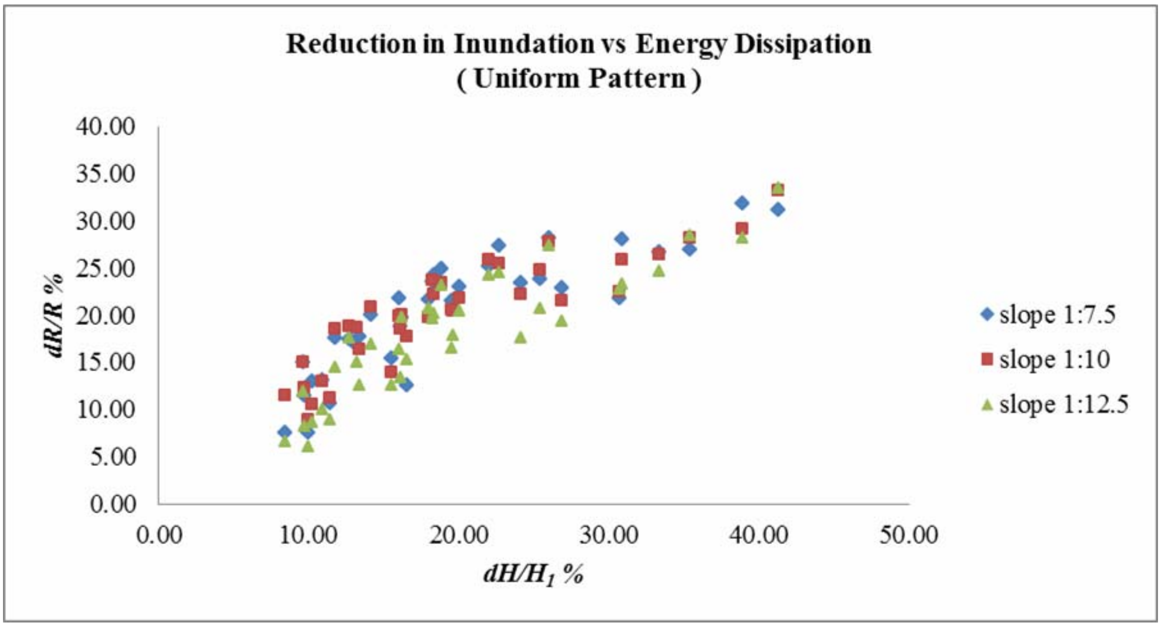

Figure 4(b): *Levels of Impact mitigation and Energy dissipation*

As indicated in Table 2, with significant energy dissipation levels reaching 48 % in parallel with reduction levels of inundation extent reaching 38 %, it is evident that vegetation is effective in mitigating adverse impacts of tsunami inundation. The dependence of reduction of inundation extent on energy dissipation by coastal vegetation is clearly evident in Figure 4(a) and Figure 4(b).
Relative influence of the various characteristics of the vegetation can be assessed by comparing the results of relevant model tests. The comparison of tests (3,12,21 and 30), (1,2 and 3) and (3, 6 and 9) reveals the influence of thickness of the vegetation belt, size of individual plants and plant density on energy dissipation as shown in Figure 5(a).

Two grid patterns of vegetation, staggered and uniform have been considered in testing in order to represent the irregular pattern of naturally grown vegetation and regular pattern in plantations. The Figure 5(b) reveals that the higher levels of energy dissipation occurred with staggered pattern of vegetation, possibly due to high levels of flow interception than uniform pattern, indicating the significance of natural coastal vegetation belts.

The influence of vegetation characteristics in reducing inundation distance was also considered and the approximately same order of influence was observed as in energy dissipation. This further reveals the dependence of reduction in inundation distance on energy dissipation.

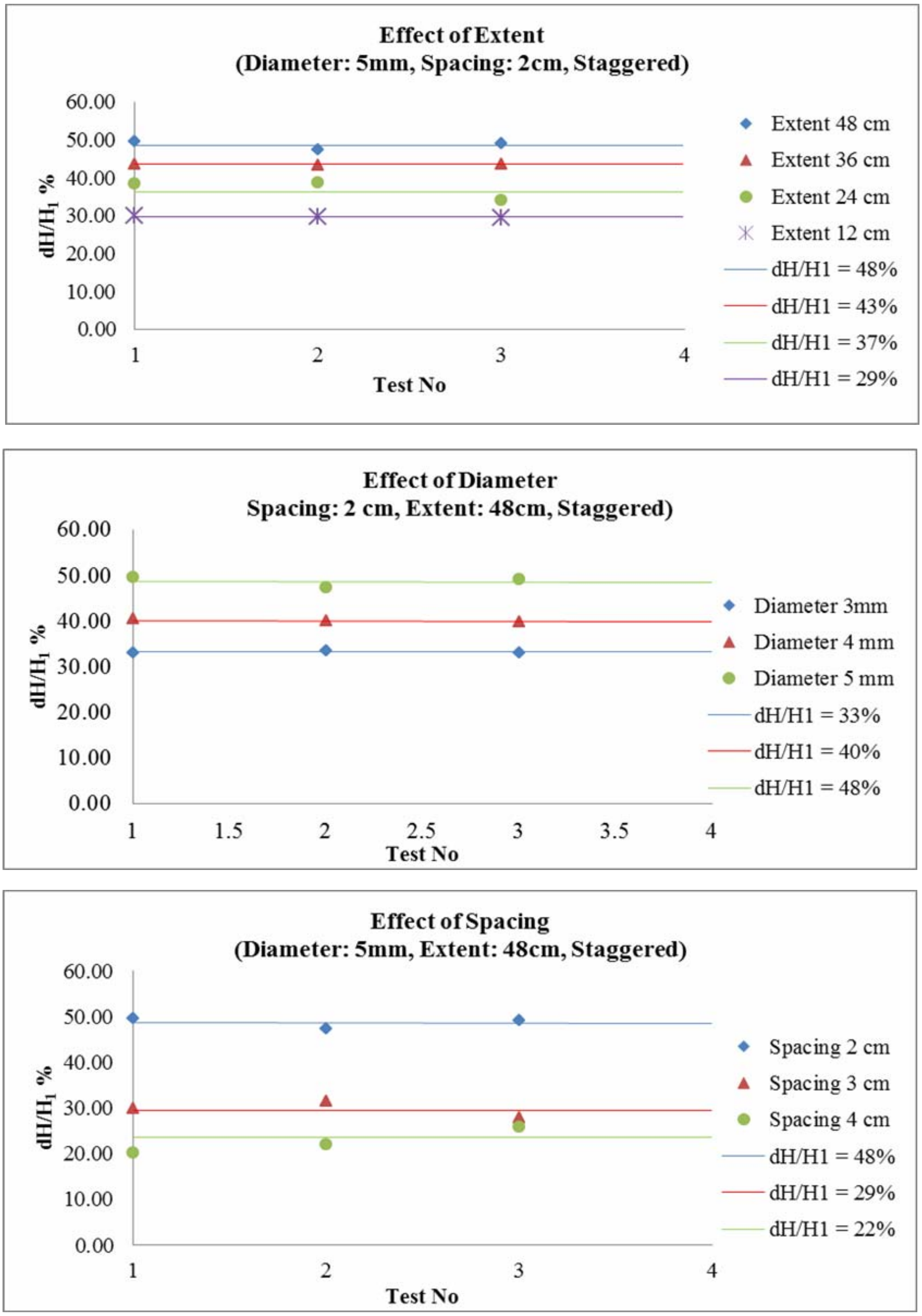

Figure 5(a): *Relative Influence of various characteristics (Extent, Size and Density) of vegetation in Energy dissipation*

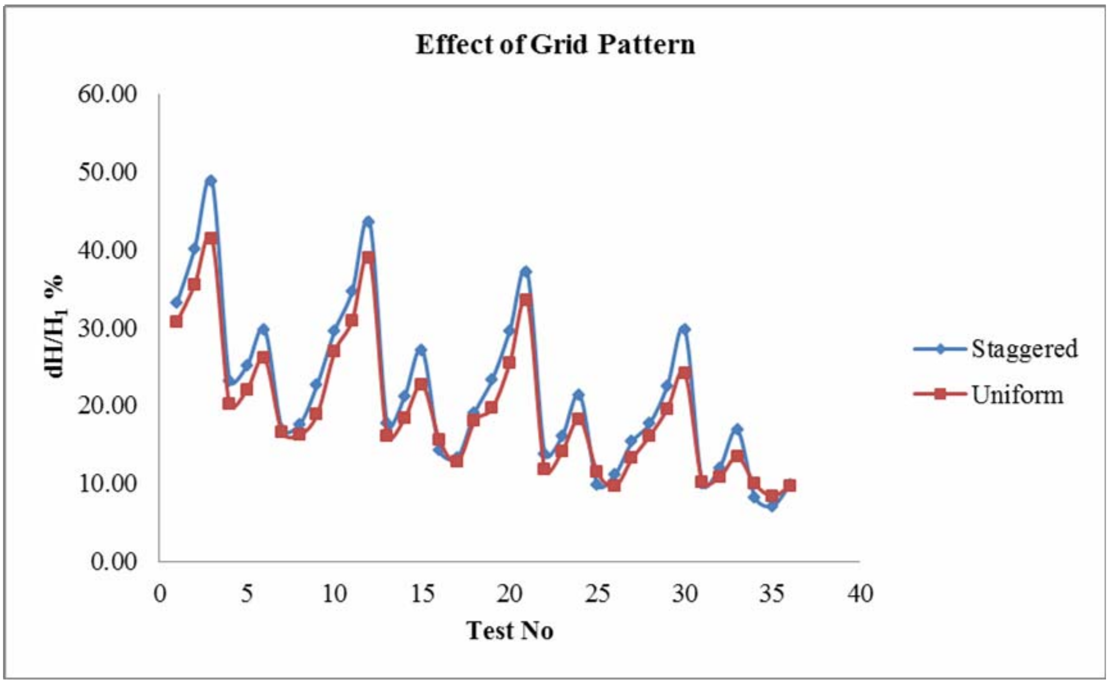

Figure 5(a): *Relative Influence of various characteristics (Pattern) of vegetation in Energy dissipation*

6 Concluding Remarks

The results of an investigation carried out by using small scale physical models under both steady flow conditions and unsteady flow conditions to assess the effectiveness of coastal green belts in mitigating impact and energy dissipation of tsunami overland flow are presented. Significant levels of energy dissipation and reduction in inundation extent were observed through experimental studies and relative influence of vegetation characteristics in impact mitigation such as extent, plant size spacing/density and distribution pattern were identified by the study.

In spite of the restrictions imposed by the small scale used in the tests, as the analysis is based on assessing the relative influence of various characteristics of vegetation, the results are expected to provide useful guidance on the effective use of coastal green belts as a possible tsunami impact mitigation measure.

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Effects of Moisture Content and Shrinkage on Soil-Thermal Properties for Peat Soils in Japan

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Abstract: Wetland is known as a source of atmospheric methane, typically produced by microbiological and chemical processes under anaerobic conditions. Soil temperature in the wetlands is a key factor to control the processes. Peat soils can be found in many types of wetlands. Peat soils contain high organic matter content and thus shows unique physical properties such as high total porosity and shrinkage. This study aims to study the heat transport of peat soils at variably saturated conditions and effects of volume shrinkage on thermal properties of peat soils. Study area of this research is Bibai marsh, Hokkaido in Japan. Undisturbed peat samples were obtained from two different peat profiles at different depths. In general, the thermal conductivity (TC) and the heat capacity (HC) of peat soils linearly increased with increasing volumetric water content, and simple two-phase (solid and water phases) models for TC and HC could generally express TC and HC behaviors, respectively, for most of peat soils. In addition, the observed volume-shrinkage of the peat soils under dry conditions did not affect the TC and HC behaviors for the studied samples.

Keywords: Peat soil, Thermal properties, Shrinkage

1 Introduction

Wetlands are recognized as a significant element in the natural environment. Various projects on the wetland conservation and restoration have been implemented since wetlands possess a great diversity of ecosystem and have functions to store and purify water. Furthermore, in developing countries, wetlands are also important as the sites for residential or industrial developments, and other infrastructure developments such as a landfill.

The wetland is also known as a source of atmospheric methane, typically produced by microbiological and chemical processes under anaerobic conditions. Soil temperature in the wetlands is a key factor to control the processes. Microbiological respiration rates and degree of anaerobic condition depend strongly on soil temperature [1]. A decrease in soil temperature reduces the rate of decomposition and increases the rate of peat accumulation [2]. Chapman and Thurlow [3] reported for a bog in Scotland that an increase in surface temperature of 4.5 °C might double CO_2 emissions and increase methane emissions by 60% based on observations at two different wetland sites. Thus, the knowledge of heat transport process in the wetlands is essential for assessing the environmental risk in the wetlands under natural conditions and developments, hereunder understanding and simulating the emissions of the greenhouse gases from the wetlands.

Peat can be found in many types of wetlands. Peat contains high organic matter content and has unique physical properties such as a high total porosity and shrinkage characteristics. Water content of peat soils can vary from about 200% to more than 2000% of dry weight. Hobbs [4] reported that 5 m of fibrous peat may contain 4.7 m of water and as little as 300 mm of solid [4]. These unique physical properties may influence heat transport characteristics for peat soils.

Heat transport in soils is governed by thermal properties such as thermal conductivity and specific heat capacity. In this study, the thermal properties for differently-decomposed and variably saturated Peat soils were measured to investigate the effects of moisture content and shrinkage on heat transport.

2 Material and Methods

The study site was Bibai marsh, Hokkaido in Japan. Undisturbed Peat samples were taken from two different sites in Hokkaido Bibai marsh at different depths using 100cm^3 cylindrical cores (i.d.:5.01cm, length: 5.11cm). Peat 1 was sampled inside the marsh area, while Peat 2 was sampled from the area nearby a drainage ditch surrounding the marsh. Physical and chemical properties of the Peat samples are shown in Table 1. Fiber content show that Peat 2 is more decomposed than Peat 1.

Table 2*: Soil physical and chemical properties for Peat soil samples [5]*

Site	Depth (cm)	Particle density ρ_s (g/cm^3)	Dry bulk density ρ_d (g/cm^3)	Gravimetric water content w (%)	Porosity Φ (cm^3/cm^3)	Saturated hydraulic conductivity Ks (cm/s)	Loss-on-ignition Li (%)	SOC	SON	Fiber Content
Peat 1	10	1.42	0.092	1211	0.93	3.68E-03	82.5	60.6	1.2	84.4
	20	1.49	0.158	573	0.86	3.96E-03	48.7	33.3	1.5	91
	30	1.37	0.108	592	0.92	3.69E-03	56.5	36.5	1	86.9
Peat 2	10	2.63	0.315	283	0.88	5.75E-03	78.8	89.7	2.1	42.0
	20	1.86	0.112	700	0.94	-	94.6	73	1.3	75.2
	40	1.44	0.130	922	0.91	-	96.7	86.6	1.1	62.5
	50	1.8	0.110	955	0.94	1.72E-03	96.8	73	0.9	73.4

The peat samples were initially saturated and subsequently drained using two different methods corresponding to the matric suction ranges. A hanging water suction method was used for low matric suctions up to pF 2 (- 100 cm H_2O) and a pressure plate apparatus for medium suctions (pF 2 to pF 4, i.e., - 100 cm H_2O to -10000 cm H_2O). Finally, the samples were air-dried (defined as pF 6 condition).The thermal properties (thermal conductivity and specific heat capacity) of the samples at different soil moisture suction levels were measured by using Decagon KD2-Pro probe.

3 Results and Discussion

Figure 1 shows water retention characteristics and volume shrinkage of Peat 1 and Peat 2 at different depth levels as a function of pF value. Except for surface layers (i.e., 10 cm depth) for both Peat 1 and Peat 2, all soils exhibited showed higher water retention characteristics up to pF 2, where around 60-70% of water saturation is still maintained, indicating a formation of well-developed organic matrix with micro-pore structure with increasing a degree of decomposition. As shown in Figure 2, both Peat 1 and Peat 2 samples gradually shrank with increasing pF (i.e,. drying), showing 50% to 85% of shrinkage under dry conditions. Peat 1 at 20 cm depth and Peat 2 at 50 cm depth showed high volume shrinkage at pF 4 condition, while the volume shrinkage for Peat 1 at 10 cm was not significant as compared to that for other soils likely because a surface layer in Peat 1 is mainly composed of fresh *Sphagnum* mosses.

Figure 2a and 2b show thermal conductivity (TC) and heat capacity (HC) as a function of volumetric water content. The solid lines in Figure 2 represent calculated TC and HC lines by assuming soil volume containing 10% of organic matter whose TC and HC are assumed as 0.25 W/m/K from de Vries [6] and 2.5 MJ/m^3/K from Campbell and Norman [7], respectively, and 90% of soil pore. Linear increases of TC and HC with increasing volumetric water content were considered. The TC of 0.60 W/m/K and HC of 4.18 MJ/m^3/K for water were used in the calculation.

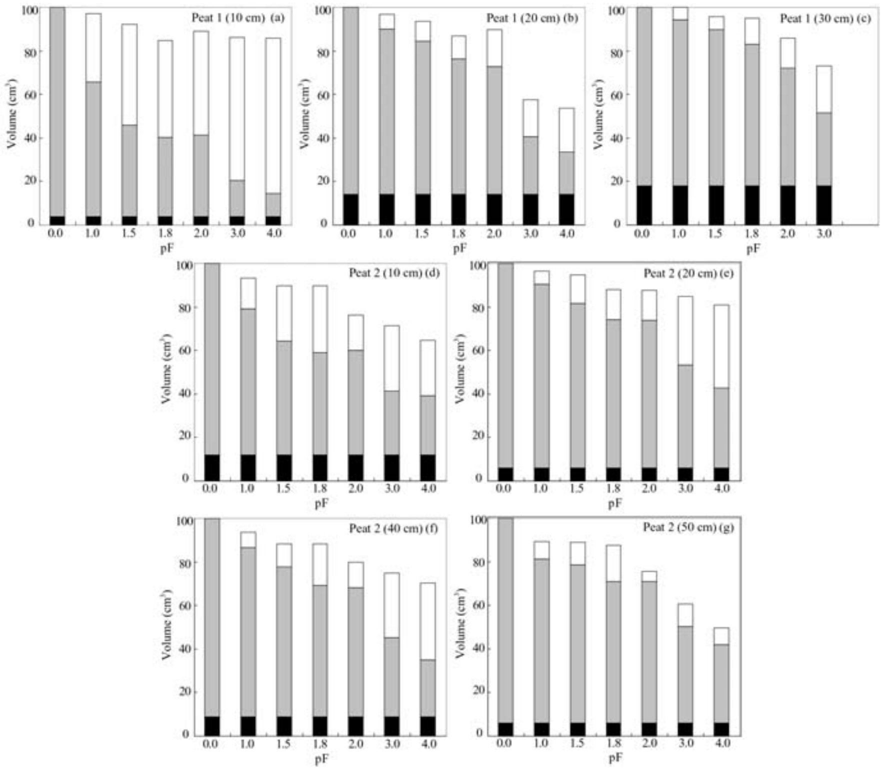

Figure 1: *Water retention and shrinkage characteristic of Peat 1 and Peat 2 soils with different depths. (Solid: ■ Water: ▩ Air: □)*

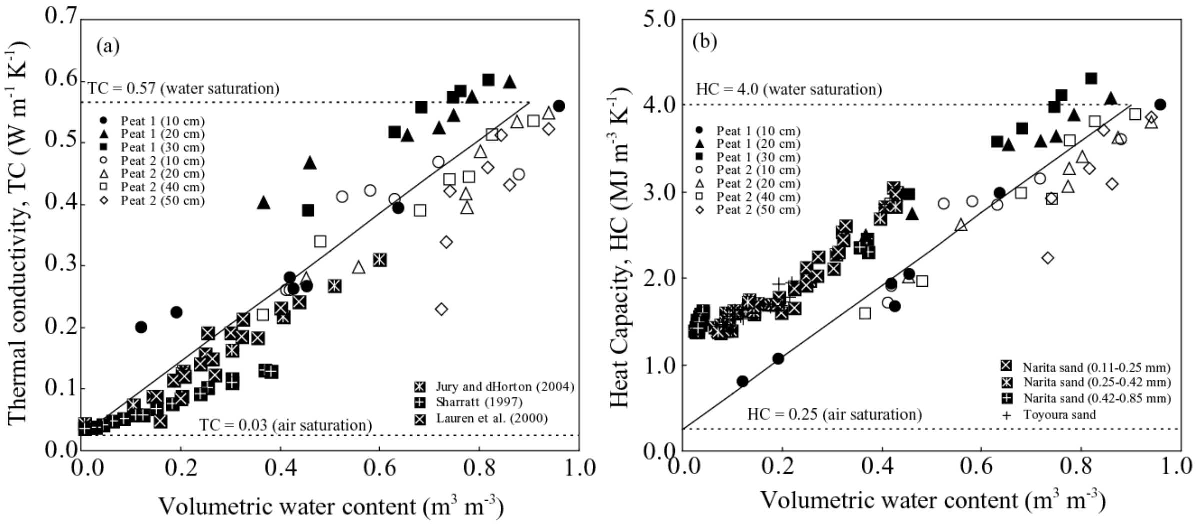

Figure 2: *(a) Thermal conductivity and (b) heat capacity as a function of volumetric water content.*

For sandy and loamy-clayey soils, Hamamoto et al. [8] and many previous works have reported a rapid increase of TC under dry condition due to an improvement of thermal contact between adjacent solids but lower incremental increase of TC under dry condition where the water film becomes thicker and the increase in TC with increasing soil water content depends largely on the displacement of air by water. In contrast to the above TC behaviors for normal soils, as shown in Figure 2a, the TC for all soils including three different peat soils from literature linearly increased with increasing volumetric water content, suggesting that heat transport through water phase highly governs heat transport characteristics for the peat soils. The linear TC behavior for the peat soils as a function of water content even under dry conditions may also indicate small shrinkage effects on the TC. The linear increase of TC for the peat soils has been also reported by Hamamoto et al. [8].

Except for Peat 1 at 20 cm and 30 cm depths, the predictive line captured the general trend of the TC behavior for all soils including literature data but slightly overestimated them. Since the line is calculated based on only volumetric fraction of water and organic matter, the finding indicates that water-phase tortuosity reduced the TC values for the peat soils. The TC for Peat 1 at 20 cm and 30 cm depths showed higher values than those for Peat 2. The difference in solid constituent (i.e., organic matter and small amount of mineral component) might affect the TC behaviors for Peat 1 and Peat 2 samples, as partially expected by lower loss in ignition (Li) values for Peat 1. Detailed physical properties for Peat 1 at 20 and 30 cm samples will be further investigated.

Similar to the TC data, the HC data for all soils (including reference HC data for four different sand size fractions) linearly increased with increasing volumetric water content (Figure 2b). The HC for Peat 1 at 20 cm and 30 cm depths showed higher values as compared to other peat soils and predictive line. In addition, the HC behavior for the Peat 1 at 20 cm and 30 cm depths under dry condition was similar to those for the sandy soils, likely supporting the unique solid constituents for the peat soils, which significantly governs the HC behaviors.

4 Conclusions

The thermal conductivity (TC) and heat capacity (HC) of the peat soils are mainly affected by the volumetric water content, showing the linear increase of TC and HC with increasing water content. The trend was generally described by simple two-phase (i.e., volumetric fractions of organic matter and water) models, respectively, except for the data for Peat 1 at 20 and 30 cm depths. It was suggested that the difference in solid constituent for the peat 1 at 20 and 30 cm depths might affect the TC and HC behaviors. In addition, clear shrinkage effects on the TC and HC were not observed for studied samples.

In perspective, with accumulations of TC and HC data for soils including more decomposed peat soils and micro-scale observations of pore structure e.g., using X-ray CT scanner, the effects of complex soil-pore structure induced by rich organic matter on thermal properties should be further investigated and accurate predictive TC and HC models available for peat soils will be developed.

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Acknowledgements

This publication made possible by the JSPS Grant-In-Aid for Scientific Research no. 22860012, and JSPS Asia and Africa Science Platform Program.

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APPLICATION OF FLOATING WETLANDS AT TROPICAL CONTEXT FOR LAKE WATER RECLAMATION

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Abstract: Pollution of lakes increases rapidly due to the urbanization in developing countries. Therefore, it is necessary to set up feasible mitigatory measures to address eutrophication issues, concurrently considering the lack of land availability as well as low cost involvement. This study was carried out to find out possible application aspects of floating wetland units for lake reclamation. Hence, two types of macrophytes, i.e. *Typha angustifolia* and *Canna iridiflora,* were employed in the pilot scale experiments with two floating wetland systems and monitored water quality for the removal of BOD_5 and inorganic nitrogen. Over 80% of BOD_5 and NH_4^+-N removal capabilities were obtained while NO_3^--N removal was recorded as over 40%. On the other hand, the root growth and its density of *T. angustifolia* was higher than that of *C. iridiflora*, resulting relatively better performance by *T. angustifolia* compared with *C. iridiflora*. Consequently, floating wetlands with *T. angustifolia will be an app*ropriate solution in lake restoration, especially located at congested areas.

Keywords: Eutrophication, Floating wetlands, Lake restoration

1 Introduction

Kandy (N 7° 17' 47", E 80° 38' 6"), the last kingdom of Sri Lanka, has been recognized as a world heritage city by UNESCO for its archeological importance. Kandy Lake is one of the most important manmade structure, constructed during 1810- 1812 A.D. by the last king before becoming Sri Lanka a British Colony. The lake covers an area of 0.18 km^2 and a maximum depth of 13m. It has a capacity of 0.348 MCM within a perimeter of 3.25 km [1]. However, any recreation activity other than riding boats is prohibited and the lake water is used neither for irrigation nor any other domestic activity as the lake water is extremely polluted due to effluent discharges and surface runoff.

It has been reported in the previous studies that Kandy Lake is enriched with P and N compounds and polluted by some heavy metals [1]. Usually, the first flush of storm water from the adjoining residential and commercial areas is a major cause of pollution in similar types of lake surrounded by urban settlements [2]. In addition, the increasing inhabitant bird population, such as resident cormorant (about 250) and roosting bats (about 2500), makes direct contribution to the nutrient pool in lake body [1]. Quality of lake water is speculated to change topographically and seasonally.

Further, Kandy Lake water was studied for several metal ions and found that the Fe^{2+} concentration (> 100 µg/l) was increased in offshore area towards the deepest point, which is found in between the sluice gate and the island at centre [3]. Hence, relatively more reducing conditions prevail in offshore region. Because of the high traffic jam in the peripheral road of the lake, particularly vehicular emissions containing Pb likely to be entered to the lake water while Zn and Cd are added from the small scale industries scattered in lake catchment [3]. Consequently, large fish mortality was observed from mid to end of year 2009, reporting maximum as 150 deaths per day.

In order to mitigate the water pollution on these water bodies, it is necessary to have proper feasible mitigatory measures. Using plants to purify wastewater is feasible option due to its cost effectiveness and environmental sensitivity. Within highly urbanized catchments, where land utilization is limited, more innovative treatment options will be needed. In that case, floating treatment wetlands may represent a potentially suitable solution for improving the water quality in lakes considering their various advantages such as; 1) improvement of the water quality, 2) immediate greening, 3) durable construction in stainless steel, 4) simple installation, 5) almost maintenance free, 6) root horizon as colonization space for microorganisms, 7) nest and brooding spaces for birds, 8) spawning space for fish and 9) shadowing and cooling of shallow water.

Artificially created floating wetlands have been used for a limited range of applications to date, such as water quality improvement, habitat enhancement [4] and aesthetic purposes in ornamental ponds and lakes. In terms of water quality improvement, the main application was the treatment of storm water, combined storm water-sewer overflow, sewage [5], acid mine drainage, piggery effluent [6], poultry processing waste water and water supply reservoirs [7]. However, there is no research found on floating wetland systems done in Sri Lanka at its environmental conditions. Hence, in this research it was expected to determine the viability of using floating wetland systems for water quality improvement establishing general guidelines in application.

2 Objectives and Methodology

The main objective was to evaluate the performance of a pilot scale floating wetland system for lake water reclamation in tropical climate. In this regards, the following methodology was employed:

1. Developed a floating wetland system using locally available material with a sufficient uplift and sustainability at prevailing ambient conditions.
2. Compared the plant growth characteristics and nutrient removal capabilities of two emergent macrophytes (*Typha angustifolia* and *Canna iridiflora*) in pilot scale floating wetland systems.

2.1 Design of floating mats

Premises in Bio technical research center (Faculty of Agriculture, University of Peradeniya, Sri Lanka) was selected to establish the experimental setup and carryout the experiment. The existing three identical tanks were allocated for launching the floating wetland system. The floating wetland models (each of 100 x 50 cm^2) were consisted of a floater and a frame for keeping the vegetation (PVC pipes), media for growth of vegetation (coconut coir pith, PVC net and GI mesh), an anchoring system (cement weights) and vegetation The total weight of the model (initially) was 18.3 kg and the maximum weight that could be carried by the model using the bouncy was estimated as 25.4 kg, keeping a maximum weight of 7.1 kg for the vegetation.

T. angustifolia and C .iridiflora were selected as macrophytes for experiment purpose since these two types of macrophytes were available and sustainable at the environment in Kandy. Macrophytes approximately of 20 cm shoot height were chosen carefully and planted in the wetland units with a density of 10 no of plants/ m^2.

2.2 Experimental procedure

Batch reactor method was selected to test the model of floating wetland system with 12-14 days as hydraulic retention time. After running in tap water for a period of one week to acclimatize the systems, the two floating wetland units were put in to the tanks filled with wastewater coming from

Akbar hall residence at Faculty of Engineering, University of Peradeniya, Sri Lanka. A control volume was maintained near to the tanks with floating wetland units.

Experiment was carried out at three stages and three effluent samples were taken at each stage as initial (prior to launch the system), intermediate and final (prior to remove the system) and were taken at surface level of water body. Each sample was tested for BOD_5, NH_4^+ -N, NO_3^- -N at the environmental engineering laboratory in University of Peradeniya [8]. In addition, shoot height and root depth were measured at predetermined occasion.

3 Results and Discussion

3.1 Monitoring of plant morphology

The root structure and the length observations (Figure 01) have shown that the growth rate of *C. iridiflora is greater than T. angustifolia.* However, the root density was relatively high in *T. angustifolia*. On the other hand, *T. angustifolia* showed a gradual increment in average shoot height through out the experimental period while *C .iridiflora* shoot height was increased in early days and saturated at around 42 days. It indicates that *T. angustifolia* plants still could not reach to the maturation level while *C .iridiflora* plants were observed getting into the matured conditions. After 52 days, one out of eight mother plants of *C .iridiflora* were observed to deliver flower buds. In general, plants growing at nutrient poor conditions will often develop more extensive root systems in order to increase the surface area available for nutrient uptake.

The growth rates of *Canna* sp. was recorded as 3100 $gDWm^{-2}yr^{-1}$ [9] while it was observed greater in *Typha* sp. as 4000 $gDWm^{-2}yr^{-1}$ [10]. Hence the biomass production of *T. angustifolia* could be greater and therefore, *T. angustifolia* impacts much on nutrient removal by harvesting. It has been also estimated that C*anna sp.* may remove an amount of 85 $gNm^{-2}yr^{-1}$ by above-ground biomass harvesting [9] and that for *T. angustifolia* has reached to a much better level of 266 $gNm^{-2}yr^{-1}$ [11].

However, it is possible to manipulate the dissolved oxygen concentration in the water column by including open water zones that allow for re-aeration through algal photosynthesis diffusion across the air-water interface. The effect of nutrient concentration on root development may be less straight forward. On one hand, a ready availability of nutrients generally promotes good plant growth and vigor.

3.2 Evaluation of treatment efficiencies

The experiment done at a HRT of 14 days shown that *T. angustifolia* performs well in removal of BOD_5 than that of *C .iridiflora* (Stage 1 & 2, Table 1). However, at early stages, both macrophytes proved their capacity on making higher reduction of BOD_5 than the removal at the absence of macrophytes (Stage 3, Table 1). However, with the maturation of plants, *C .iridiflora* could improve its contribution on reduction of BOD_5 than that of *T. angustifolia*. Comparing two macrophytes, *C .iridiflora* showed a higher root growth rate at early days while root density of *T. angustifolia* was increased at later stage. Hence, the radial oxygen lose (ROL) in *C .iridiflora* could be high at early days and it might have caused on the better performance in BOD_5 removal at early stage.

2.0 – 5.0

3.0 – 10.0

After 4 weeks

25.0 – 30.0

20.0 – 25.0

b) After 6 weeks

35.0– 40.0

30.0 – 35.0

c) After 8 weeks

C .iridiflora *T. angustifolia*

Figure 1: Comparison of the root development patterns of *T. angustifolia* and *C .iridiflora* at different time intervals (*all values are in cm*)

Usually, ROL creates aerobic conditions in the rhizosphere. The oxygen transfer rate to below ground was about 80 $gm^{-2}day^{-1}$ in a well matured wetland system [12]. The macrophyte root and rhizomes in the rhizosphere leak oxygen into the microzones in anaerobic condition. Hence, the addition of oxygen stimulates the breakdown of carbonaceous compounds resulting in BOD_5 removal of 78–91% at 165–237 mgl^{-1} of inflow BOD concentration with *Typha sp.* [13].

On the hand, N removal has varied with the type of macrophytes (Table 2). As well, there was no significant different at the presence and absence of floating wetland systems ($p<0.05$). This could be created due to the interference of high algae growth in the control system. However, the algal growth was controlled in the planted systems due to the competition for nutrients. NH_4^+-N and NO_3^--N were recorded over 80% and 40% respectively in floated wetland systems.

Table 1: *The variation of BOD_5 removal efficiency of each macrophytes specie with the time (n=3)*

Days	BOD_5 values (mgl^{-1})			BOD_5 removal efficiency (%)		
	T. angustifolia	*C .iridiflora*	*Control*	*T. angustifolia*	*C .iridiflora*	*Control*
Stage 1						
0	22.1	22.1	22.1			
5	11.3	5.5	15.8	48.5	75.3	28.6
14	10.3	3.3	10.4	53.2	85.0	53.0
Stage 2						
0	20.1	20.1	20.1			
5	8.8	7.3	9.2	56.2	63.5	54.4
14	4.8	5.8	6.6	76.1	71.3	67.4
Stage 3						
0	28.1	28.1	28.1			
1	20.2	21.6	26.3	28.1	23.1	6.4
2	13.7	15.3	22.0	51.2	45.6	21.7
3	10.2	12.3	19.6	63.7	56.2	30.2
4	8.5	9.7	18.8	69.8	65.5	33.1

Table 2: *Comparison of the averaged nitrogen removal efficiencies of two floating wetland systems with time (n=6)*

Wetland system	Sampling duration (days)	NH_4^+-N	NO_3^--N	NH_4^+-N	NO_3^--N
Control	0	25.0	7.8		
	7	13.8	-	44.8	
	14	6.9	4.4	72.4	43.6
T. angustifolia	0	25.0	7.8		
	7	12.5	2.7	50.0	65.4
	14	3.4	4.6	86.4	41.0
C .iridiflora	0	25.0	7.8		
	7	10.4	3.3	58.4	57.7
	14	4.6	3.9	81.6	50.0

In general, nitrification followed by denitrification, volatilization, plant uptake and substrate adsorption are the major NH_4^+-N removal mechanisms in a wetland system [14]. At regular ambient conditions, denitrification is probably the most significant pathway of NO_3^--N removal from a wetland system [15]. The loss through volatilization of NH_4^+-N represented, on average, 20% of the initial concentrations at the similar pH range (7.8 – 8.4) as observed in this experiment [16]. This could be greater in the control system than planted system due to its greater exposure to the atmosphere. On the other hand, the contribution to total nitrogen removal by direct plant uptake was limited as 4-11% [15]. Also, the adsorption by sediment might contribute extensively in nitrogen removal [15].

Usually, floating wetland systems and the root and rhizome system assist in nutrient removal by providing space for the attached growth of micro-organisms colonies, creating the bio-film, and take nutrients out of the water. Hence, when nitrogenous compounds pass through the metabolism or the micro-organisms and are thus transformed into an easier digestible form, and then the plants take them in and build with them the biomass above the water level as leaves, stems and sometimes flowers. Finally, the biomass harvesting assists in taking the excess nutrients effectively and permanently out of the water. Therefore, Plant roots are believed to play a major role in treatment processes within floating wetland systems.

However, further fundamental experimental researches are required in order to establish a relationship between loading rate per unit surface area of floating wetland. This would then enable to produce guidelines on the surface area of floating wetland systems.

4 Conclusions

The experimental results have proven the effectiveness of floating wetland systems in removing both carbonaceous and nitrogenous compounds from polluted water. However, comparing two macrophytes species, *T. angustifolia* performs well in removal of BOD_5 and inorganic nitrogen than those of *C .iridiflora*.

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Acknowledgements

Authors would like to be grateful to Mr. J.M.K Bandara, Mr. W.D.A.U Withana and Mr. D. Jayathilake of Faculty of Engineering, University of Peradeniya, Sri Lanka for the all hard work done in the experimental field and laboratory to make the experiment successful. In addition, the heartiest gratitude goes to Dr. C.S. Kalpage, Dr. G.B.B.Herath and Mrs. G.M.P.R. Weerakoon for their guidance given during the experimental period.

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EFFECTIVENESS OF COASTAL FORESTS IN MITIGATING TSUNAMI DAMAGE AT EASTERN COAST OF SRI LANKA

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Abstract: This study investigates the effectiveness of coastal forests in mitigating the tsunami damage using the field data of forests. A filed survey was conducted on *Casuarina equisetifolia* forests that established after the Indian Ocean tsunami on 26 December 2004, at eastern coast of Sri Lanka. Tree and forest characteristics were measured in order to analyze the effectiveness of the forests in mitigating the tsunami damage. In addition, a numerical simulation was carried out to find out the optimum conditions of the *C. equisetifolia* forests. Results revealed that the spacing between the trees had a positive correlation with trunk diameter where larger diameter trees required greater spacing. Moreover, drag coefficient was varied along the tree height and it was affected considerably by the branches and the leaves. A numerical simulation was performed for evaluating the quantitative effect for tsunami reduction and damage. It found that the tsunami force was reduced largely and the tsunami velocity and depth were reduced slightly subsequent to the forest. The most appropriate tree density was found as 0.3 trees/m^2.

Keywords: Coastal forests, tsunami damage, drag force

1 Introduction

The tsunami on 26 December 2004 caused due to a massive undersea earthquake, measured at 9.3 on the Richter scale, the world's largest earthquake after the Alaskan event of l964. It has caused economic and ecological disaster in 13 Asian and African countries (Kandasamy and Narayanasamy 2005). About two-thirds of Sri Lanka was severely damaged on a scale this country has never experienced before (Tanaka et al. 2007). These damages give emphasis to develop methodologies to prevent or minimize the damages of future tsunamis. Goto and Shuto (1983) found that the energy associated with the tsunami was dissipated as for a tsunami passing through an obstacle. This means that the establishment of obstacles such as sea walls, wave dissipating concrete blocks, or rock breakwater structures would help to mitigate the adverse effects of tsunami. However, the developing countries cannot bear the high capital cost associated with them. In addition, these structures would adversely affect the ecology and aesthetic of the coastal environment. Coastal vegetation can significantly use in reducing the severity of tsunami waves and dissipating the amount of energy associated with them (Harada et al. 2002; Kandasamy and Narayanasamy 2005; Tanaka et al. 2007). Moreover, coastal vegetation would positively affect the ecology and aesthetic of the coastal environment.

Many researchers have experimentally and numerically investigated the effectiveness of coastal vegetation in mitigating the tsunami damage. Harada et al. (2000) proposed the tsunami numerical simulation including the effect of costal forest resistances. Harada and Imamura (2001) proposed the resistance coefficients due to mangrove under the unsteady flow from the hydraulic experiment analysis. The effectiveness of coastal forests against tsunami was analyzed statistically by considering the physical damage on pine trees in Japan (Shuto 1987). In addition, Tanaka et al. (2007) demonstrated the effectiveness of different coastal tree species in mitigating the tsunami damage in Sri Lanka and Thailand after the tsunami on 26 December 2004. However, any of the above studies have not investigated the effectiveness of established *Casuarina equisetifolia* forests in mitigating tsunami damage. In addition, they did not consider the risks associated with the coastal forest during the tsunami.

Thus, the objectives of this study are to investigate, (1) the effectiveness and (2) the optimum conditions of *C. equisetifolia* forests in mitigating the tsunami damage.

2 Materials and methods

2.1 Site description

A field survey was conducted from 24-27 May 2010 at eastern coast of Sri Lanka (Figure 1). The area investigated covered about 72 km (11 locations) from Passekudah to Kalmunai. The areas were mainly covered with *C. equisetifolia* forests that established under the various projects intended to protect people, the infrastructure and the environment from future tsunami hazards. The tree and forests characteristics, such as tree height (H), trunk diameter at breast height, tree density, forests length (L), forests width (W), the spacing between the trees in the shore and cross-shore directions (l_1 and l_2, respectively) (Figure 2), and the distance from the forest to the sea were measured during the field survey. In addition, the tsunami water depth and flow velocity were obtained from the available data.

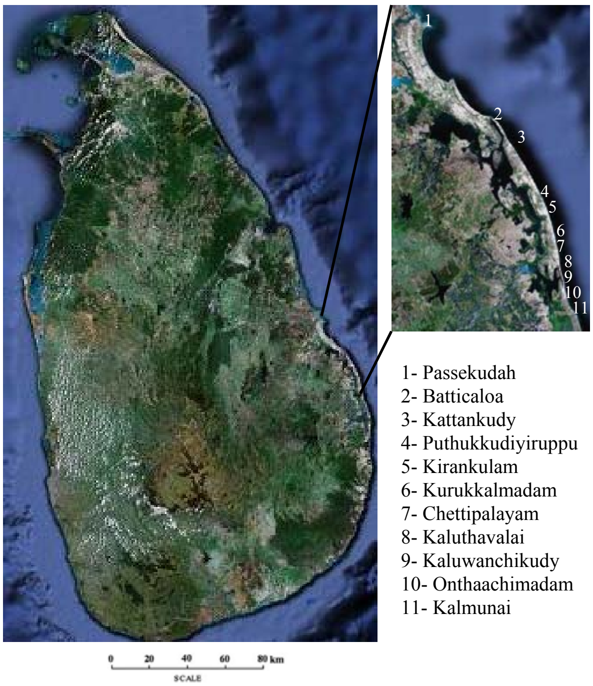

Figure 1: The locations of the investigation sites

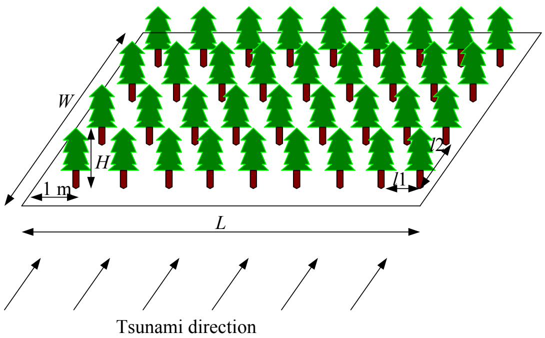

Figure 2: Definitions of the tree and the forest characteristics

2.2 Estimation of drag force coefficient using field data

The physical characteristics of coastal vegetation were considered by means of drag force of trees along a width of W (m) and a length of vegetation of 1 (m) (Figure 2). The following equation shows the cumulative drag force acting on the forest (Tanaka et al. 2007).

$$D_{cum} = n * (\text{drag force on one tree}) = n * \int \frac{1}{2} C_{di} \rho u_i^2 dA_i$$

$$= \frac{n}{2} (\alpha \beta C_d) \rho U^2 (h \frac{d}{100})$$

$$D_{cum} = \frac{1}{2} (\frac{d n \alpha \beta}{100}) C_d \rho U^2 h \qquad (1)$$

where D_{cum} is the cumulative drag force of trees a width of W (m) and a length of 1 (m), n is the number of trees in a vegetation width of W (m) and length of 1 (m), d is the reference tree trunk diameter at 1.2 m above the ground (cm), α and β are additional coefficients representing the effects of branches and leaves on the drag force, respectively, C_d is the drag coefficient, ρ is the density of salt water (kg/m^3), U is the depth-average velocity (m/s), and h is the tsunami depth (m). Coefficients α and β were chosen according to the average tree height.

Equations 2, 3, and 4 define the vertical vegetation structure, C_{d-all}, the effective vegetation thickness, dN_{all} (cm/ (vegetation width x 1 m^2)), and the vegetation thickness per unit area, dN_u (cm/unit vegetation area m^2), as follows.

$$C_{d-all} = \alpha\beta * C_d \tag{2}$$

$$dN_{all} = \alpha\beta * dn \tag{3}$$

$$dN_u = \frac{dN_{all}}{l^2 n} = \frac{\alpha\beta d}{l^2} \tag{4}$$

where l is the average spacing of the trees (m). Eqs. 2, 3, and 4 are related to the drag force in Eq. 1. C_{d-all} describes the characteristics of the tree itself, dN_{all} describes the characteristics including the effects of the tree structure $\alpha\beta$ in the W (m) x 1 (m) vegetation, and dN_u describes the characteristics of a unit vegetation area.

2.3 Numerical simulation including coastal forests

In order to evaluate the effect of tsunami reduction quantitatively, the tsunami numerical simulation of run up including the resistance of the control forest was carried out and the change of hydraulic parameters (velocity and tsunami depth) and the tsunami force on the land were examined. A coastal forest at Batticaloa site (length = 410 m and width = 100 m) was selected as an example to carry out numerical simulation. To evaluate the tsunami reduction effects by coastal forest, the variation of tsunami height, velocity, and tsunami force subsequent to the forest were examined with input data, including the topography, tsunami conditions, and different tree densities. Four tree density values (0.1, 0.2, 0.3, and 0.4 trees/m^2) were used in numerical simulation. The conditions for tsunami numerical simulation are shown in Figure 3.

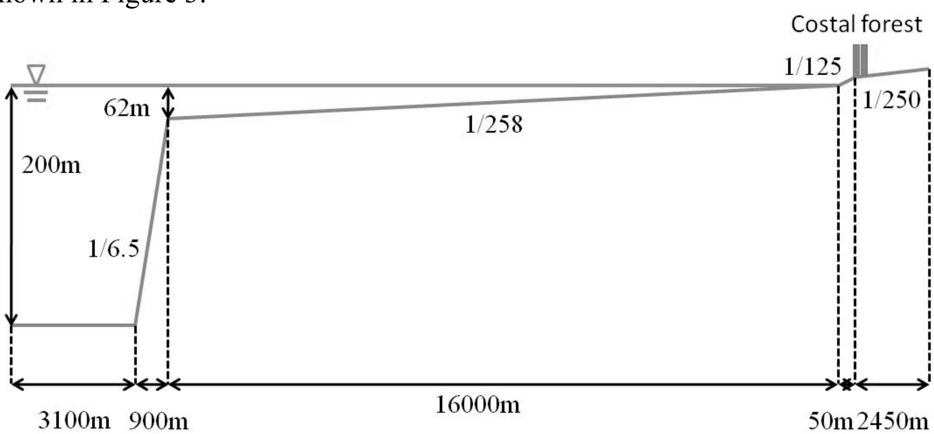

Figure 3: The section of coastal topography used in numerical simulation

The governing equations used for the numerical simulation were the continuity equation (5), the momentum equation in X and Y directions (6) and (7), and the equation for drag force (8).

$$\frac{\partial \zeta}{\partial t} + \frac{\partial Q_x}{\partial x} + \frac{\partial Q_y}{\partial y} = 0 \tag{5}$$

$$\frac{\partial Q_x}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_x^{\ 2}}{d}\right)+\frac{\partial}{\partial y}\left(\frac{Q_xQ_y}{d}\right)+gd\frac{\partial \zeta}{\partial x}+\frac{\tau_{bx}}{\rho}+\frac{F_x}{\rho}-E_{vx}=0 \quad (6)$$

$$\frac{\partial Q_y}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q_xQ_y}{d}\right)+\frac{\partial}{\partial y}\left(\frac{Q_y^{\ 2}}{d}\right)+gd\frac{\partial \zeta}{\partial y}+\frac{\tau_{by}}{\rho}+\frac{F_y}{\rho}-E_{vy}=0 \quad (7)$$

$$F=\frac{1}{2}\rho C_{d-all}AU^2 \quad (8)$$

where, x and y are coordinates, t is time, ζ is water level, Q_x is discharge (x-direction), Q_y is discharge (y-direction), d is water depth, h is static water depth, g is acceleration due to gravity, ρ is density of water, τ_{bx} is bottom shear force (x-direction), τ_{by} is bottom shear force (y-direction), F_x is drag force of trees (x-direction), F_y is drag force of trees (y-direction), E_{vx} is eddy viscosity force(x-direction), E_{vy} is eddy viscosity force(y-direction), F is drag force on tress, and A is projected area of trees facing to the tsunami.

3 Results and discussions

3.1 Variation of drag coefficient

Figure 4(a), (b), and (c), show the relationship between the trunk diameter and the average apace between each tree, the vertical distribution of $\alpha\beta$, and the relationship between dN_u and the tsunami height, respectively. Figure 4(a) shows that the average spacing becomes larger with increasing trunk diameter. This demonstrates that a lager tree requires a larger spacing (lower tree density) and vice versa. Tanaka et al. (2007) obtained similar type of results for correlation between trunk diameter and the average space between the trees. In addition, Harada and Kawata (2004) obtained a positive and significant correlation between forest density and diameter of trunk for the coastal forest conditions in the actual field.

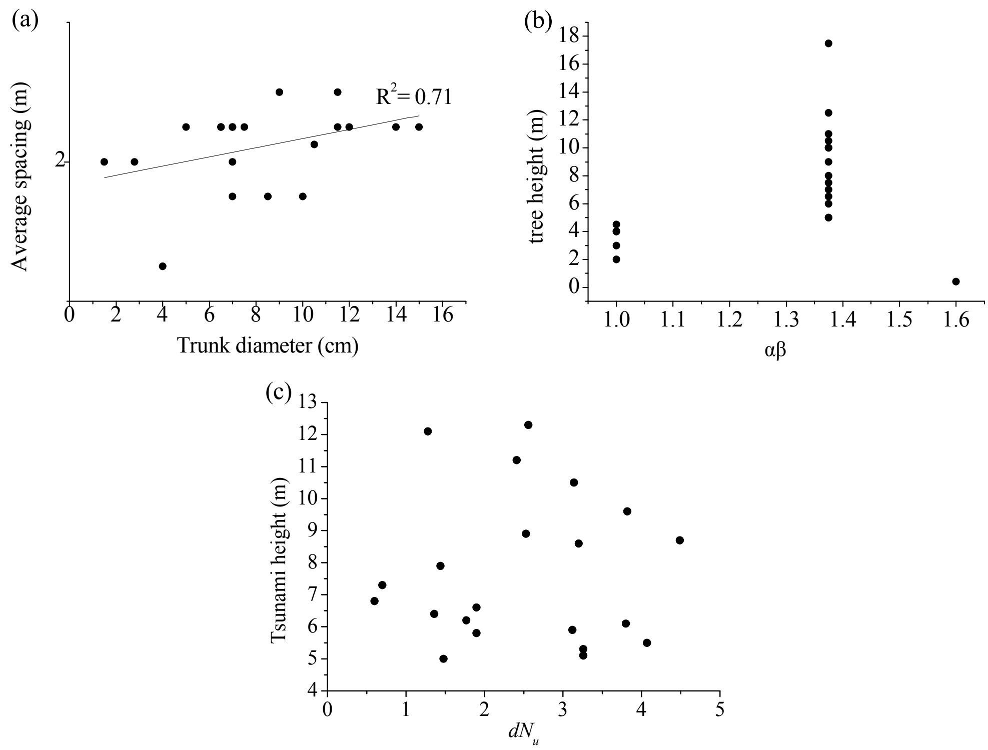

Figure 4: Characteristics of *C. equisetifolia* forests at the investigated sites with the tsunami water depth at 2004 Indian Ocean tsunami

Coefficients $\alpha\beta$ was increased (Figure 4(b)) with increasing the tree height due to large amount of branches and larger leaf area density. Figure shows that $\alpha\beta$ of the trunk was about 1 and it was nearly 1.4 for the upper part of the tree. Similar types of results were obtained by Tanaka et al. (2006) and (2007) during the field investigations in Sri Lanka and Thailand. The correlation between dN_u and the tsunami height was not clear. However, Tanaka et al. (2007) found that young *C. equisetifolia* (d=0.15 m) was effective especially in protecting tsunami higher than 10 m because it grew densely and was not broken by the tsunami. Further they found that the value of dN_u for large-diameter *C. equisetifolia* was quite small.

3.2 Results of numerical simulation

Figure 5 (a), (b), and (c) show the variation of maximum velocity, tsunami depth and tsunami force in unit width, respectively for the tree density value of 0.3 trees/m^2.

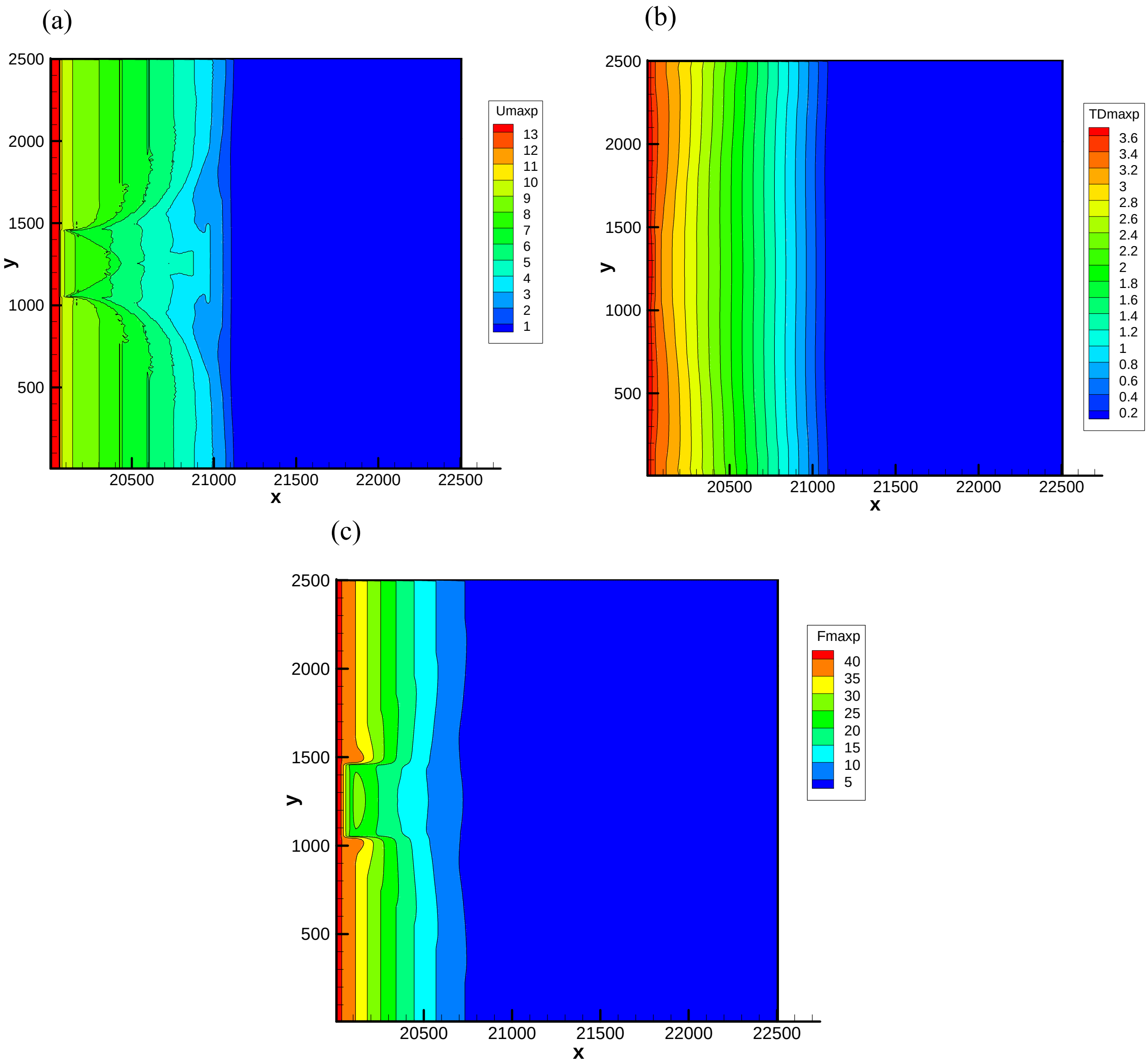

Figure 5: Variation of (a) maximum velocity (m/s), (b) tsunami depth (m), and (c) tsunami force in unit width (kN/m) in X and Y directions

The velocity of tsunami flow was reduced subsequent to the forest. The flow velocity at both ends of the forest was decreased considerably in comparison with the middle section. Consequently, people living near the middle section of the forest would suffer highly due to the tsunami. The tsunami depth shows (Figure 5(b)) comparatively slighter reduction subsequent to the forest. The depth was reduced gradually because trees were planted in rows at equal distances. The tsunami depth was comparatively greater even after the forest. The tsunami force (Figure 5(c)) was decreased significantly after the coastal vegetation. The force became almost half of its initial value just behind the forest. The main cause of force reduction was the drag force exerted by the trunks and the branches of the trees. The tsunami force near the middle section of the forest was comparatively greater as observed in the tsunami velocity. Thus, it can be observed that a dangerous zone was created near the middle section behind the forest. Since the tsunami force exhibited greater reduction subsequent to the forest in comparison with the tsunami velocity and depth, the role of the coastal forests in mitigating the tsunami damage can be described mainly by the tsunami force.

3.3 Effect of forest density to tsunami reduction

Figure 6(a), (b), (c), and (d) show the variation of percentage remaining of the tsunami force for the tree densities 0.1, 0.2, 0.3, and 0.4 trees/m^2, respectively.

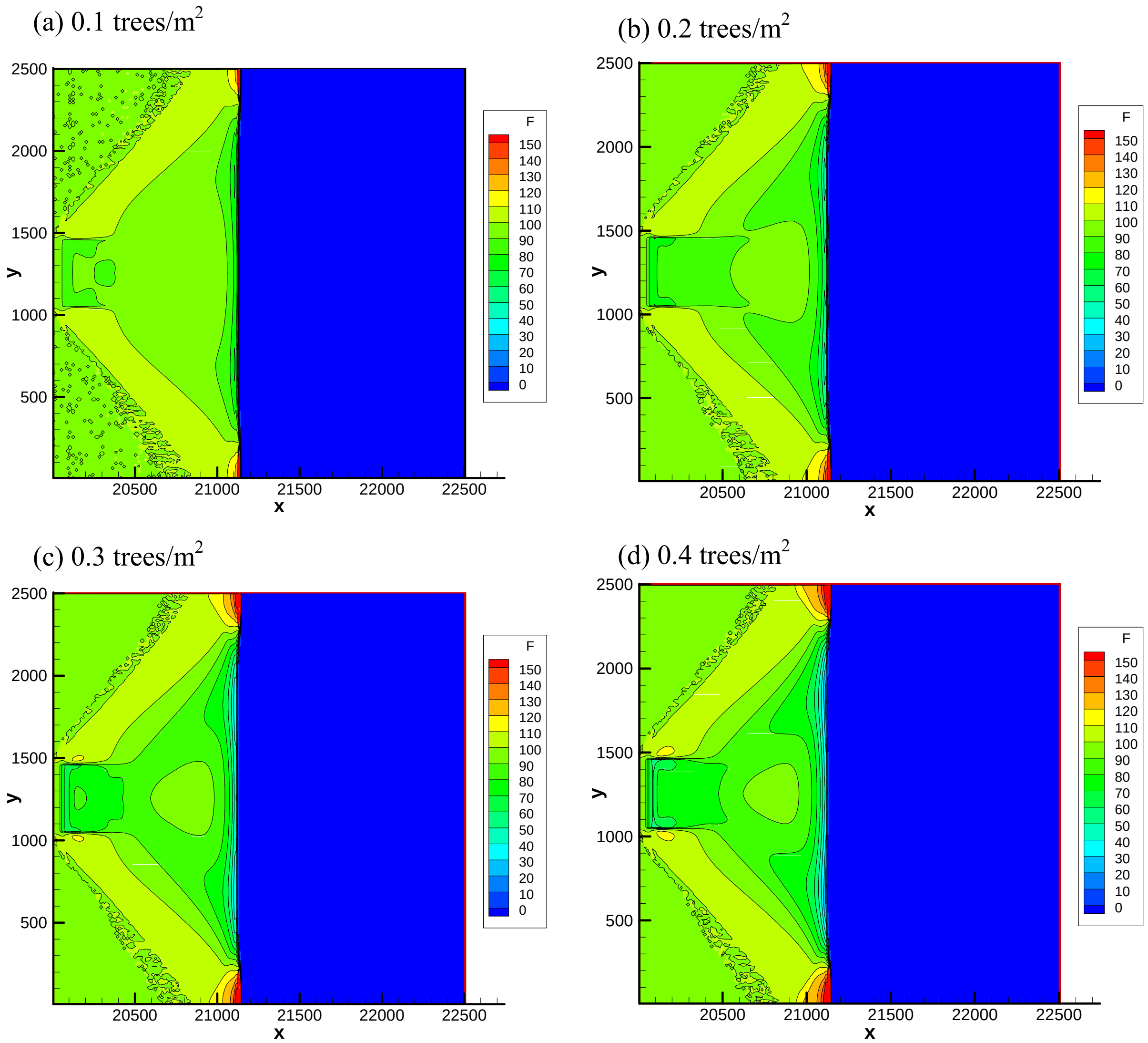

Figure 6: Percentages remaining of the tsunami force

The percentage remaining of the tsunami force was nearly 100% behind the forest in the case of tree density 0.1 (trees/m^2). The force was reduced about 30% in a small area just behind the forest. The percentage reduction of force was about 30-40% in a considerable area subsequent to the forest in the case of tree density 0.2 (trees/m^2). However, still there was a large area where the force reduction was about 0%. When compare Figure 6(c) and (d), both conditions provided better reduction of the tsunami force. About 30-40% of the force was reduced in a large area behind the forest in the case of tree density 0.4 (trees/m^2) in comparison with that of 0.3 (trees/m^2). Further, the area of the dangerous zone was relatively small. Thus, it seems that 0.4 (trees/m^2) would be the optimum tree density has to be selected when designing the coastal forests in mitigating the tsunami damage. However, the value of 0.4 (trees/m^2) is assumed to be too thick and it will create some problems, such as social, environmental, and aesthetic. Hence, 0.3 (trees/m^2) was the most appropriate tree density that should be selected when designing the coastal forests in mitigating the tsunami. Harada and Kawata (2004) carried out a numerical simulation with forest model to evaluate the quantitative effect of tsunami reduction, and the results revealed that the inundation depth, the current and the hydraulic force just behind the forest was decreased with the increase of forest density. However, they did not find an optimum tree density value. Harada and Imamura (2005) found that tree density 10 trees/100 m^2 provided the highest reduction rate of maximum current and maximum hydraulic force against the tsunami. They used the tsunami height as 3 m. The difference of the optimum tree density value in comparison with our study may be due to lesser tsunami height.

4 Conclusions

The coastal forest conditions in the actual field were complied to obtain the relationships between the forest and the tree characteristics. The average space between the trees was increased linearly with increasing the trunk diameter. This revealed that the larger diameter trees required larger spacing. Thus, these characteristics of vegetation need to be discussed as a combined effect. In addition, coefficient $\alpha\beta$ was increased with tree height due to the branches and the leaves. The value $\alpha\beta$ was equal to 1 at the trunk and 1.4 at the upper part of the tree. The results of the numerical simulation revealed that the tsunami flow velocity and depth were reduced considerably and the tsunami force was reduced largely due to the coastal forest. The tsunami force was the key parameter that should be used to describe the effectiveness of the coastal forests. The most appropriate tree density was selected as 0.3 (trees/m^2) by analyzing the percentage remaining of the tsunami force subsequent to the forest. In addition, a risky zone by the collision of repelling flow was observed behind the forest in the cases of tree density 0.3 and 0.4 (trees/m^2), but the tsunami force is less than the value without forest. The value has possibility to change tsunami condition, forest condition and slope condition. More study is needed on that point.

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Acknowledgements

The authors would like to acknowledge the Department of Civil Engineering of University of Peradeniya for their assistance in the field investigations. This work was supported in part by JSPS AA Science Platform Program.

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PERFORMANCE EVALUATION OF SUB-SURFACE FLOW CONSTRUCTED WETLAND SYSTEMS UNDER VARIABLE HYDRAULIC LOADING RATES

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Abstract: Wastewater treatment has given an immense attention in the field of pollution control throughout the world. This has become a challenge in developing countries due to the limitations of resources and expertise. Constructed wetlands where water, plants and microorganisms interact to improve the quality of water have been proven to be an effective low-cost wastewater treatment technology in many parts of the world, which does not necessarily require skilled personnel to run the system. However, these systems are not yet widely spread in developing countries due to lack of information.

Constructed wetlands can be designed as surface flow or subsurface flow systems, depending on the level of the water column. This study compares the performance of vertical subsurface flow (VSSF) and horizontal subsurface flow (HSSF) constructed wetland systems at laboratory scale at tropical condition. This paper also evaluates the effects of Hydraulic Loading Rate (HLR) on treatment capacity of wastewater parameters such as Five day Biochemical Oxygen Demand (BOD_5), Total Suspended Solids (TSS), Nitrate Nitrogen (NO_3^-N), Phosphate (PO_4^{3-}), Ammonia Nitrogen (NH_4-N), Fecal Coliforms (FC) and Total Coliforms (TC).

Six wetland models of size 1.4 m x 0.5 m x 0.5 m (L x W x H) were constructed and arranged: 1) Two models as VSSF system with plants, 2) Two models as HSSF system with plants, 3) One model as a VSSF control without plants and 4) One model as a HSSF control without plants. An emergent macrophyte specie; cattail (*Typha angustifolia*), gravel media (size 10 – 20 mm) and synthetic wastewater with average concentrations of BOD_5 ; 29.51 ± 4.21 mg/L, NO_3^- - N ; 3.22 ± 1.25 mg/L, NH_3^- - N ; 15.14 ± 2.65 mg/L, PO_4^{3-} ; 6.78 ± 5.67 mg/L, Fecal Coliform $495.12 * 10^3 \pm 307.12 * 10^3$ counts/100 mL and Total Coliform $915.5 * 10^3 \pm 719.83 * 10^3$ counts/100 mL were used in this study. The HLR was increased from 2.5 – 25 cm/day at 12 days interval during two and a half months period. Sampling was carried out with each HLR from both influent and effluents of each wetland system after 12 days of constant flow rate, and wastewater quality parameters such as the BOD_5, TSS, NH_4-N, NO_3^--N, PO_4^{3-}, pH, Conductivity, FC and TC were measured in all samples. Results show that VSSF systems perform better than horizontal systems, but the treatment performance declines with the increasing HLR in all six wetland models.

Keywords: Wastewater treatment, Constructed wetlands, Vertical Subsurface Flow, Horizontal Subsurface Flow, tropics, variable Hydraulic loading rate, synthetic wastewater

1 Introduction

There is a growing demand for the development of appropriate and affordable wastewater management technologies particularly in developing countries like Sri Lanka to reduce the pollution of fresh water resources from unacceptable ways of wastewater discharges. Compared to conventional wastewater treatment technologies, constructed wetlands offer low cost, easy to operate, efficient and robust treatment [1] and have been used internationally with good results [2] mostly in temperate countries. The treatment performance of constructed wetlands is expected to be higher in tropical regions due to the higher temperatures and associated higher bacterial activities. Therefore, they are currently being studied as a wastewater treatment technology in tropical countries for many kinds of wastewaters including high strength wastewaters from agricultural fields, landfill leachate, mine drainage, sludge dewatering and municipal wastewaters from small communities [1]. However, the treatment performance of constructed wetlands depend on various factors like inflow pollutant characteristics, wetland design, Hydraulic and nutrient loading rates, climatic variations and essentially the required effluent characteristics [3]. In addition it has to be designed specifically to suit the local climatic conditions to take advantages of unique wetland properties to accomplish direct objectives [4].

Basically there are two types of constructed wetlands; sub-surface flow (SSF) wetlands which maintain the water level below the filter media and free water surface (FWS) wetlands which expose the water surface to the atmosphere. Distinctive advantages of SSF systems over FWS wetlands include, lack of odour problems, lack of mosquitoes and other insect vector problems and the minimal exposure of contact with wastewaters to general public [5]. SSF constructed wetlands can be further divided according to the flow direction as horizontal SSF and vertical SSF wetlands. VSSF systems have a much greater oxygen transfer capacity over the HSSF systems and hence VSSF can achieve very good results in removing organic material and to enhance the nitrification [6].

The wastewater flow into a constructed wetland can be fluctuated with the seasonal water consumption pattern. According to Brix et. al (2007) constructed wetlands can tolerate a high variability in loading rates and wastewater quality [1]. Wetland hydraulics, namely the hydraulic loading rate (HLR), and the hydraulic retention time (HRT) are directly affects the treatment performance of a constructed wetland [7]. Several studies reveal that by decreasing the HLR (ie. longer HRT) the pollutant removal efficiency in a constructed wetland system can be improved. The most effective HRT is ranged in between 4-15 days [8]. However, to incorporate a smaller hydraulic loading or longer retention time, the land area requirement for a constructed wetland is also become high. As there is a higher pollutant removal possibility by constructed wetlands in tropical regions, investigation of the treatment efficiencies with higher hydraulic loading rates or shorter retention times will lead for an optimum design to suit the local climate.

The objective of this study is to evaluate the pollutant removal performance under increasing hydraulic loading rates from sub-surface flow wetland systems (HSSF & VSSF systems) at tropical condition using cattail (*Typha angustifolia)* as the wetland vegetation and synthetic wastewater at laboratory scale. Cattail has been selected in this study as they are easily found in Sri Lanka and are very often a part of natural and constructed wetlands worldwide [9]. Also, cattail is a persistent plant, spreads rapidly and has a reproduction potential. In addition, cattail is capable in thriving and diverse environmental conditions [10]. Its biomass can be used as a valuable insulation material [9] or for weaving purposes.

2 Materials and Methods

2.1 Wetland Mesocosm Arrangement

In this study, Vertical Sub-surface Flow (VSSF) and Horizontal Sub-surface Flow constructed wetland systems were used. As illustrated in Figure 1 (a), Six wetland mesocosms of size 1.4 m x 0.5 m x 0.6 m were constructed with brick masonry and cement mortar and arranged as follows.

1. One mesocosm as HSSF without vegetation
2. Two mesocosms as HSSF with vegetation [Figure 1(b)]

3. One mesocosm as VSSF without vegetation
4. Two mesocosm as VSSF with vegetation [Figure 1 (c)]

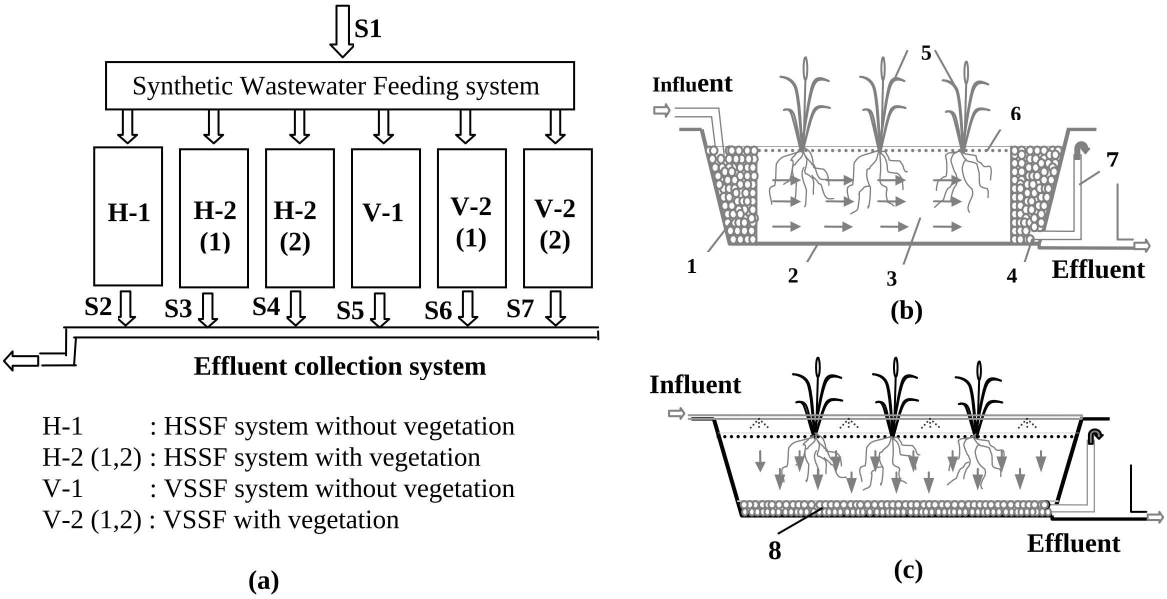


Figure 1. (a). Arrangement of wetland mesocosms [S 1 – S 7 are sampling points], (b). Schematic diagram of a HSSF wetland system with vegetation and (c). Schematic diagram of a VSSF wetland system with vegetation ; 1. Inlet zone, 2. Impermeable barrier, 3. Wetland media, 4. Outlet zone, 5. Wetland Vegetation, 6. Water level, 7. Swivel pipe, 8. Drain field.

To facilitate easy distribution and/or collection of wastewaters, the drain field of VSSF systems and the inlet and outlet zones of HSSF systems, were filled with 30 – 50 cm size gravel. However, in all the systems10 – 20 mm gravel was used as the wetland media. In addition, each system comprises with a surface layer of 10 cm deep soil (< 5 mm particle size) specially to support the vegetation. A nylon mesh was inserted in between soil and gravel layers to prevent soil sinking into the gravel layer. A locally available emergent macrophyte, *typha angustifolia* (cattail), found from a sludge lagoon of a municipal water treatment plant was used as the vegetation in vegetated beds.

2.2 Synthetic wastewater preparation

Wastewater preparation was done artificially by using 6 g of Urea, 20 g of Sugar, 1 g of Ammonium Chloride, 10 mg of Potassium Hydrogen Phosphate, 100 mL of Fertilizer solution and 650 mL of sludge in 250 L of tap water. The sludge was collected from municipal gulley suckers used to empty septic tanks from individual houses to large business establishments, and stored in a refrigerator below 4^0C. After adding all the ingredients in 250 L tap water, it was mixed thoroughly and pumped into an overhead tank. Each mesocosm was supplied wastewater from this tank evenly through a distribution system.

2.3 Operational procedure

To investigate the effect of hydraulic loading rate (HLR) on treatment efficiency, the HLR was increased in each mesocosm from 2.5 cm/day – 25 cm/day by 2.5 cm/day. The corresponding flow rates were calculated using the surface area and it was controlled by using a control valve arrangement. The flow was changed to the next HLR level after a 12 days period and the adjusted flow rate was monitored daily to minimize errors. The Hydraulic Retention Time (HRT) was also calculated for each HLR, using the porosity of the wetland media. The selected HLRs and corresponding flow rates and HRTs in this study are shown in the Table 1.

Table 1 : Selected HLRs and corresponding flow rates

HLR (cm/day)	2.5	5	7.5	10	12.5	15	20	25
Flow rate (mL/min)	12.2	24.3	36.5	48.6	60.7	72.9	97.2	121.5
HRT (days)	8	4	2.7	2	1.6	1.3	1	20 hrs

2.4 Sampling and analysis of wastewater

Sample collection was done at 12 days intervals at the end of each HLR application. Influent and effluent samples were collected in 500 mL plastic bottles and immediately transferred into the environmental laboratory. Wastewater quality parameters such as pH, conductivity, Dissolved Oxygen (DO), BOD_5, FC counts, TC counts, TSS, ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and phosphate phosphorus (PO_4-P) were measured in all samples following Standard Methods of water and wastewater analysis. Then the removal efficiency of each parameter was calculated by using equation (1).

$$\text{Removal efficiency} = \frac{C_i - C_o}{C_i} \times 100\% \qquad (1)$$

Where, C_i = concentration of wastewater parameters at the influent and C_o = concentrations of wastewater parameters at the effluent. Then statistical analysis was carried out to test the significant treatment differences between each system.

3 Results and Discussion

The characteristics of synthetic wastewater fed to the wetland mesocosms have been varied during the study period (Table 2). From the table it can be seen that even though the wastewater quality parameters such as pH, BOD_5, NH_3^-- N and conductivity has not varied significantly DO, TSS, PO_4-P, NO_3^- -N, FC and TC has varied significantly. However, the most remarkable variation has been observed in FC and TC counts. This variation of wastewater characteristics might be due to the fast growing rate of micro-organisms and the type of sludge used to prepare the synthetic wastewater during the study period.

Table 2 : Influent synthetic wastewater characteristics range throughout the study period

Parameter	Quality range
pH	6.99 ± 0.21
Conductivity (µs / cm)	268.44 ± 52.23
DO (mg/L)	4.48 ± 2.18
BOD_5 (mg/L)	30.12 ± 4.34
TC (count/100 mL)	$888 \times 10^3 \pm 678 \times 10^3$
FC (count/100 mL)	$514 \times 10^3 \pm 293 \times 10^3$
NO_3^- - N (mg/L)	3.31 ± 1.20
NH_3^-- N (mg/L)	15.68 ± 2.96
PO_4^{3-} (mg/L)	2.69 ± 1.11
TSS (mg/L)	171.78 ± 59.02

A constructed wetland should improve the quality of effluent water and this reduction of pollutants at the effluent can be caused by sedimentation, sorption, plant uptake and microbial activities. Different water parameters such as BOD_5, TSS, pH, Nitrogen, and coliform concentration are affected by microbial activities including nitrification-denitrification, utilization and predation. A well developed biofilm is essential for the effectiveness of the wetland system [12].

3.1 Effect of HLR in pollutant removal

Average water quality parameters at different hydraulic loading rates in both influent and effluents and the percentage removal efficiencies in different types of wetland mesocosms used in this study are shown in table 3. Sampling was done for about four month period at a 12 days interval from August to November 2010. Results show that even though there is some differences in removal efficiencies among the systems, all wetland types show a significant increase in water quality even at higher hydraulic loading rates. The V-2 system, that is VSSF system with plants, shows the best overall performance in pollutant removal.

Table 3 : Average water quality parameters of influent and effluent at different HLR and the percentage removal efficiencies if each parameter

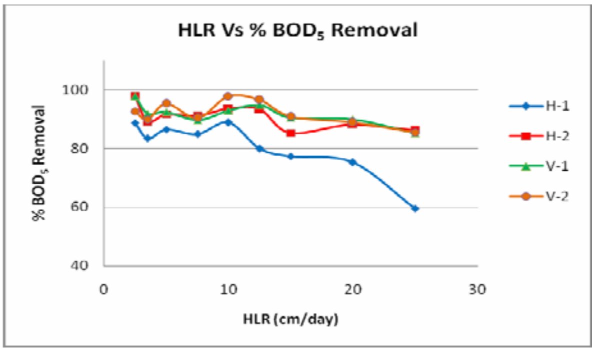
HLR (cm/day)	Influent	Effluent H-1	Removal H-1 (%)	Effluent H-2	Removal H-2 (%)	Effluent V-1	Removal V-1 (%)	Effluent V-2	Removal V-2 (%)
				BOD_5 (mg/L)					
2.5	29.7	3.35	88.72	2.64 ± .09	97.86	1.64	94.45	1.16 ± 2.79	92.73
3.5	28.9	4.80	83.40	3.12 ± 0.54	89.21	2.33	91.94	2.91± 0.4	89.93
5.0	28.3	3.80	86.57	2.35 ± 1.1	91.70	2.15	92.40	1.33 ± 0.06	95.32
7.5	23.5	3.54	84.94	2.06 ± 0.76	91.23	2.43	89.66	2.27 ± 0.47	90.36
10.0	30.0	3.33	88.89	1.9 ± 0.35	93.66	2.12	92.93	0.64 ± 0.32	97.88
12.5	26.6	5.32	79.98	1.73 ± 0.24	93.49	1.39	94.77	0.91 ± 0.52	96.60
15.0	31.0	7.03	77.29	4.56 ± 1.32	85.27	2.94	90.50	2.84 ± 1.03	90.84
20.0	38.2	9.44	75.28	4.52 ± 0.02	88.17	3.83	89.97	4.26 ± 0.4	88.84
25.0	29.5	11.95	59.49	4.3 ± 0.75	86.1	4.38	85.15	4.28 ± 0.8	85.49
				TSS (mg/L)					
2.5	139	34	75.54	62 ± 42.43	55.40	33	76.26	57 ± 1.41	58.99
3.5	128	98	23.44	20 ± 0	84.38	55	57.03	17.5 ± 3.54	86.33
5.0	158	63	60.13	37 ± 5.66	76.58	38	75.95	22.5 ± 0.71	85.76
7.5	296	92	68.92	47.5 ± 9.19	83.95	104	64.86	60.5 ± 4.95	79.56
10.0	228	52	77.19	13 ± 4.24	94.30	84	63.16	39 ± 9.9	82.89
12.5	190	30	84.21	6.5 ± 2.12	96.58	18	90.53	6 ± 2.83	96.84
15.0	170	20	88.24	39 ± 24.04	77.06	25	85.29	54 ± 49.5	67.65
20.0	112	52	53.57	39 ± 12.73	65.18	61	45.54	14.5 ± 0.71	87.05
				Fecal Coliforms (FCU/100 mL)					
2.5	432000	6300	98.54	3950 ± 212	99.09	3600	99.17	2440 ± 509	99.44
3.5	864000	6800	99.21	4050 ±919	99.53	3800	99.56	2000 ± 282	99.77
5.0	320000	9600	97.00	8700 ± 424	97.28	9000	97.19	8000 ± 565	97.50
7.5	240000	4000	98.33	3000 ± 0	98.75	2400	99.00	1930 ± 99	99.20
10.0	255000	8700	96.59	7750 ± 495	96.96	7600	97.02	7150 ± 495	97.20
12.5	370000	5570	98.49	4600 ± 283	98.76	6400	98.27	3000 ± 283	99.19
15.0	400000	12800	96.80	7300 ± 2404	98.18	7800	98.05	4100 ± 283	98.98
20.0	1E+06	64800	94.00	37800 ± 7637	96.50	21800	97.98	13000 ± 283	98.80
25.0	665000	33250	95.00	23275 ± 4702	96.50	20750	96.88	28275 ± 16440	95.75
				Total Coliforms (TCU/100 mL)					
2.5	992000	4500	99.55	3400 ± 283	99.66	4800	99.52	3500 ± 141	99.65
3.5	1E+06	7600	99.40	5350 ± 212	99.58	8800	99.30	4200 ± 849	99.67
5.0	434000	6160	98.58	4960 ± 57	98.86	4800	98.89	3920 ± 1018	99.10
7.5	430000	4400	98.98	3500 ± 424	99.19	4800	98.88	3500 ± 141	99.19
10.0	408000	7200	98.24	5650 ± 495	98.62	5800	98.58	3500 ± 141	99.14
12.5	480000	5430	98.87	5200 ± 283	98.92	6200	98.71	4200 ± 283	99.13
15.0	800000	44600	94.43	24900 ± 2970	96.89	32000	96.00	21300 ± 1556	97.34
20.0	3E+06	100800	96.00	69300 ± 8910	97.25	39600	98.43	25050 ± 778	99.01
25.0	665000	33250	95.00	23275 ± 4702	96.50	20750	96.88	28275 ± 16440	95.75

				PO_4^{3-} (mg/L)					
2.5	3	1.32	56.00	1.37 ± 0.82	54.33	0.61	79.67	0.13 ± 0.04	99.77
3.5	2.4	0.9	62.50	0.35 ± 0.49	85.42	0.3	87.50	0.15 ± 0.15	99.82
5.0	5.1	4	21.57	0.22 ± 0.01	95.78	0.23	95.49	2.31 ± 2.4	97.59
7.5	1.66	0.81	51.20	1.0 ± 0.18	40.06	0.36	78.31	0.94 ± 0.51	97.65
10.0	2.57	0.7	72.76	1.49 ± 1.15	42.02	0.7	72.76	1.15 ± 0.78	97.28
12.5	2	0.5	75.00	0.61 ± 0.13	69.50	0.18	91.00	0.85 ± 0.06	98.78
15.0	2.1	0.82	60.95	0.29 ± 0.01	86.19	0.82	60.95	0.66 ± 0.04	99.23
20.0	1.7	0.79	53.53	0.17 ± 0.09	90.29	1.04	38.82	0.56 ± 0.49	99.39
25.0	3.7	0.88	76.22	0.64 ± 0.22	82.84	0.55	85.14	0.44 ± 0.52	99.47
				NH_4^+- N (mg/L)					
2.5	12.3	8.3	32.52	9.05 ± 0.21	26.42	0.3	97.56	0.59 ± 0.16	97.77
3.5	11.7	8.2	29.91	8 ± 0.85	31.62	0.1	99.15	1.1 ± 0.14	96.52
5.0	14.1	9.6	31.91	4.15 ± 0.64	70.57	2.5	82.27	1.05 ± 0.49	98.51
7.5	14.9	5.8	61.07	3.35 ± 3.04	77.52	2.1	85.91	1.25 ± 1.34	98.39
10.0	18.2	3.8	79.12	1.85 ± 0.49	89.84	0.5	97.25	1.7 ± 0.42	98.11
12.5	13.8	5.9	57.25	2.45 ± 2.76	82.25	0.3	97.83	0.55 ± 0.35	99.33
15.0	18	17.7	1.67	8.15 ± 7.14	54.72	6.3	65.00	1.2 ± 0.85	97.81
20.0	18.1	11.5	36.46	15 ± 0.14	17.13	10.5	41.99	5.45 ± 0.21	68.18
25.0	20	20.25	-1.25	13.25 ± 11.31	33.75	2.75	86.25	4 ± 1.77	88.15
				NO_3^-- N (mg/L)					
2.5	2.3	0.1	95.65	0.8 ± 0.28	65.22	1.2	98.16	1.25 ± 0.21	98.08
3.5	2.4	0.9	62.50	0.85 ± 0.49	64.58	0.4	99.38	1.55 ± 1.06	97.60
5.0	2.3	0.1	95.65	0.8 ± 0.28	65.22	2	96.93	1.25 ± 0.21	98.08
7.5	2.8	1.2	57.14	1.25 ± 0.35	55.36	2.2	96.03	1.45 ± 0.21	97.38
10.0	4	2.5	37.50	2 ± 1.41	50.00	0.1	99.80	1.35 ± 0.64	97.30
12.5	5	4.3	14.00	0.95 ± 0.35	81.00	0.1	99.88	0.9 ± 0.28	98.89
15.0	2	0.3	85.00	0.9 ± 0.28	55.00	0.8	98.55	0.45 ± 0.07	99.18
20.0	5	2.4	52.00	1.2 ± 1.56	76.00	1.5	98.03	2.4 ± 0.28	96.84
25.0	4	0.2	95.00	0.65 ± 0.49	83.75	0.1	99.88	0.2 ± 0.0	99.76

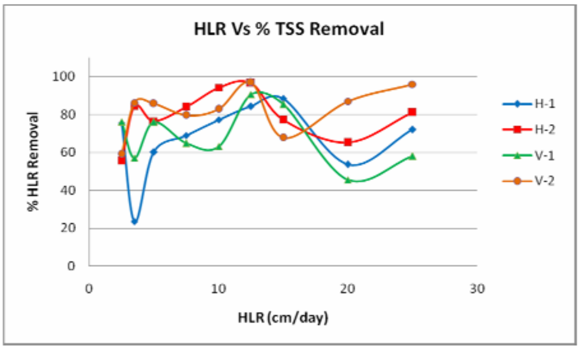
The efficiency of BOD_5 removal at the effluent in all wetland cells has reduced significantly with the increase of HLR beyond 10 cm/day. Compared to all other systems horizontal unplanted (H-1) system has more deviation in effluent quality with the HLR increment (Figure 2 (a)). Also, it is evident that the BOD_5 removal in planted systems (H-2, V-2) is higher than that of corresponding unplanted systems (H-1, V-1). However, there is no significant difference of effluent qualities in vertical systems beyond 7.5 cm/day HLR. This might be due to the better oxygen transfer capacity in VSSF system. Vertical systems and planted horizontal system have given nearly 86% of BOD removal at the highest HLR (25 cm/day) in this study. But unplanted horizontal system has given a poor removal of 60% at the highest HLR.

From the graphical representation shown in Figure 2 (b) and Table 2, it can be seen that there is a greater fluctuation in removal efficiency of TSS with the increase of HLR. Though it is expected to have a decreasing trend in TSS removal, there is a quick increase at the highest HLR application in this study. This might be due to the dilution occurred with the rainfall which has not thoroughly analyzed in this paper. However, even though the removal pattern is not very clear among different wetland types, the higher removal efficiency has varied between vertical and horizontal planted systems within 60 – 97% range during the study. Also, it was observed that the vertical systems (V-1, V-2) and horizontal systems (H-1 and H-2) follow almost similar removal pattern throughout the study.

According to the Figure 2 (c) and (d), it can be seen that both Fecal and Total coliform removal patterns of all the wetland systems follow the same until 12.5 cm/day HLR. Within this period, the removal efficiency varies between 96.4 – 99.8% in all the systems. Beyond this limit until the highest HLR, the removal efficiencies in V-1, V-2 and H-2 systems does not show much difference. It varies only between 95.75 – 99.2% in these systems. However, only the H-1 system shows a little deviation from others varying the removal efficiency from 94-98%. This is also not much significant. All the systems were able to achieve two log removal until 12.5 cm/day HLR and then one log removal until 25 cm/day HLR.



(a)



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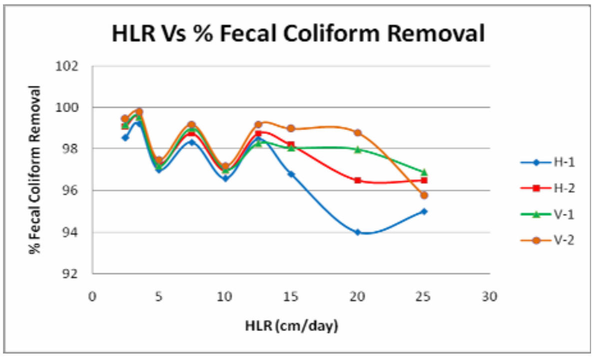
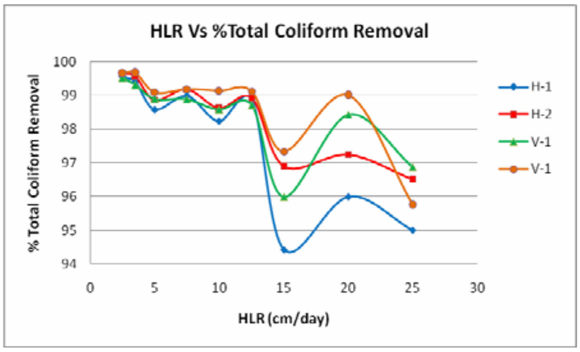


(c)



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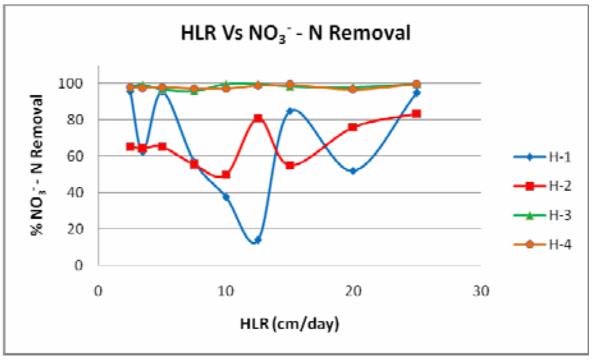
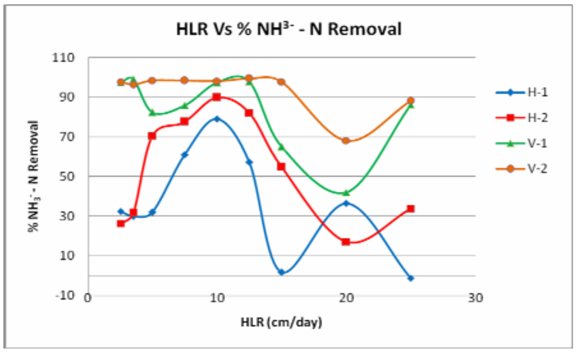
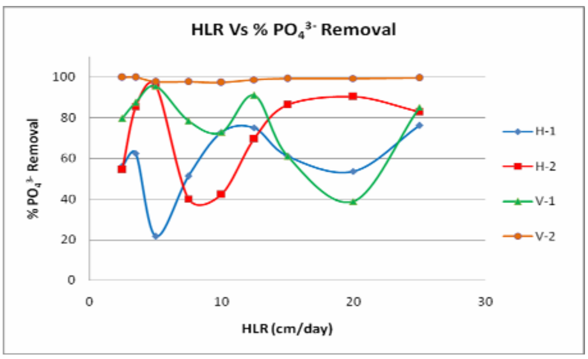


(e)



(f)



(g)

Figure 2 : Variations of percentage BOD_5, TSS, FC, TC, NO_3^--N, NH_4^+-N and PO_4^{3-} removal in different wetlands systems with hydraulic loading rate.

Figure 2 (e) shows the NO_3^-- N removal efficiency in all vertical wetland systems (V-1 and V-2) is almost same throughout the study period giving 98 – 99.8% removal range. This might be due to the enhance nitrification within the vertical system. However, the horizontal systems (H-1 and H-2) give a less removal with a wide variation during the study period. It also shows that the planted system performs better than the unplanted system. Figure 2 (f) shows the NH_4^+-N removal efficiencies in different wetland system. It shows the best removal efficiency has achieved by the vertical planted system (V-2). Horizontal systems, both planted and unplanted, show poor NH_4^+-N removal efficiency with a wide variation throughout the study. A very good PO_4^{3-} removal efficiency has achieved in vertical planted system (Figure 2 (g)). In contrast other three systems show a greater variation in PO_4^{3-} removal. However, from unvegetated systems vertical system show a better performance than the horizontal system for removal of nutrients.

4 Conclusions

The experimental results show that the constructed wetland systems provide a promising technology for wastewater treatment in tropical regions. Even though more long-term data are required, the results generated so far indicated that vegetated VSSF constructed wetland system (V-2) provide better treatment performance over the other systems in the study; viz. vegetated HSSF system and unvegetated VSSF & HSSF systems (H-2, H-1 & H-2) under increasing HLRs up to 25 cm/day. However, at lower HLRs up to 10 cm/day (corresponding HRT = 2 days in this study) BOD_5, TSS, FC and TC removal efficiencies in vegetated systems (H-2 & V-2) does not show a significant variation. But unvegetated systems show a little deviation of performance specially in BOD_5 and TSS reduction. In contrast, coliform removal has not affected by the type of the wetland system up to 12.5 cm/day HLR. However there is a little deviation of removal efficiencies beyond that limit. On the other hand, NO_3^--N, NH_4^+-N and PO_4^{3-} removal efficiencies in the V-2 system has given a very good performance throughout the study period where other systems show a significant decrease of pollutant removal with the HLR increment. Therefore, it can be concluded that, vegetated VSSF systems give better results in pollutant removal than vegetated HSSF systems or unvegetated HSSF and VSSF systems. In addition when comparing wetland types separately, vegetated systems perform better than unvegetated systems, and vertical systems perform better than horizontal systems under variable HLRs.

As removal patterns of some pollutants are observed to be complex this study can be continued to gather more data to find out the most favorable HLR for optimum pollutant reduction in tropical countries.

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Acknowledgements

The authors like to acknowledge The Crossing Boundaries project for Integrated Water Resource Management of Cap-Net, for providing funds to carry out this study and to the staff of the Environmental Engineering Laboratory in Department of Civil Engineering, the Department of Agricultural Engineering and the Postgraduate Institute of Agriculture, University of Peradeniya for the generous support extended throughout the study.

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CONSOLIDATION CHARACRACTERISTICS FOR SRI LANKAN AND JAPANESE CLAYS: VOID INDEX IN RELATION TO STRESS STATES AND SEDIMENTATION ENVIRONMENT

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Abstract: It is well known that cementation/aging and sedimentation environment affect significantly a compressibility of natural clays. In this study, one-dimensional consolidation curves (e-log p) have been measured using a standard oedometer test for several Sri Lankan and Japanese clays with different sedimentation environment (i.e., freshwater and marine sediments). The void index proposed by Burland (1990) was used to analyze the measured cosnsolidation curves. As a result, void index of marine sediments is higher than that of freshwater sediments and drastically decrease after consolidation yield stress. On the other hand, void index of Sri Lankan clays is quite low and gently narrow as increase consolidation stress. That indicates the Burland's void index well characterized the effects of sedimentation enviroments on the consolidation characteristics of clays.

Keywords: clay, consolidation, sedimentation environment, void index, cementation

1 Introduction

A compressibility of the soils is one of important geotechnical properties which is highly affected by fabric (arrangement of particles) and interparticle bonding. The structure of natural clays (i.e., fabric and bonding) depends on many factors such as depositional conditions, aging, cementation, and leaching. The compressibility of reconstituted clays can be used as a framework for interpreting these structural features for the corresponding properties of natural clays.

In this study, one-dimensional consolidation curves (e-log p) have been measured using a standard oedometer test for several Sri Lankan clays and Japanese clays in Kanto alluvial lowland with different sedimentation environment (freshwater and marine sediments). The void index proposed by Burland [1] was used to characterize the compressibility, stress state, and structure of natural clays.

2 Sample and Method

2.1 Sample

Soil samples were taken from three points in Kanto alluvial lowland, Japan: Kasukabe and Toda in Saitama, and Kameido in Tokyo, Japan (Figure 1). The samples were taken from the depth of 7 m down to 32 m. The sedimentation environments for Japanese clays are tabulated in Table 1. For each site, sediments were deposited under either freshwater or marine sediments. In addition to the measurements for Japanese clays, data for soil samples from various sites in Sri Lanka were used in this study. The Sri Lankan soil samples were mostly taken from relatively shallow layers less than 3 m depth. Basic soil physical properties for Japanese and Sri Lankan were also shown in Table 1 and Table 2. The Japanese marine sediments showed higher water content compared to that for freshwater sediments and Sri Lankan clays. In addition, water content of all marine sediments was higher than liquid limit. On the other hand, the values of liquid limit for the Sri Lankan clays are similar to Japanese clays, but higher than water content.

2.2 Methods

A standard oedometer test was performed according to JIS (Japanese Industrial Standards) A-1217 with a standard cell (6 cm in inner diameter and 2 cm in height) for Japanese undisturbed soils. The load is doubled at each increment until reaching the maximum required load (1256 kPa). The duration of the application of each load was 24 hr. The data for consolidation curves for Sri Lankan soils were also obtained by the oedometer test with maximum load from 314 to 781 kPa.

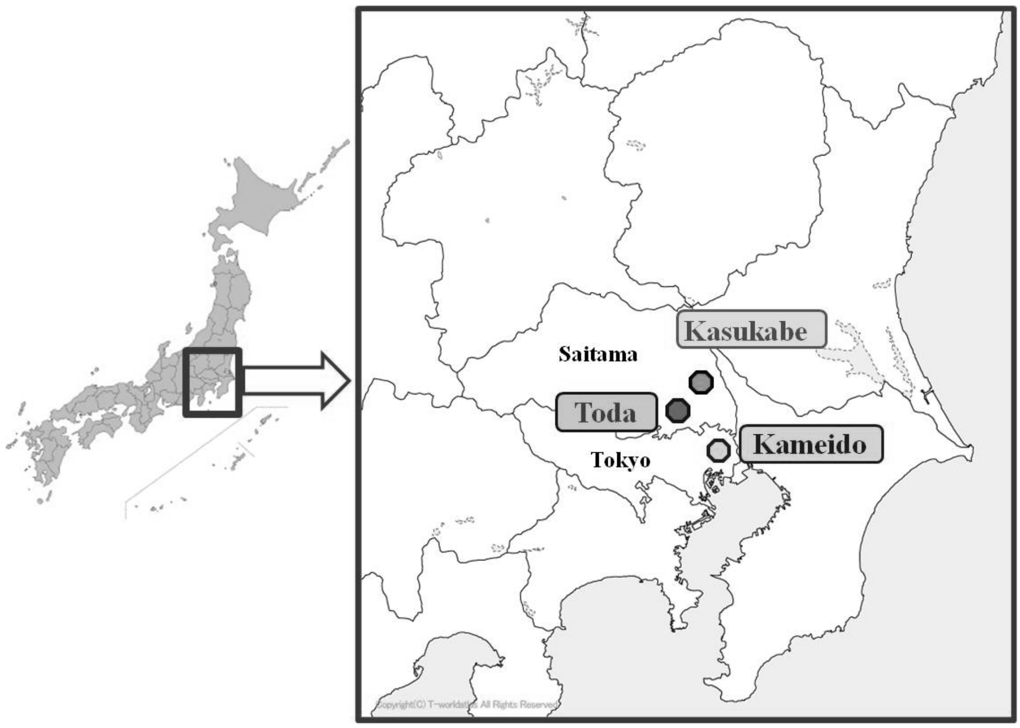

Figure 1: *Sampling site of Japanese soil [2]*

Table 1: *Sedimentation environments and basic soil physical properties (Japanese)*

depth(m)	sedimentation environment	w_n(%)	w_L(%)	G_s(g/cm^3)	e_L	e_{100}^*	C_c	C_c^*
KASUKABE								
7	Freshwater	61.4	56.2	2.63	1.480	0.971	0.49	0.34
9	Freshwater	64.9	50.1	2.68	1.341	0.898	0.59	0.30
11	Marine	90.6	78.3	2.67	2.092	1.286	1.12	0.50
15	Marine	94.6	76.8	2.64	2.027	1.253	1.39	0.48
21	Marine	82.4	75.8	2.57	1.949	1.213	1.09	0.46
27	Marine	88.6	75.3	2.64	1.986	1.232	0.91	0.47
31	Freshwater	46.1	48.1	2.61	1.254	0.852	0.82	0.28
TODA								
9	Freshwater	41.5	42.3	2.70	1.141	0.792	0.34	0.25
12	Marine	49.2	39.5	2.69	1.064	0.750	0.42	0.23
16	Marine	81.0	69.5	2.73	1.889	1.783	0.82	0.45
19	Marine	47.1	43.2	2.68	1.158	0.801	0.47	0.26
22	Freshwater	37.4	37.4	2.74	1.026	0.729	0.36	0.22
KAMEIDO								
9	Freshwater	48.9	42.3	2.71	1.144	0.793	0.43	0.25
12	Freshwater	41.9	34.7	2.71	0.938	0.681	0.34	0.20
17	Marine	62.3	49.6	2.69	1.336	0.895	0.63	0.30
21	Marine	67.5	56.4	2.65	1.495	0.978	0.73	0.34
27	Marine	81.8	73.4	2.65	1.945	1.211	1.07	0.46

w_n is a natural water content, w_L is a liquid limit, G_s is a specific gravity, e_L is a void ratio at liquid limit, C_c is a consolidation index, respectively.

Table 2: *Basic soil physical properties (Sri Lanka)*

Sampling Place	depth(m)	w_n(%)	w_L(%)	G_s(g/cm^3)	e_L	e_{100}^*	C_c	C_c^*
Court Complex (Nawalapitiya) 1	1.1	23.7	55.0	2.60	1.430	0.945	0.30	0.33
Court Complex (Nawalapitiya) 2	1.0	33.6	65.0	2.60	1.690	1.080	0.21	0.39
Court Complex (Nawalapitiya) 3	1.0	33.9	66.0	2.60	1.716	1.093	0.20	0.40
University of Peradeniya 1	3.4	25.0	57.0	2.60	1.428	0.972	0.28	0.34
University of Peradeniya 2	2.4	22.3	49.0	2.60	1.274	0.863	0.22	0.29
Ulapane 1	2.0	31.6	65.0	2.60	1.690	1.080	0.18	0.39
Ulapane 2	2.0	17.5	57.0	2.60	1.482	0.972	0.17	0.34
Ulapane 3	2.5	20.9	52.0	2.60	1.352	0.904	0.17	0.31
Katugastota	1.3	18.9	36.0	2.60	0.936	0.680	0.15	0.20
Nawalapitiya	2.0	43.6	69.0	2.60	1.794	1.133	0.33	0.42

3 Void Index

The void index proposed by Burland [1] was used to analyze the measured cosolidation curves. Void Index (I_v) can be defined as following equation (Eq. (1)).

$$I_V = \frac{e - e_{100}^*}{C_C^*} \quad (1)$$

where e is the void ratio for the undisturbed samples, e_{100}^* and C_c^* are the void ratio and consolidation index for the corresponding reconstituted samples at 100 kPa, respectively. In this study, due to lack of data for consolidation curves for reconstituted samples, the following relations (Eq. (2) and Eq. (3)) proposed by Burland [1] were used.

$$e_{100}^* = 0.109 + 0.679e_L - 0.089e_L^2 + 0.016e_L^3 \quad (2)$$

$$C_C^* = 0.256e_L - 0.04 \quad (3)$$

where e_L is the void ratio at the liquid limit.

As shown in Figure 2., Burland [1] have found consistent relations between I_v and effective stress for the clay that have been reconstituted at a water content of between w_L and 1.5 w_L (preferably 1.25 w_L), called intrinsic compression line (ICL). Consistent relation between I_v and effective stress have been also reported for several marine clays (the data from Skenmpton [3]), called sedimentation compression line (SCL) [1].

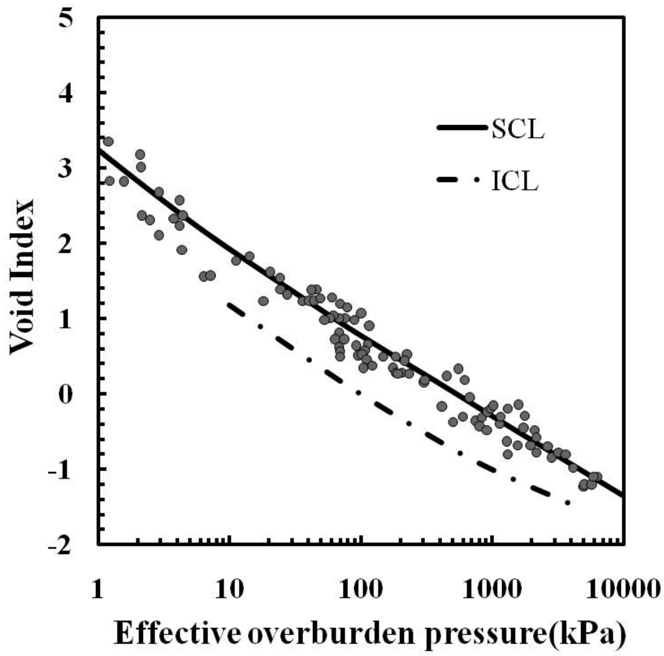

Figure 2: *Normalized compression curves for several clays (from Skempton [3]) in showing the intrinsic compression line (ICL) and sedimentation compression line (SCL) (from Burland [1])*

4 Results and Discussion

4.1 C_c and liquid limit

Figure 3 shows relation between consolidation index (C_c) and liquid limit for marine clay sediments of Tokyo bay and Osaka bay, Japan, reported by Tsuchida [4]. The measured data of this study and relation between C_c and liquid limit proposed by Terzaghi and Peck [5] (Eq. (4)) and Ogawa and Matsumoto [6] (Eq. (5)) are also plotted in the Figure 3.

$$C_C = 0.009(w_L - 10) \quad (4)$$
$$C_C = 0.015(w_L - 15) \quad (5)$$

For both literature and measured data for Japanese clays, the C_c values linearly increased with increasing the liquid limit. However, the measured data showed relatively higher C_c values especially for marine sediments at the same liquid limit as compared to the literature data. It suggests higher compressibility of marine sediments used in this study (taken from three alluvium lowland sites located at 10 km~40 km far from Tokyo bay) possibly due to a salt leaching. In contrast, Sri Lankan clays showed much lower C_c values than Japanese soils and Eq. (4). Furthermore the value of C_c of all Sri Lankan clays is lower than C_c^*.

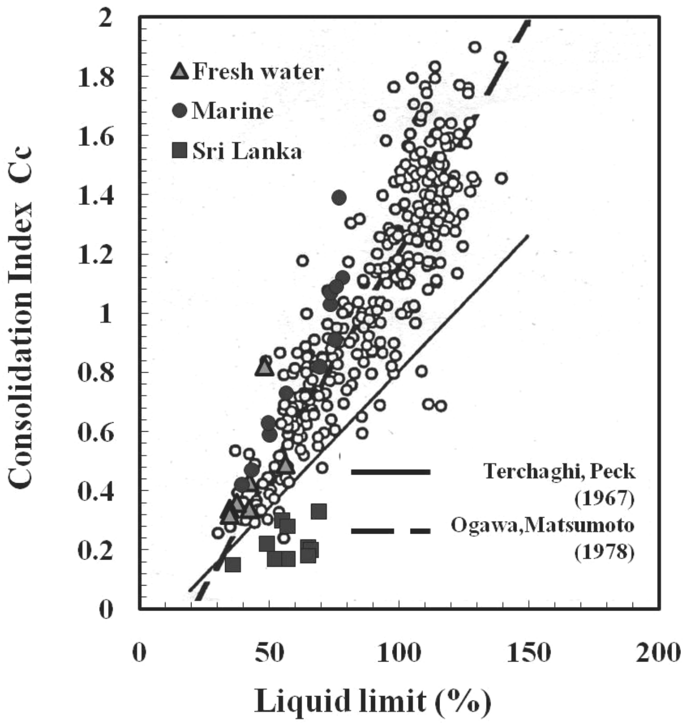

Figure 3: *Relation between consolidation index and liquid limit data in present study is added to data from Tsuchida [4]*

4.2 e-log p and Iv-log p curve

The e-log p (p: pressure, kPa) and I_v-log p curves for Japanese clays (Kasukabe) and Sri Lankan clays are shown in Figure 4 and Figure 5, respectively. Figure 4 (a) shows that marine sediments for Japanese clays showed higher e values than those for freshwater sediments, and the e values drastically decreased after consolidation yield stress (i.e., higher C_c). I_v-log p curves for both marine and freshwater sediments approached SCL after the consolidation yield stress. However, generally higher I_V values for the marine sediments were observed under variable pressure conditions, indicating the well-developed fabric likely represented by edge-to-face orientation of clay particle.

In Figure 5 (a), the e values of almost Sri Lankan clays and I_v-log p curves were quite lower than those of Japanese clays. In addition, some samples indicated different trend between e-log p curve and I_v-log p curve. For example, e-log p curve of Nawalapitiya is similar to that of other sample but I_v-log p curve of it is much higher than that of other Sri Lankan clays. This result suggests I_v can describe consolidation characteristics clearly.

I_v-log p curves of many Sri Lankan clays show similar trend as the ICL (Figure 5 (b)). It suggests poor fabric for Sri Lankan clays expected by some reasons. For example, Sri Lankan soil was deposited at inland area (i.e., under freshwater environment), Sri Lankan clays were taken from shallow sediments, so their samples indicated high over consolidation ratio. Furthermore, Sri Lankan clays have low water content indicating higher sand content than Japanese clays.

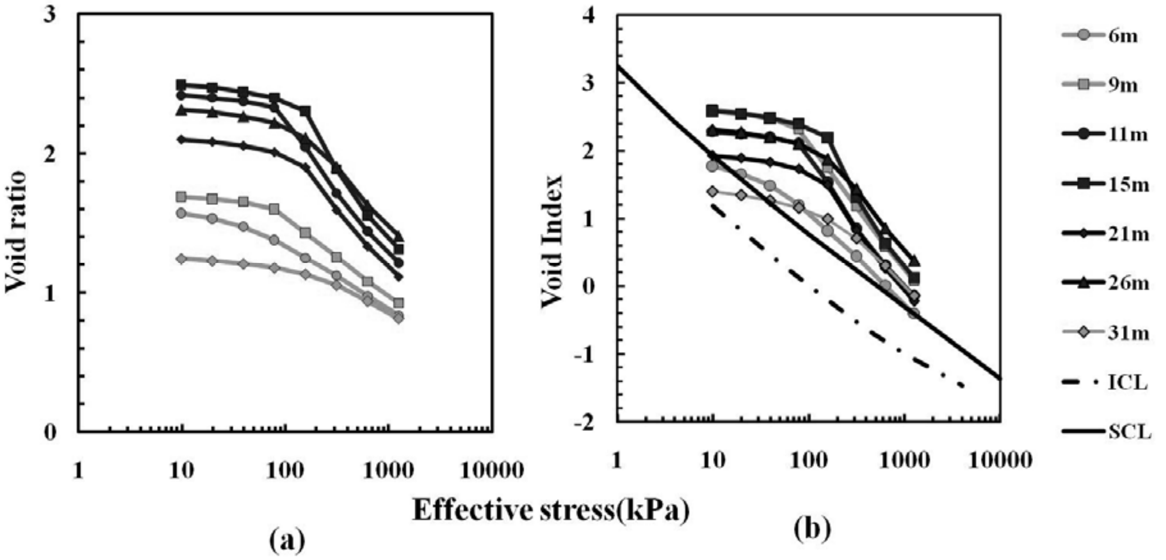

Figure 4: *(a) e-log p curve. (b) I_v-log p curve in Japanese clays (Kasukabe)*

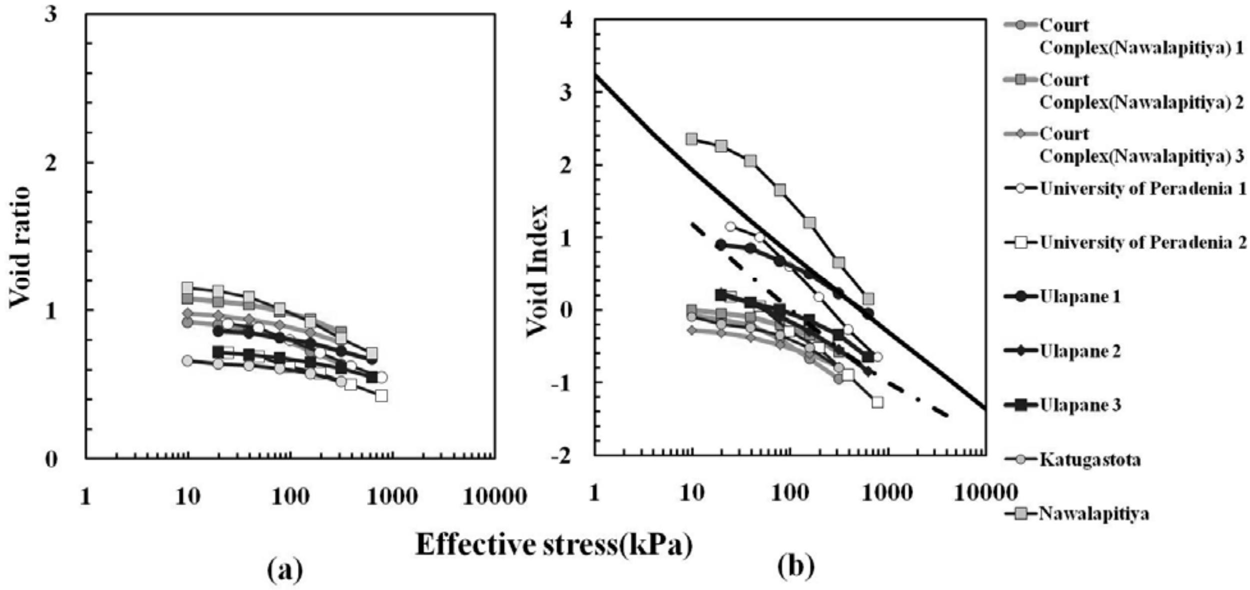

Figure 5: *(a) e-log p curve. (b) I_v-log p curve in Sri Lankan clays*

5 Conclusions and Future work

In this paper, the effect of sedimentation environment on consolidation characteristics is described by using void index (I_v). Then, some findings are shown as follows.

1. Cc values linearly increased with increasing the liquid limit, especially compressibility of marine sediments are higher than freshwater sediments. It suggests higher compressibility of marine sediments used in this study possibly due to salt leaching.
2. Marine sediments for Japanese clays showed higher I_v values than freshwater sediments for Japanese clays. In contrast, I_v values of most of Sri Lankan clays were quite lower than those of Japanese clays. It can be considered that the difference of sedimentation environment and soil

characteristics (liquid limit, water content, over consolidation ratio, sand content) which make difference of degree of fabric, has caused the difference of consolidation characteristics.

In this study, to compute void index for each samples, e_{100}^* and C_c^* are calculated by equation (Eq. (2) and Eq. (3)). To show relation “intrinsic” and “sedimentation” in consolidation characteristic explicitly, it is necessary to obtain consolidation curve of reconstituted samples, and determine e_{100}^* and C_c^* experimentaly.

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Acknowledgements

This work is partially supported by a research grant by the JSPS Asia and Africa Science Platform Program.

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ANALYSIS OF DRAG FORCE CHARACTERISTICS OF REAL TREES WITH THREE DIFFERENT TYPES OF VEGETATION FOR BIOSHIELD IN COAST

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Abstract: This paper presents the experimental investigations on drag force characteristics of vegetation in mitigating the impact of tsunami and other surge effects by the resistance offered to the flow. The experiment was conducted in a laboratory towing tank of 50m x 2m x 2m. Three types of vegetation species used were the trees with small thin broad leaves (Wetakeyya), large broad leaves (Kottamba) and stick type leaves (Kasa). The drag force characteristics of the vegetations mainly depend on the differences in the distribution of foliation, different streamlining mechanism of the leaves against flow, the roughness and the shape of the tree trunk. Drag coefficient of vegetation varies with the flow velocity; the lower flow velocities show higher drag coefficients because of the maximum frontal projected area of the plant.

The drag coefficients for the canopies show higher values for the Reynolds numbers less than 10^6. For canopies with large broad leaves (Kottamba), it ranges from 0.02 to 0.2. The drag coefficients for small thin broad leaves (Wetakeyya) and stick type leaves (Kasa) range from 0.1 to 1.7 and 0.18 to 0.7. Comparatively the drag coefficient of Wetakeyya is greater than Kottamba and Kasa at larger Reynolds numbers ($Re > 10^6$).

Previous studies on vegetal drag are mainly focused on the single rigid cylinders and colony of rigid cylinders. The studies with single rigid cylinders show an almost linear relationship between drag force and square of the mean velocity of flow. However, the limited studies with natural flexible vegetation show a linear relationship between drag force and mean velocity. Drag coefficient for the trunks of above three types of trees were found less than the smooth cylinder for the region of $Re > 60000$. For this region the drag coefficient for Kasa trunk ranged in between 0.9 to 1.0 while for the smooth PVC pipe it ranged in between 1.2 – 1.4. For Kottamba it was in between 0.8 – 0.9 and for Wetakeyya it was around 0.6.

Keywords: Vegetation, Drag Coefficient, Roughness, Foliation, Towing tank, Tsunami protection

1 Introduction

There are several evidences in favor of coastal vegetation to mitigate tsunami effects. The tree vegetation reduces wave amplitude and energy (Massel et al., 1999). In the case of a coastal forest, energy is progressively absorbed as the tsunami wave passes through it. Once the tsunami comes on shore, the amount of reduction in water depth, velocity, and force depends on how much water is reflected and energy adsorbed by the coastal forest (Keith Forbes, 2007). Without the forest barrier, the tsunami will run-up to a maximum height determined by the magnitude and nature of the seismic event that created the tsunami.

It is also recorded, based on satellite images that the coastal areas with tree vegetation were markedly less damaged than areas without them (Kandasamy et al. 2005). Shuto (1987) quantitatively estimated the effectiveness of coastal forests against tsunami by statistically analyzing the physical damage suffered by pine trees in Japan. In addition, Hamzah et al. (1999) demonstrated the effects of model mangrove stands against tsunami attack in experiments from the viewpoint of hydraulic resistance, and emphasized that such vegetation provides effective protection against tsunamis. Therefore it is very important to find out the most appropriate species to exert high hydraulic resistance by coastal canopies (Tanaka et al. 2007). This research is conducted to investigate the drag force characteristics of three different species. They are the trees with small thin broad leaves (Wetakeyya - *Pandanus odoratissimus*), large broad leaves (Kottamba - *Terminalia catappa*) and stick type leaves (Kasa - *Casuarina equisetifolia*). Findings of this study will be very useful in future landscape planning in the coastal regions.

The drag force characteristics of the vegetation mainly depend on the frontal area of the leaves. Vogel (1984) suggested that frontal area is the most influential parameter for streamlined objects at high Reynolds numbers as the drag is proportional to the dynamic pressure times the frontal area of the object. Different streamlining mechanism of the leaves can significantly affect hydraulic resistance of flexible plants. For vegetation with constant leaf mass, the product of the drag coefficient and the frontal projected area decreases with increasing velocity (Armanini et al. 2005, Wilson et al. 2008). The leaf area is not an appropriate surrogate measure for the frontal projected area as the frontal projected area depends on both leaf mass and flow velocity (Schoneboom 2008). The frontal projected area of flexible elements reduces with the increasing drag force due to reshaping and streamlining of branches and leaves (Vogel 1994). Distinct contribution of foliage to the total plant drag at different velocities particularly at lower velocities where the foliage is not streamlined and compressed is observed (Wilson 2008). The length and flexural rigidity (EI) of the trunk and the branches also affect the projected area and consequently the streamlining mechanism. The shape of the leaves become important in changing the drag characteristics of the trees. Leaves of difference shapes can be classified into small thin and broad leaves, large and broad leaves and stick type leaves.

Experimental studies with single rigid cylinders show an almost linear relationship between drag force and squared mean velocity (Nepf 1999). On the other hand, studies with natural flexible vegetation show an almost linear relationship between drag force and mean velocity (Armanini et al., 2005, Schoneboom, et al. 2008). One reason for the difference of the behaviors of rigid and flexible vegetation is associated with the streaming effects (Schoneboom et al. 2008). Another reason is the difference in the surface roughness of the natural vegetation and the rigid cylinders. The surface roughness plays an important role in the behavior of single cylinders (Xianzhi Lui et al. 2007). Within this range of Reynolds number, drag crisis as a result of the boundary layer of the cylinder surface changes from laminar to turbulent.

In addition, to surface roughness and flexibility, existence of leaves, self oscillations are also needed to be considered (Sina Wunder, 2009). In the arrangement with the rigid cylinders, it is shown that primitive Kármán vortex streets are generated behind the cylinders for small Reynolds numbers ($Re < 10^6$) (Takemura et al. 2006). In the wake behind the living tree, reverse flow was found at further downstream region than the case of a circular cylinder (Ishikawa et al. 2006).

Therefore it is clear that further studies are required to ascertain the similarity of tests with the natural trees and apply the drag coefficient in the natural environment. In this study the previous studies on rigid cylinders are extended to model the natural flexible tree trunks and canopies. Then these results can be scaled up for the natural trees and hence the drag force characteristics of an entire landscaping unit can be predicted.

2 Objectives and Methodology

The main objective is to investigate drag force characteristics of three different types of trees and to find out the potential to protect the coastal region against tsunami natural disasters

The following methodology was used:

1. Testing the model samples of trees in the towing tank in a range of higher Reynolds numbers (Reynolds number = Ud/v ; where, U is the mean velocity of carriage fixed with sample, d is the characteristics length obtained as square root of total wetted area of the sample and v is the kinetic viscosity of water). Then obtain the variation of the drag coefficient with Re Numbers ($10^5 – 6 \times 10^6$)
2. Scale up the results to obtain the drag force characteristics of the trees.

3 Experimental set up

The experiments were conducted in the laboratory towing tank of 50m x 2m x 2m. Experiment 1 was conducted to investigate the effect of leave mass (leaves density in a projected plane) and shape of leaves on drag force characteristics. Three samples (Table 1) from each species were tested while changing the velocities from 0.25 m/s to 2.5 m/s in 0.25 m/s intervals. The tests were repeated for the same canopies without leaves in order to estimate the influence of the foliage. For analyzing the effect of leaves, β is defined as the ratio between total drag force and drag force by only branches without leaves (Takenaka et al, 2010).

Table 1; Sample characteristics of the canopies used in Experiment 1

The specie	Leave area	Branch area	Frontal projected leave area	Frontal projected branch area	Projected leave area /projected branch area
Kottamba	4.70	0.163	1.569	0.052	30.2
Wetakeyya	3.38	0.132	0.135	0.042	3.2
Kasa	1.23	0.553	0.205	0.176	1.2

The experiment 2 was to investigate the effect of surface roughness of tree trunks on the drag coefficient at Reynolds numbers range from 10^4 to 2×10^5. Three trunk samples of species (Table 2) were investigated at the velocities from 0.25 m/s to 2.5 m/s in 0.25 m/s intervals.

Table 2; Sample characteristics of trunks and PVC pipe used in Experiment 2

The specie	Trunk diameter	Surface condition
Kottamba	0.106	Rough surface
Wetakeyya	0.050	Emergent roughness lines in lateral direction in smooth surface
Kasa	0.063	Cracks and trenches available in longitudinal direction in rough surface
PVC Pipe	0.075	Smooth surface

The methodology of calculation is based on study of Linder (1982) and Pasche (1984). Basis for their calculation system is the formula for drag force of an element inside a stream;

$$W_D = 0.5\, C_D \rho V_m^2 A_{veg}$$

Where W_D = drag force, V_m = averaged flow velocity; A_{veg} = projected vegetation area, C_D = drag coefficient of the element, ρ = fluid density.

Figure 1 shows the experimental set up for the measurement of drag forces of the samples. A load cell is attached at P2. Both P2 and P3 are smoothly pivoted to minimize the friction. The axial force through P2 is shown in a digital gauge (Aikoh RX IT/CB – N) attached to the load cell. By taking moments around the pivot at P3, P1 (actual drag force acting on the sample) can be calculated using the following equation;

$$P1 \times (L1 + L2) = P2 \times L1$$

Where, L1 is the distance between two pivots and L2 is the distance from P2 to the centre of area of the leaves.

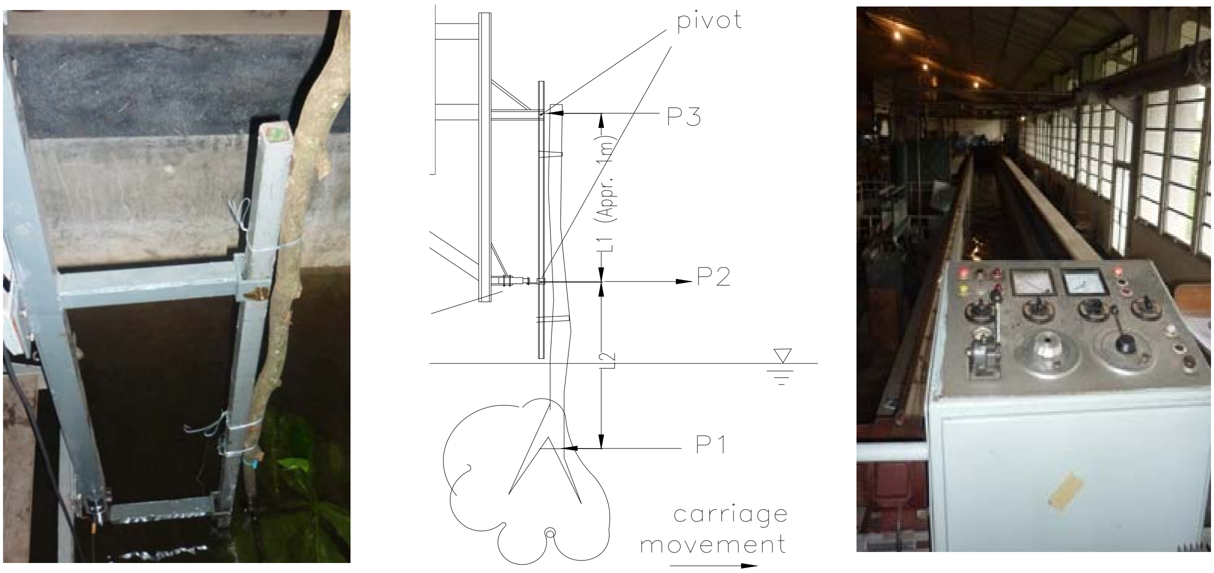

Figure 1; Experimental set up for the estimation of drag force

4 Results and Discussion

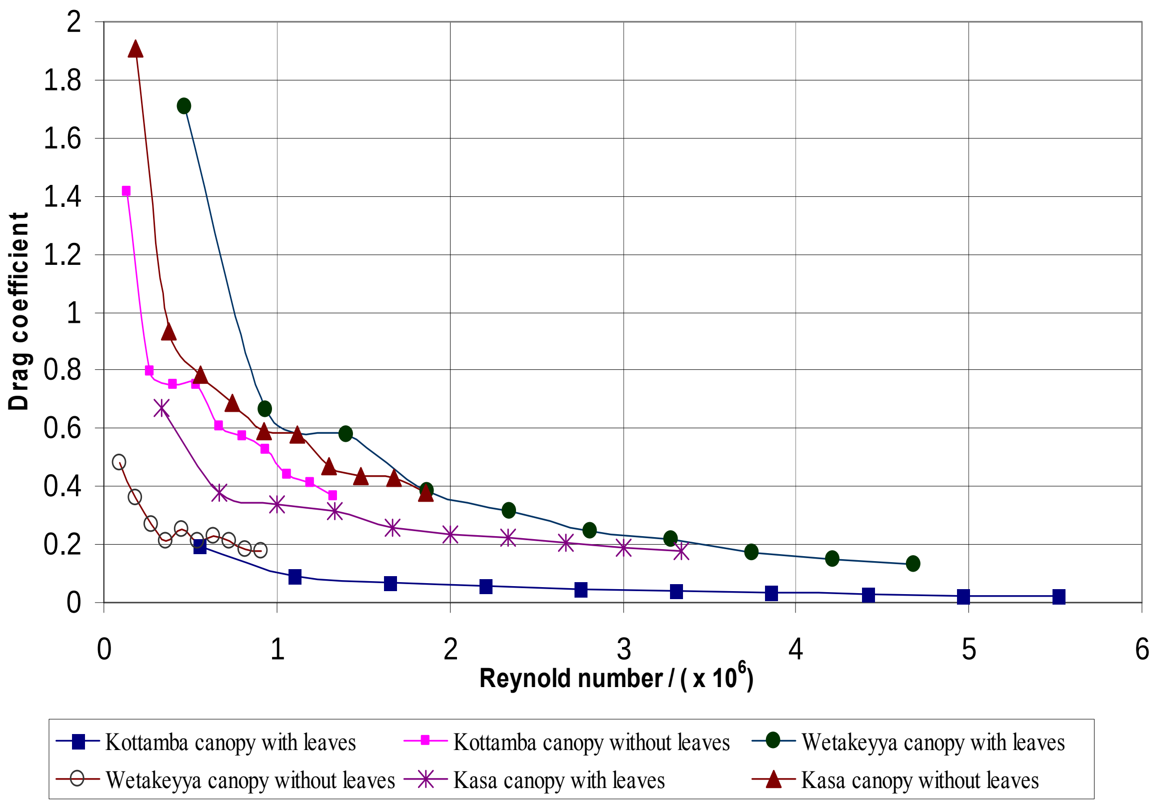

Figure 2; Variation of drag coefficient with Reynolds number for Kottamba, Wetakeyya and Kasa Canopies

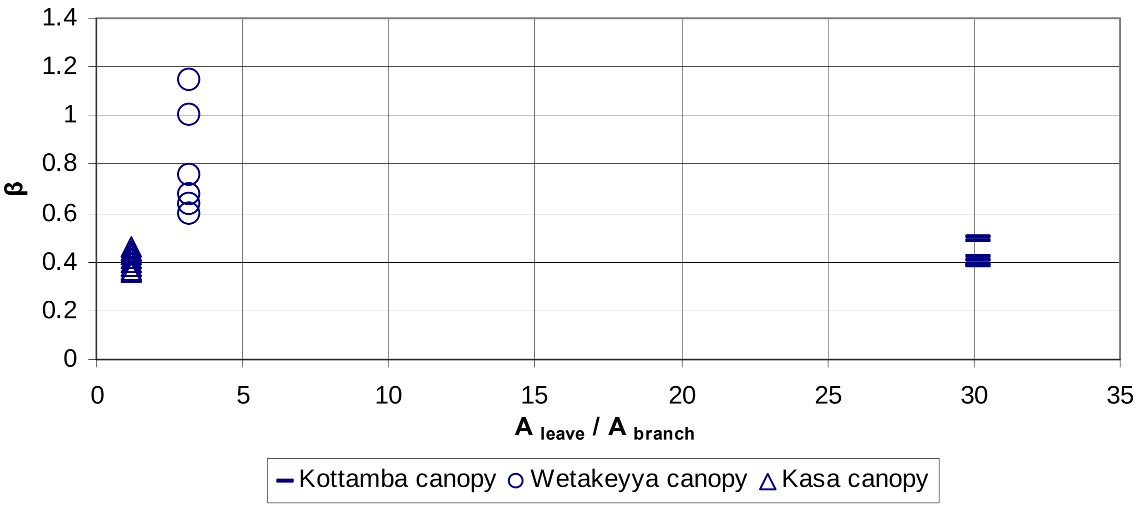

Figure 3; Relationship between β and A_{leaves}/A_{branch}, where β is defined as the ratio between total Drag force and drag force by only branches, A_{leaves} or A_{branch} is the projected area of leaves or branch, respectively.

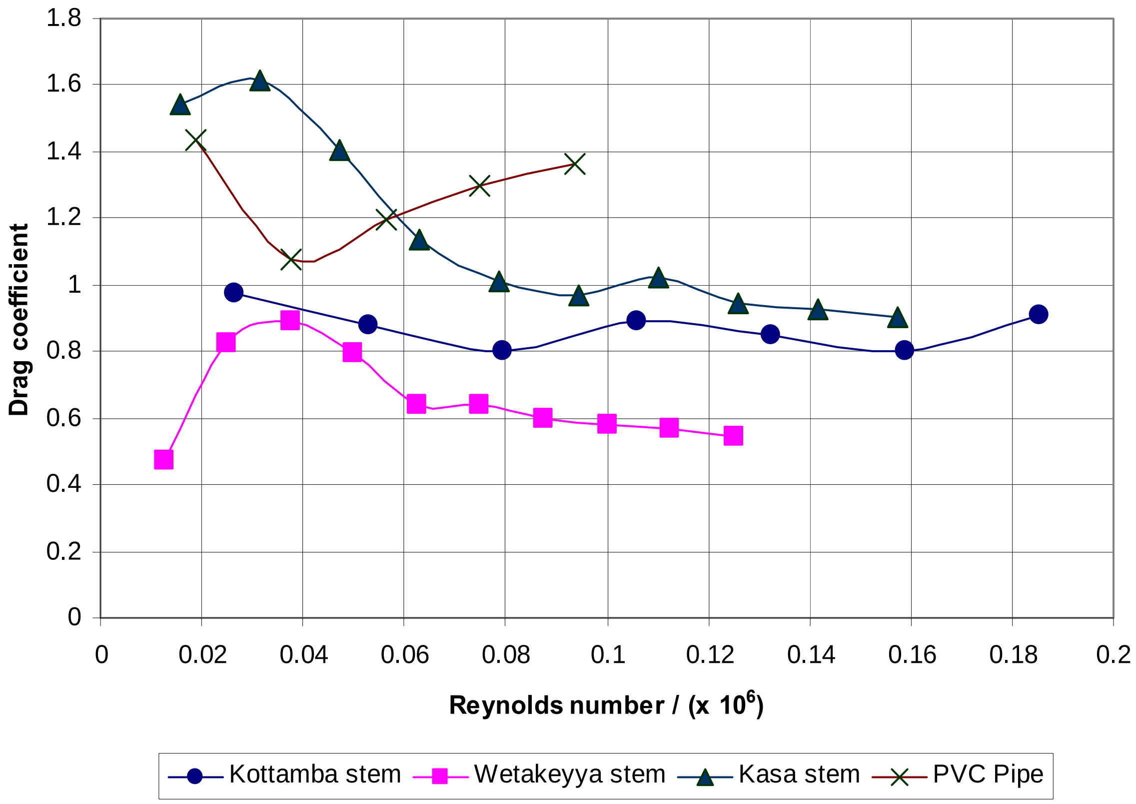

Figure 4; Variation of drag coefficient with Reynolds number for Kottamba, Wetakeyya and Kasa trunks

Figure 2 shows the experimental results obtained for the samples from Kottamba, Wetakeyya and Kasa canopies tested in towing tank. The drag coefficient of Kottamba canopies is less than 0.2, but the Kottamba canopies without leaves have higher drag coefficients. This shows the effect of foliation in drag force characteristics of vegetation. Due to the wide leaves of Kottamba and the consequent increment in the frontal projected area has reduced the drag coefficient of Kottamba canopies.

For lower Reynolds numbers ($Re < 10^6$) only Wetakeyya and Kasa show higher drag coefficients (C_D> 0.3). But for higher Reynolds numbers ($Re > 10^6$), both are having lower drag coefficients (C_D< 0.2). For Wetakeyya canopies C_D is greater than 0.2 up to the value of Reynolds number 3.5 x 10^6. But for

Kasa C_D is greater than 0.2 only up to the value of Reynolds number 2.5 x 10^6.
Figure 3 shows the relationship between β (ratio of drag force of canopy with leaves to the drag force of canopy without leaves) and ratio of frontal area of canopy with leaves to the frontal area of branch without leaves. It has been found that the value of β decreases with increasing Reynolds number.
Figure 4 shows the results obtained from the experiment 2. For low Reynolds numbers (20,000 < Re < 60,000) Kasa trunk had the highest drag coefficient than other types and the PVC pipe as well. But for the region of Reynolds number > 60 000, drag coefficient for the trunks of above three types of trees were found less than the smooth cylinder. For the greater Reynolds numbers than 60,000 the drag coefficient for Kasa trunk ranged in between 0.9 to 1.0 while for the smooth PVC pipe it ranged in between 1.2 – 1.4. For Kottamba it was in between 0.8 – 0.9 and for Wetakeyya it was around 0.6.

5 Conclusions

The drag coefficients of canopies mainly depend on the type, shape size of the leaves and the way they are fixed with the trunk. These factors affect the frontal projected area and consequently the drag coefficient. The value of β (ratio of drag force of canopy with leaves to the drag force of canopy without leaves) shows less than 1 for whole Re range investigated. This shows that the effect of foliation on drag coefficient of canopies. Kottamba and Kasa canopies without leaves have greater values for the drag coefficients than with leaves. Comparatively, Wetakeyya canopies have higher drag coefficient than Kottamba and Kasa, because Wetakeyya leaves are naturally streamlined and they have minimum frontal projected area than Kasa and Kottamba. Drag coefficient for the trunks of above three types of trees were found less than the smooth cylinder for the region of Re > 60000. This studies show the effect of surface roughness condition on the drag coefficient of tree trunks.

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Acknowledgements

This work was supported in part by JSPS AA Science Platform Program.

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COASTAL EROSION: INVESTIGATIONS IN THE SOUTHWEST COAST OF SRI LANKA

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Abstract:

Sri Lanka is an island with a coastline of length approximately 1600 km. Coastal erosion has been identified as a major hazard in many coastal areas, particularly along the densely populated southwest coastline of the country. Numerical studies were conducted to assess the sediment transport rates in selected areas along the southwest coast. Field investigations were carried out at several locations to assess the behaviour of the coastline. In this on-going study, seasonal trends of sediment transport rates are to be assessed and compared with measured shoreline behaviour.

Keywords: Coastal Erosion, Sediment Transport, Southwest Coast

1 Introduction

Sri Lanka is an island with a coastline of length approximately 1600 km. Coastal erosion has been identified as a major hazard in many coastal areas, particularly along the densely populated southwest coastline of the country. In this region, the nearshore wave climate varies with the four climatic seasons caused mainly by the monsoonal winds. These seasons are the first inter-monsoon (March-April), southwest monsoon (May-September), second inter-monsoon (October-November), northeast monsoon (December-February). In this study, investigations were carried out to assess the sediment transport rates and behaviour of shoreline at selected locations along the southwest coastline.

2 Methodology

Numerical studies were conducted to assess the sediment transport rates in selected areas along the southwest coast. Field investigations were carried out at several locations to assess the behaviour of the coastline.

The studies conducted to assess the sediment transport rates were based on an investigation conducted earlier, namely CCD-GTZ Coast Conservation Project (Fittschen et al, 1992) in which the coastline in the western to southern region has been considered in terms of a number of coastal cells as indicated in **Fig.1**. In this study, eleven coastal cells (S5 to S16) betweeen Galle and Colombo were selected (**Fig. 1**).

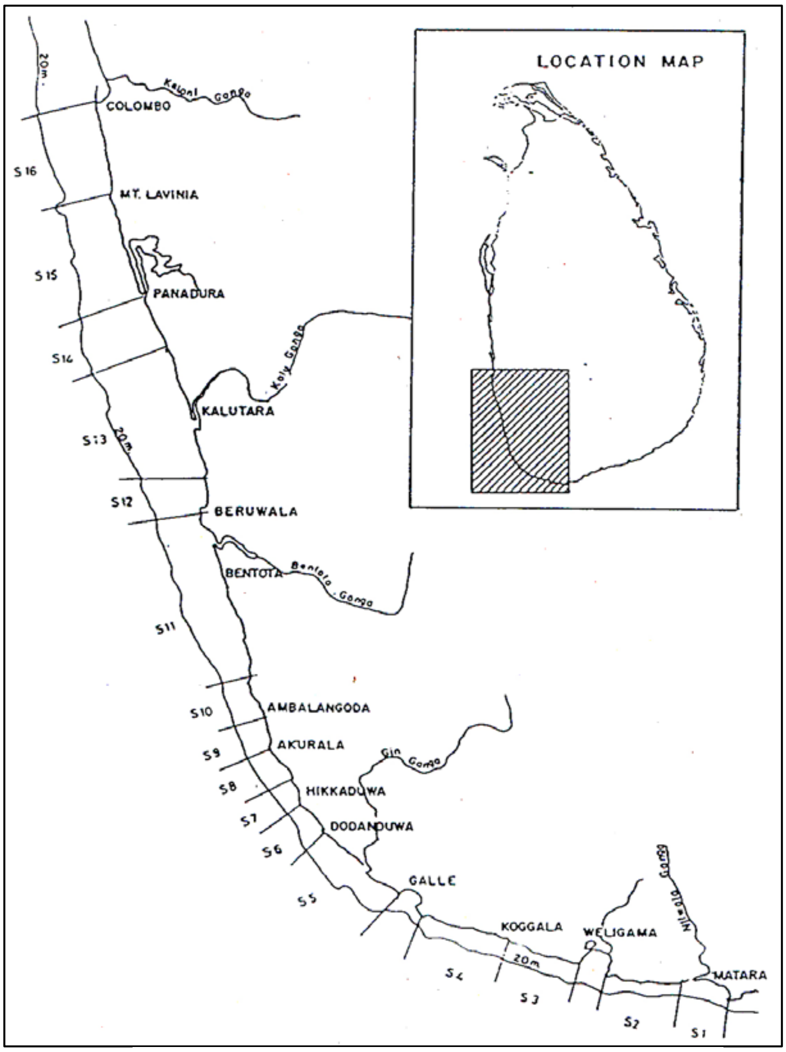

Fig. 1 Location of coastal sections S1 – S16

3 Investigations on Sediment Transport

In the absence of nearshore wave data required to assess the sediment transport, numerical modelling techniques were used to transform offshore wave measurements to selected coastal locations. Offshore wave data at -70 m depth at Galle has been collected by the Coast Conservation Department, Sri Lanka over a four year period (mid 1989-1995) was used in this study. The predominant direction of swell waves is southwest whereas sea waves have wide directional spreading. **Fig.2** illustrates the annual wave rose pattern of both swell and sea waves at Galle offshore. Admiralty charts were used to prepare digitized bathymetric data along the southwest coastline which is required to transform offshore wave conditions to nearshore regions using numerical models. MIKE 21 NSW (Nearshore Spectral Waves) model was used for the transformation. The NSW model takes into account of wave refraction, shoaling, bottom dissipation, wave breaking, wave-current interaction and wind-wave generation. At breaking depth, wave parameters which were required for the sediment transport calculations were extracted.

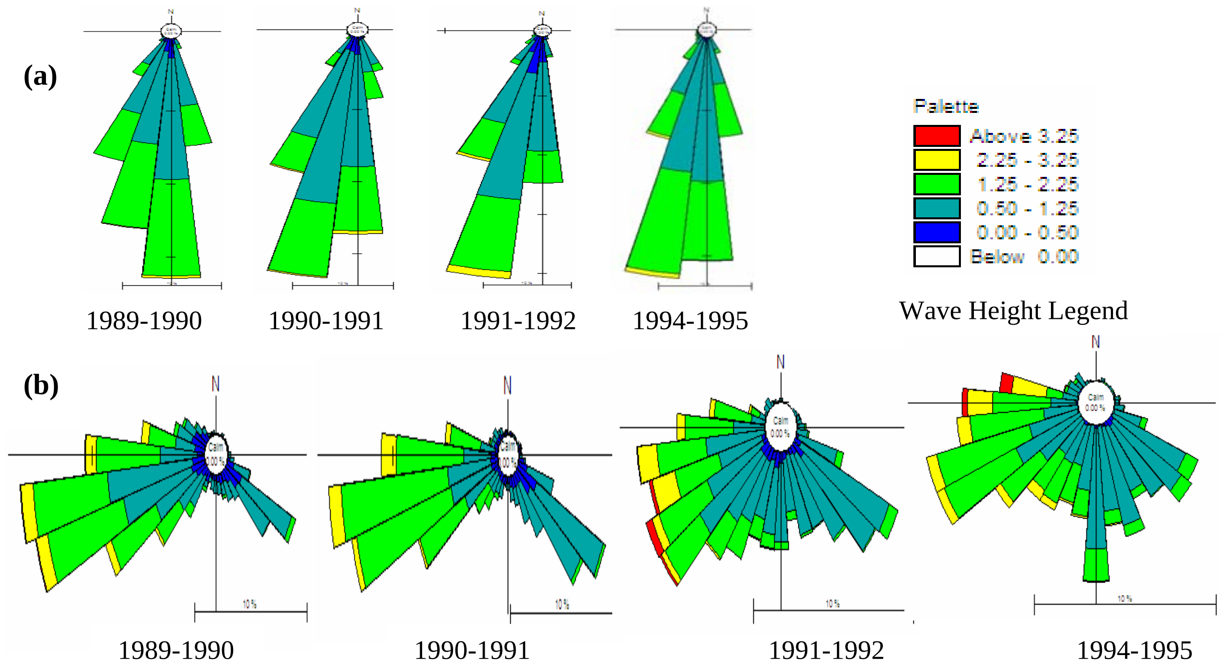

Fig. 2 Galle offshore wave Climate (a) Swell waves (b) Sea Waves

Nearshore wave climate established was used to assess alongshore sediment transport rates using empirical expression. There are many empirical formulae (CERC (1984), Bailard (1984) and Bijker (1971)) reported in literature that for the estimation of sediment transport rate Kamphuis (2002) formula is found to be more consistent and applicable to both field and model data (Smith et al, 2004) and it was used in this study. It is expressed in equation 1-a & 1-b as,

$$Q_{lst,m} = 2.27 H_{sb}^{2} \; T_{p}^{1.5} \; m_{b}^{0.75} \; d_{50}^{-0.25} \; \sin^{0.6}(2\theta_{b}) \qquad \text{1-a}$$

$$Q_{lst,m} = (\rho_{s} - \rho)(1-a) Q_{lst} \qquad \text{1-b}$$

in which $Q_{lst,m}$ is the transport rate of underwater mass in kg/s, Q_{lst} is the transport rate in m^3/s, H_{sb} is the significant wave height in m, T_p is the peak wave period in s, m_b is the beach slope from the breaker line to the shoreline, d_{50} is the median grain size in m, θ_b is the wave breaking angle, ρ_s and ρ are the density of sediment and sea water respectively and a is the porosity of the sediment.

The 1-D morphology equation (Kamphuis, 2000), expresses conservation of sand and calculates the change in the shoreline with regard to the distance along the shore. It was used to calculate corresponding shoreline variations with estimated sediment transport rates. To calculate the closure depth which was required in 1-D morphology equation, Hallermier's (1978) expression was used.

4 Investigations on Shoreline Behaviour

A series of field measurements were carried out in order to assess the behavior of the shoreline at selected coastal cells. The positions of the important features of the shore were measured with respect to a local reference line (**Fig. 3**). Monthly measurements were conducted to assess the seasonal variation of shoreline by measuring the movements of shoreline points and berm line points.

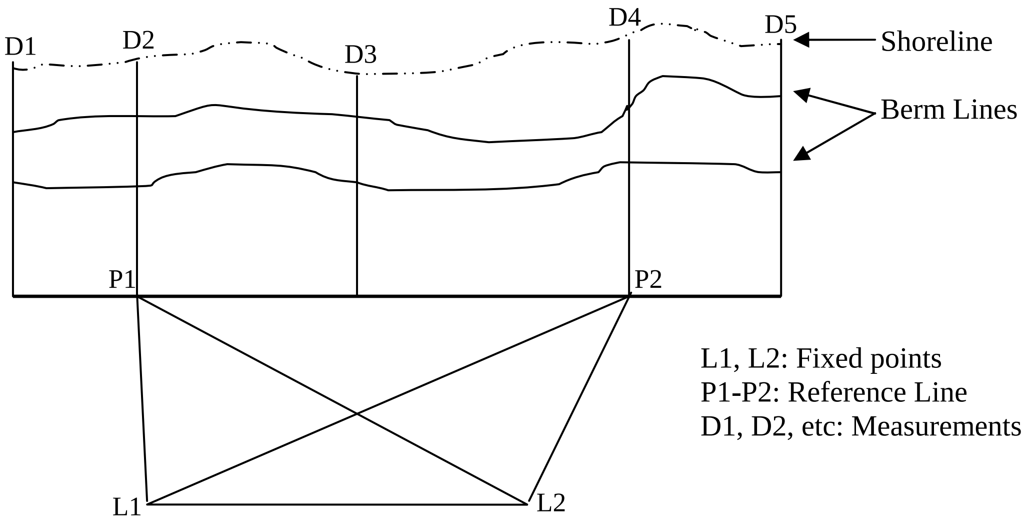

Fig. 3 Shoreline Measurements

5 Results and Analysis

The alongshore sediment transport rates estimated from wave conditions for different seasons have been tabulated in **Table 1**. The transport rates induced by swell are significant and directed northwards throughout the year, whereas sea wave has low transport capability and moves monthly net sediment either in northward or southward direction. The order of magnitude of the monthly sediment transport rate in the southwest coastline was found to be 10^5 m^3 in the southwest and northeast monsoon seasons. **Table 2** shows the possible seasonal (monthly) shoreline variation from one line model calculations in the selected locations. It can be identified whether the shoreline will erode or accrete in a particular season and the amount of possible shoreline variation.

Shoreline measurements revealed monthly variation of shoreline. When season changes from inter monsoon-2 to southwest monsoon, the field measurements have shown distinct changes of pattern in shoreline variation as shown in **Fig. 4**.

In this on-going study, seasonal trends of sediment transport rates are to be assessed and compared with measured shoreline behaviour.

Table 1: Alongshore Sediment Transport Rate

LOCATION		SW[a]	IM 1[b]	NE[c]	IM 2[d]
		x10^5 m^3/month			
Colombo	Swell	1.74	0.90	0.31	0.52
	Sea	0.24	0.07	0.00	0.16
	Total	1.98	0.97	0.31	0.68
Mount Laviniya	Swell	1.77	1.06	0.29	0.57
	Sea	0.09	0.05	-0.01	0.17
	Total	1.86	1.11	0.28	0.74
Wadduwa-Panadura	Swell	1.88	1.03	0.34	0.59
	Sea	0.15	0.05	-0.03	0.15
	Total	2.03	1.08	0.31	0.74
Kalutara	Swell	1.07	0.52	0.25	0.34
	Sea	0.00	0.02	-0.04	0.08
	Total	1.07	0.54	0.21	0.42
Maggona-Paiyaga	Swell	2.76	1.69	0.73	1.07
	Sea	0.39	0.10	0.03	0.02
	Total	3.15	1.79	0.76	1.09
Bentota- Beruwala	Swell	1.90	0.97	0.37	0.58
	Sea	0.48	0.09	0.04	0.10
	Total	2.38	1.06	0.41	0.68
Ahungalle-Kosgoda	Swell	2.16	1.07	0.41	0.64
	Sea	0.12	0.05	-0.02	0.13
	Total	2.28	1.12	0.40	0.77
Balapitiya	Swell	5.22	3.57	1.15	1.75
	Sea	0.28	0.12	0.03	0.03
	Total	5.50	3.69	1.18	1.78
Akurala-Ambalangoda	Swell	2.85	1.68	0.58	0.99
	Sea	0.16	0.07	0.00	0.20
	Total	3.01	1.75	0.58	1.19
Dodanthuwa-Hikkaduwa	Swell	1.25	0.70	0.23	0.35
	Sea	-0.03	0.03	0.01	0.20
	Total	1.22	0.73	0.24	0.55
Gintota-Dodanthuwa	Swell	1.28	0.83	0.23	0.37
	Sea	-0.44	-0.03	-0.04	0.20
	Total	0.84	0.80	0.19	0.57

[a]Southwest Monsoon, [b]First Inter Monsoon, [c]Northeast Monsoon, [d]Second Inter Monsoon

Table 2: Shoreline Variation

Location	Shoreline Variation (m)			
	SW	IM 1	NE	IM 2
Mount Laviniya	-0.83333	0.972222	-0.20833	0.416667
Wadduwa-Panadura	1.349206	-0.2381	0.238095	0
Kalutara	-6.71329	-3.78322	-0.71329	-2.23776
Maggona-Paiyaga	22.24599	13.37968	5.903743	7.176471
Bentota- Beruwala	-6.41667	-6.08333	-2.91667	-3.425
Ahungalle-Kosgoda	-1.02041	0.612245	-0.15306	0.918367
Balapitiya	31.56863	25.19608	7.696078	9.941176
Akurala-Ambalangoda	-31.9231	-24.8718	-7.69231	-7.61538
Dodanthuwa-Hikkaduwa	-26.3235	-14.9559	-5.05882	-9.41176
Gintota-Dodanthuwa	-7.67677	1.353535	-0.92929	0.40404

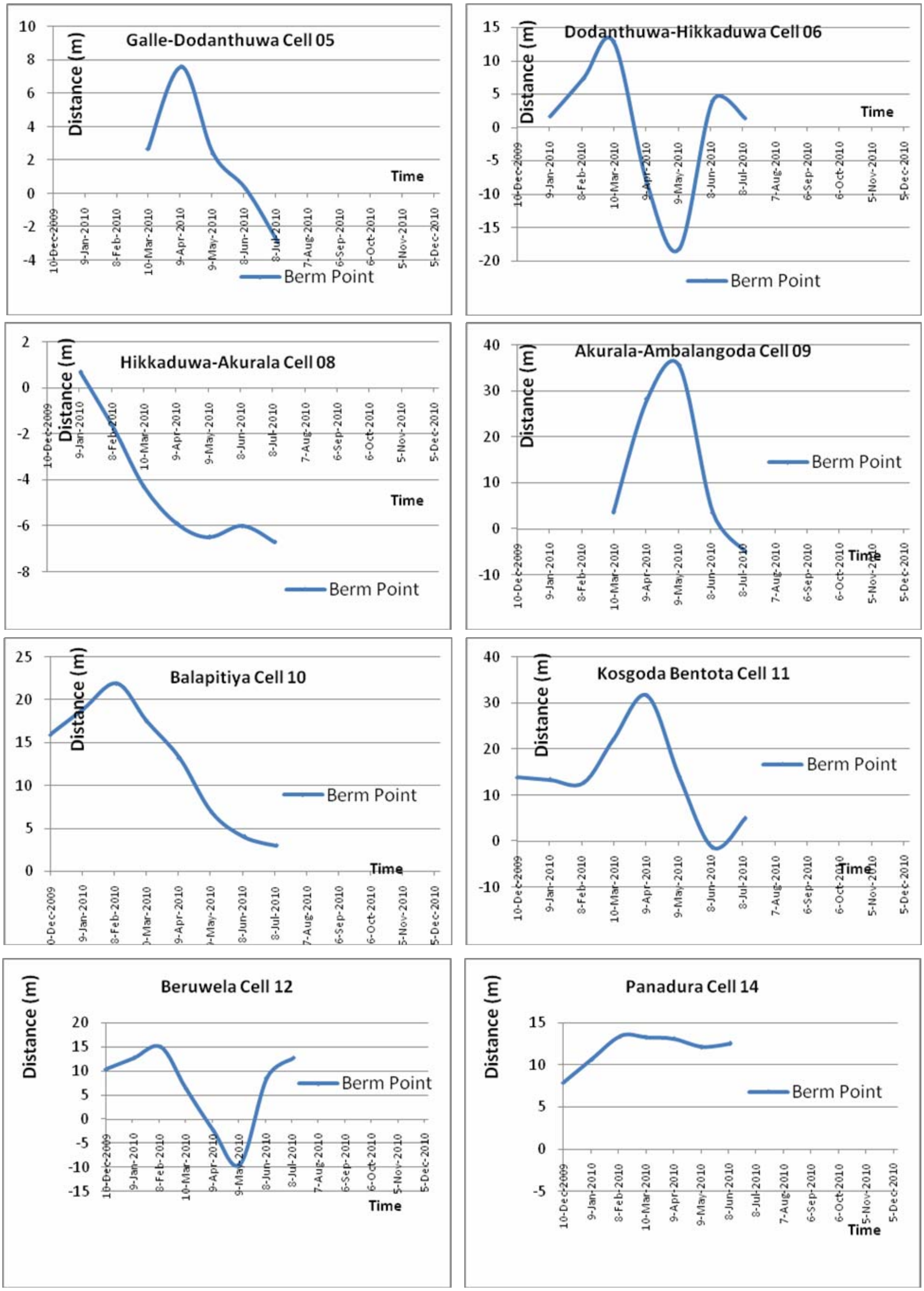

Fig. 4 Field measurements of shoreline variation

Acknowledgements

The staff of the Lanka Hydraulics Institute (LHI) supported by giving offshore wave records and the technical staff of Hydraulic Engineering Laboratory of the Department of Civil Engineering.

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