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Significance of Mangroves in Flood Protection of Coastal area: A Case Study of Mithi River, Mumbai, India

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Abstract:
The world's coastal margins are among the most densely populated and intensively used places on earth. Coastal populations are growing rapidly, as is associated infrastructure, industry and agriculture. Coastal populations are particularly vulnerable to the impacts of extreme events such as floods and hurricanes; tsunami etc. Mangroves have been found effective natural structure at bank of shore to reduce the flood water height, force of flood water and ultimately saving the dense population from flood hazards. Mangrove forests are increasingly being promoted and used as a tool in coastal defense strategies. All literature and studies suggest that mangroves can reduce the height of wind and swell waves over relatively short distances. This research focuses on mangrove forests at banks of Mithi River and the role it can play in reducing flood and its hazards. The study reveals that Mangroves forest at Mithi River reduces the flood wave height and reduces the inundation area by 21 percentages by saving the property and population from flood hazards. By reducing wave energy and height, mangroves can potentially reduce associated damage. This study directs the attention of citizens, government, private sectors and urban planners to the vanishing mangrove forest around banks of Mithi River.

Keywords: ArcGIS 10.1, Flood protection, HecGeoHMS, HEC-HMS 3.5, HEC-RAS 4.1, Mangroves, Mithi River.

1.0 Introduction
The world's coastal margins are among the most densely populated and intensively used places on earth. Coastal populations are growing rapidly, as is associated infrastructure, industry and agriculture. These populations and coastal lands can be at risk from natural hazards such as waves, storms and tsunamis; the numbers of people at risk are increasing with the expansion of human populations, and the risks will likely be exacerbated by the effects of climate change and sea level rise. Mangrove forests span the interface between marine and terrestrial environments, growing in the mouths of rivers, in tidal swamps, and along coastlines, where they are regularly inundated by saline or brackish water (Sterling, *et a*l., 2006). Mangroves can also play a role in defending coasts from storm surges (Krauss, *et al*., 2009; Zhang, *et al*., 2012) and from erosion (Thampanya, *et al.*, 2006). Mangrove forests play a vital role in coastline protection, mitigation of wave and storm impacts and mudflat stabilization, and protection of near-shore water quality. They also provide critical habitat for fish and wildlife. Many documented in mangrove forest areas in Vietnam (Thompson and Thompson, 2008). Mangrove forests are thought to play an important role in flood defence by dissipating incoming wave energy and reducing erosion rates (Hong and Son, 1993, Wu, et al., 2001). Coastal mangrove forests can mitigate high waves, even tsunamis. By observing the casualties of the tsunami of 26th December 2004 (Kathiresan and Rajendran, 2005) highlighted the effectiveness of mangrove forest in reducing the impact of waves. Human death and loss of wealth were lower in areas of dense mangrove forests. A review by (Alongi, 2008) concluded that tsunami wave flow pressure was significantly reduced when the mangrove forest was 100 m wide. The wave energy spectrum and wave power are dissipated within a mangrove forest even over a small distance (Vo-Luong and Massel, 2008). The magnitude of the energy absorbed depends strongly

on the mangrove structures (e.g. density, stem and root diameter, shore slope) and the spectral characteristics of incident waves (Massel, *et al.,* 1999, Alongi, 2008). The dissipation of wave energy inside mangrove forests is caused mostly by wave-trunk interactions and wave breaking (Vo-Luong and Massel, 2006). Mangrove forests fringing tropical coast lines are very important not only from local viewpoints regarding wood resources, food resources and land protection in tropical coastal regions but also from the global view point of earth's total environment (Robertson and Alongi, 1992). Since the late 19th century mangrove forests have been destroyed on a global scale due to human interaction. Consequently, this degradation of mangrove forests has also had a discernible impact on human existence; for example, in South East Asia the deforestation of mangrove areas adjacent to the open sea has sometimes exacerbated coastal erosion from sea waves (Hong and San, 1993; Mazda, *et al.,* 1997a). During the process of deforestation and reclamation, a few mangrove patches are still left in the heart of the city, which proves that today's megacity had a luxuriant past of mangrove forests. Major mangroves are seen today in Mumbai along the Vasai Creek, Thane Creek, Manori and Malad, Mahim - Bandra, Versova, Siwri, Mumbra - Diva and few more places. However, the physical processes of wave attenuation in mangroves are not widely studied, especially in India, because of the difficulties in analyzing flow fields in vegetation and the lack of comprehensive data. This research tries to find the effectiveness of mangroves forest in reducing the flood wave and its hazards. The HEC-HMS 3.5 and HEC-RAS 4.1 model is used to prepare the flood inundation map considering and neglecting the effect of mangroves effect.

2.0 Description of study area

2.1 Location of study area

Greater Mumbai comprises Mumbai, South Salsette and Trombay Islands, bounded by 18° 53' and 19° 20' north latitude and 72°45' and 73°00' east longitude (Ranade and Hasan). The area considered in this study is Mangroves at Mithi River which is located between north latitudes of 19°1'36"and 19°10'9" and east longitudes of 72°49'59" and 72°56'33". The location of the Mithi River has been shown in Figure a.

The maximum annual rainfall ever recorded was 3,452 mm (136 inch) for 1954 (Mumbai plan, 2009). The highest rainfall recorded in a single day was 944 mm (37 in) on 26 July 2005. (Kishwar and Madhu, 2006). The average total annual rainfall is 2,146.6 mm (85 inches) for the Island City, and 2,457 mm (97 inches) for the suburbs (Mumbai plan, 2009). Nearly 90% of its area has been developed for residential, commercial, industrial and institutional use while 10% is covered by green cover and mangroves (Mujib, 2012). Rapid urbanization and industrial growth have vanished mangroves forest on the bank of Mithi River. Currently it is remaining only close to Mahim causeway and Bandra. The Mangroves forests distributions have been shown in Figure b.

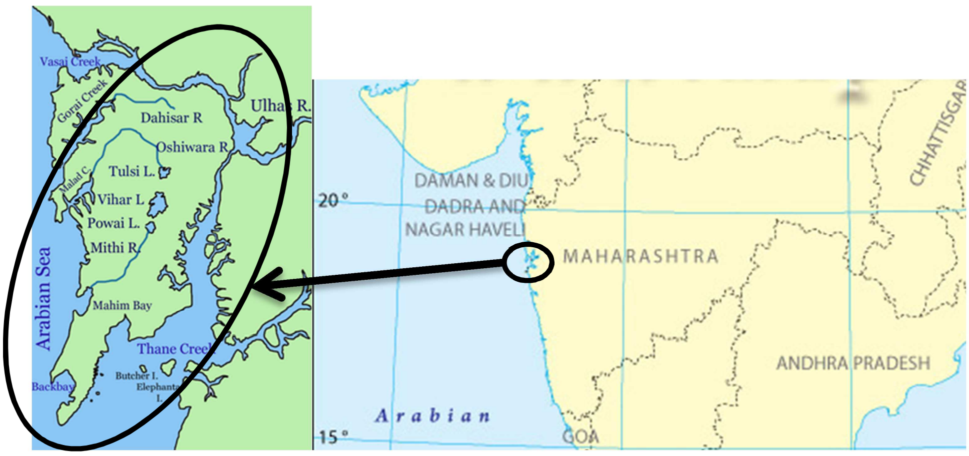

Figure a: Location of Mithi River (Source: Mithi River, India Lat & Lon Map., 2012)

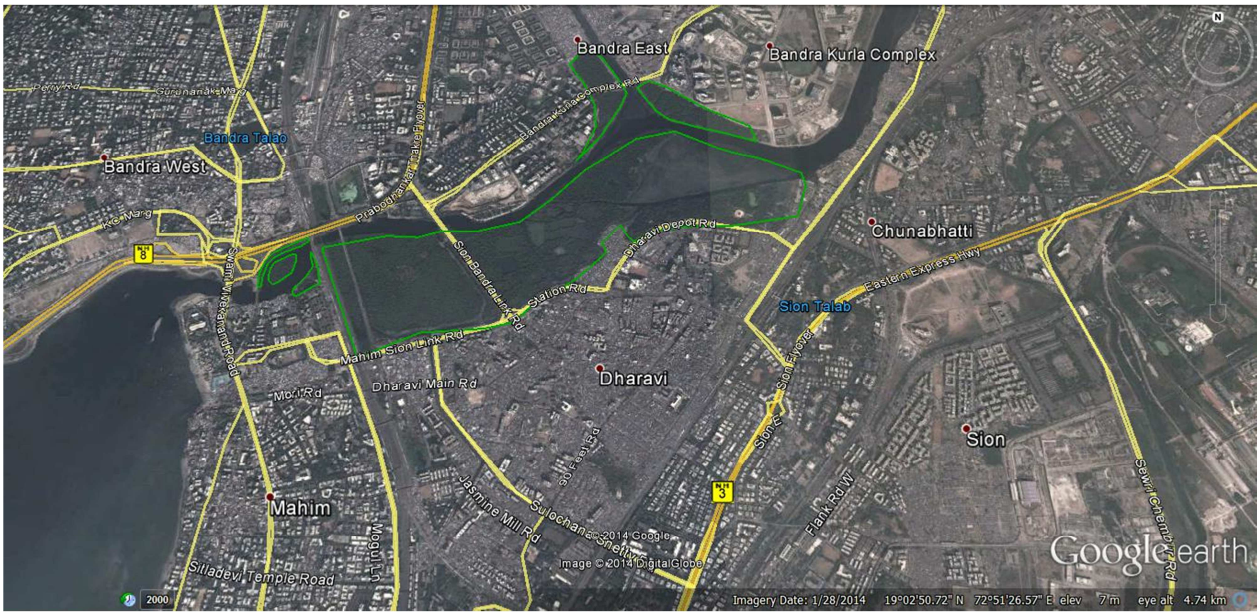

Figure b: Zone of Mangroves forest at Mithi River (source: Google earth, 2014)

3.0 Flooding problem in Mumbai and its causes

Mumbai city having an area of 437 sq km with a population of 12 million came to a complete halt due to the unprecedented rainfall of 944 mm during the 24 hours starting on 26th July 2005; with 380 mm falling in just 3 hours between 14:30 to 17:30 and hourly rainfall exceeding 190 mm/hr (Gupta, 2006). The immediate impact of the heavy rainfall was that there was a total collapse of the transport and communication system. Both the main Mumbai Santacruz airport and Juhu airport had to be closed down for two days on 26-27 July, 2005, thus forcing over 705 flights either to be diverted or cancelled. Most arterial roads and highways in the suburbs were severely affected due to water logging and traffic jams resulting from breakdown of vehicles in deep waters. Intercity train services had to be cancelled for over a week, while suburban trains could not operate from 16:30 (Gupta, 2007) onwards for the next 36 hours. Many people spent the night in offices, schools, trains and some even on the top of the buses. Most part of the Mumbai city areas have been developed through filling, and effective drainage is not possible, especially during high tide conditions. Furthermore, Mumbai city is affected by the tidal variations, making the problem more complex. The reason behind flooding in Mumbai is unusual heavy rains**,** extensive reclamation, and faltering drainage systems and cutting of mangroves forest along the bank of Mithi River.

4.0 Mangrove destruction in Mumbai

Rapid developments like housing, industrialization, pollution and increasing population of Mumbai has resulted into degradation of mangroves. Large demographic pressure is exerting tremendous stress on the coastal environment. The main culprit in the destruction of mangroves is man. To achieve harmful supremacy over nature, human have destroyed this magnificent ecosystem almost irreparably. Land reclamations and industrial effluents are the major causes of mangroves degradation. Systematic dumping of all kinds of waste and debris in the mangrove areas destroys them. Land reclamations and industrial effluents are the major causes of mangroves degradation. This waste/debris creates a barrier preventing the sea water from entering the mangroves and eventually kills the mangroves. In many instances, this is done intentionally to reclaim land for construction activity. There is an urgent need to stop this systematic degradation of mangroves. The Figures c and d shows the development is encroaching to Mithi River bank and leading to vanishing of mangroves. Almost all part of the Mithi River catchment has been encroached from both sides of the bank. The historical image is not available for analysis. Presently the mangroves are present at Mithi river bank close to Mahim causeway, Bandra Kurla complex and Dharavi.

Figure c: Encroachment of mangroves (Source: Mumbai Mangroves, 2007)

Figure d: Development into Mangroves (Source: Mumbai Mangroves, 2007)

5.0 Importance of mangroves to Mumbai

By reducing flood wave and trapping silt, mangroves maintain the integrity of Mumbai's shoreline. This is a vital service to the city of Mumbai as it is very prone to erosion, having been built on reclaimed land that is battered by the sea on all three sides. The recent rains in Mumbai and the disaster that followed demonstrated the consequence of tampering with the ecology of fragile ecosystems like mangroves. Had Mumbai's Mithi River and Mahim creek mangroves not been destroyed by builders, fewer people would have died and the property damage would have been dramatically less. The Mangroves along the path of the Mithi River, especially at the Mahim Creek, act as natural lungs for the city. They are part of the natural ecology which is biological in nature, and cannot be uprooted and substituted with artificial gardens.

5.1 Flood resilience property of mangroves

Studies that have measured the attenuation of wind and swell waves in mangroves are shown in Table 1. All these studies found a reduction in wave height as waves passed through mangroves. The level of wave attenuation varied between 0.0014 /m and 0.011 /m (Table 2). These attenuation rates suggest that across a 500 m width of mangrove forest, wave height would be reduced by 50 to 99%. These studies support the frequent assertion that mangroves can indeed attenuate wind and swell waves.

5.2 Wave attenuation by mangroves

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5.3 Factors affecting wave attenuation in mangroves

The factors known to affect the reduction in wave height as waves pass through mangroves include water depth, which is a function of topography/bathymetry and tidal phase, wave height, and various aspects of the structure of mangrove trees, which depend on their species, age and size (Figure e). The research result of wave attenuation cannot be standardized because the parameters of test are different at different locations.

Table 1: Literature showing significance of mangroves forest

Sr No	Literature	Flood wave attenuation
1	Brinkman, et al., 1997; Massel, *et al.*, 1999	The wave energy transmission factor varies between 0.45 and 0.8 (where 1 is no loss of wave energy) 150 m into the forest. The transmission factor is the standard deviation of the wave energy spectrum at a point x divided by the standard deviation of the incident wave energy spectrum.
2	Mazda, *et al*. 1997a	Rate of wave height reduction up to 20% per 100m of mangroves (6 year old *Kandelia candel* trees that had been planted). Young mangroves (2 month old *Sonneratia caseolaris*) did not reduce waves.
3	Mazda, *et al.* 2006	Rate of wave height reduction varied between 0.0014 and 0.0058 per m cross-shore. The rate of wave reduction over 100 m of mangrove forest was calculated as 45% when water depth was 0.2 m and 26% when the water depth is 0.6 m.
4	Quartel *et al.* 2007	Wave height reduction varied between 0.002 and 0.011 per metre cross-shore. The measured wave height reduction in the mangrove was higher than over the sandy surface.
5	Vo-Luong and Massel, 2006, 2008	50-70% of the wave energy was dissipated in the first 20 m of mangrove forest when the water level (measured from the area without mangroves) was 1.9 and 2.1 m deep; 50% was dissipated over 40 m when water level was 2.5 m deep. After this initial drop, wave height continued to decrease only slightly.
6	Bao, 2011	Mean wave height reduction (calculated using data from graphs in Bao, 2011) was 0.0054/m over 80m of mangrove forest

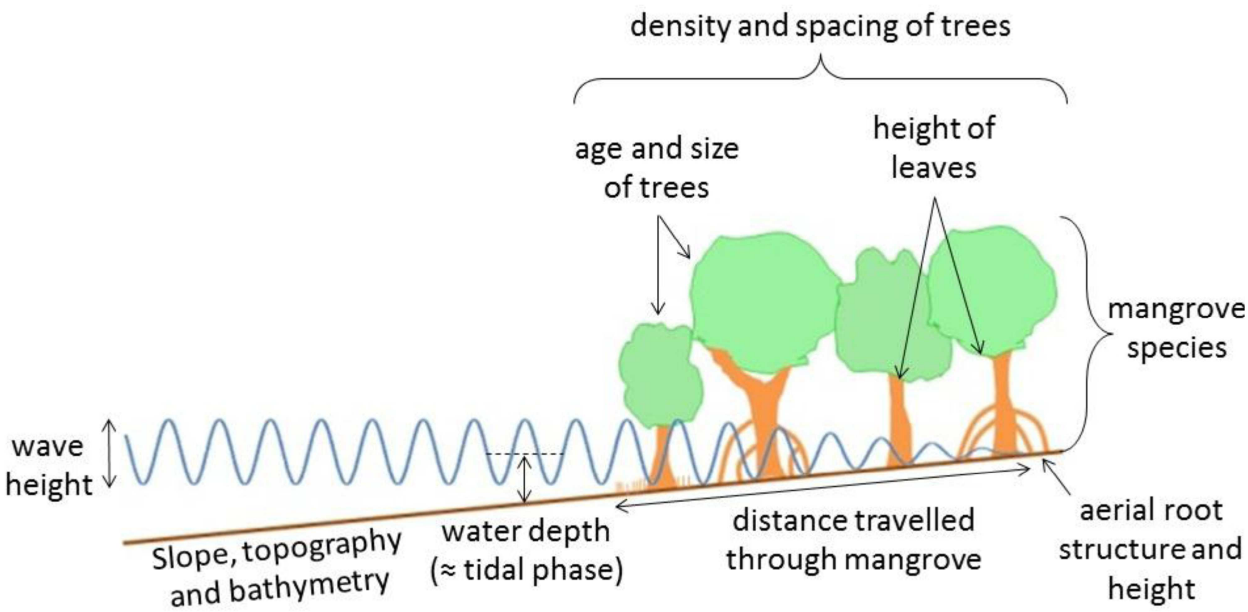

Figure e: Interaction of Mangroves with flood water (source: McIvor, *et al.,* 2012)

6.0 Data preparation

6.1 Delineation of Mithi River catchment using HecGeoHMS and ArcGIS 10.1

The Mithi river catchment has been obtained using HecGeoHMS and Arcmap tool in ArcGis. The following procedure has been adopted to obtain the catchment of Mithi River.

6.2 Obtaining and importing a digital elevation model (DEM)

The raw masked DEM has been shown in Figure f. SRTM Data has been downloaded through website http://srtm.csi.cgiar.org/. The SRTM data has been extracted in Geotiff format. The area is located between latitudes 15° to 20° N and longitude 70° to 75° E.

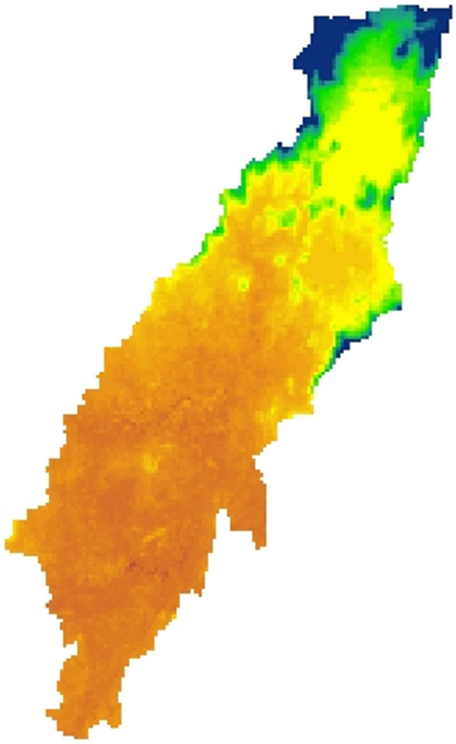

Figure f. Raw DEM

6.3 Creating depression less DEM

A fundamental problem in using such DEMs is the presence of sinks in the data. Sinks are grid cells with no neighbors at a lower elevation and, consequently with no down slope flow path to a neighbor. Sinks occur on both flat areas and in closed depressions. They also tend to be more common in low relief terrain then in high terrain. While a few of these sinks may represent real landscape features, the majority are spurious features which arise from interpolation errors during DEM generation, truncating the interpolated values on output, and limit the special resolution of the DEM grid. Therefore the depression and flat areas has been filled from the Dem by sink filling. The method (Tarboton & Rodriguez-Iturbe, 1989) is used to remove all sinks in the data. The DEM filled sink has been shown in Figure g.

Figure g. Depression less DEM

6.4 Calculation of Flow direction

Flow direction was determined using sink filled DEM as an input. To create a grid of flow direction from each cell to its steepest down slope neighbor the FLOW DIRECTION function has been used. For every 3 x 3 cell neighborhood the grid processor stop in the center cell and determines which neighboring cell is lowest and determines the flow direction. Maximum drop = (Difference in elevation between cells / Distance between cell centers) x 100. The flow direction grid has been shown in Figure h.

6.5 Calculating flow accumulation and Stream net

To create a grid of accumulated flow to each cell Flow direction grid has been used as an input. To get the accumulated flow into each down slope cell the FLOWACCUMULATION function has been used. The

Figure h. Flow direction

Figure i. Flow accumulation

accumulated flow is based upon the number of cells flowing into each cell in the output grid. The threshold has been set to 2.5 sq km. Output cells of flow accumulation are areas of concentrated flow and have been used to identify stream channels. The result of FLOWACCUMULATION has been used for generating a stream network by applying a threshold value to select cells with a high accumulated flow. The flow accumulation grid has been shown in Figure i. The stream grid has been shown in Figure j.

6.6 Basin Generation

The BASIN function has been used to delineate drainage basins within the analysis window by identifying ridge lines between basins. BASIN function analyzes the flow direction grid to find all sets of connected cells that belong to the same drainage basin. The drainage basin grid then is converted into coverage and basin shape files. Similarly the stream net has also been converted to shape file. The micro basins are then merged to derive the macro basins. Sub basin of Mithi River has been shown in Figure k.

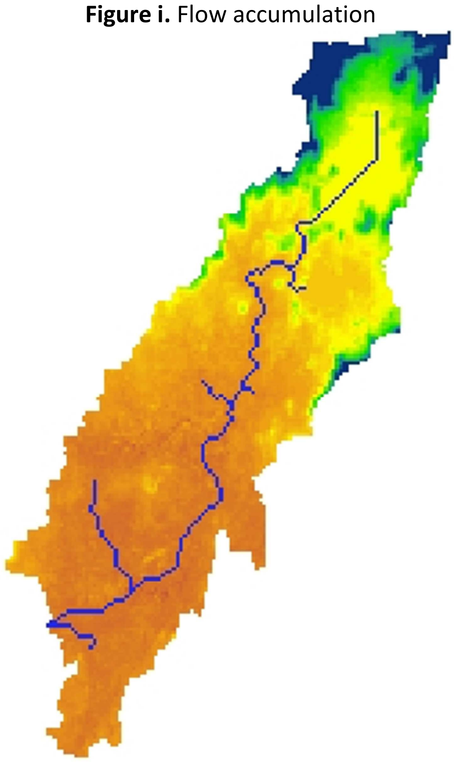

Figure j. Stream generation

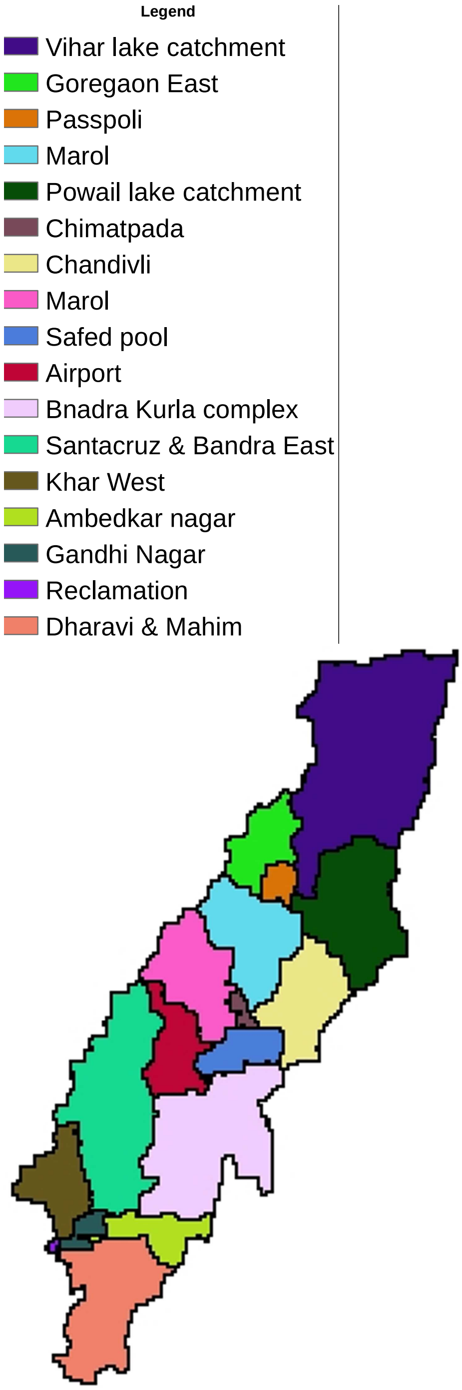

Figure k. Sub basins of Mithi River

7.0 Results and Discussions

7.1 Estimation of flood discharge near to mangroves using HecGeoHMS and HEC-HMS 3.5

The basin file for HEC-HMS 3.5 have been prepared using HecGeoHMS tool in Arcmap 10.1 (ArcGIS). The SRTM data was downloaded from USGS website www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1. Further the data was processed in Arcmap software to obtain the HEC-HMS basin file as shown in Figure l.

The basin model for Mithi River is executed in HEC-HMS 3.5 and flood flow for rainfall of 26th July has been obtained as shown in Table 2.

7.2 Simulation of water depth at mangroves using HEC-RAS 4.1

The water depth at location close to mangroves was calculated using HEC-RAS 4.1. The river geometry is prepared in HEC-RAS 4.1 have been shown in Figure m. The manning's roughness constant was used as 0.018 for the Mithi River since most of the river bed is dredged. The flood value obtained using HEC-HMS 3.5 is used in HEC-RAS to calculate water depth at various locations. It was assumed that flow will be steady at the time of peak flow and will produce the uniform water depth. The results obtained have been shown in Table 2.

Table 2: Flood magnitude and water depth at Mangroves

Location ID	Location	Flood flow (m^3/sec) using HEC-HMS 3.5	Water depth (m) using HEC-RAS 4.1
30	Sion	1800	3.63
20	Khar	1850	5.08
10	Bandra	2172	5.44

Figure l: HEC-HMS basin using HEC-GeoHMS (source: Google earth, 2014)

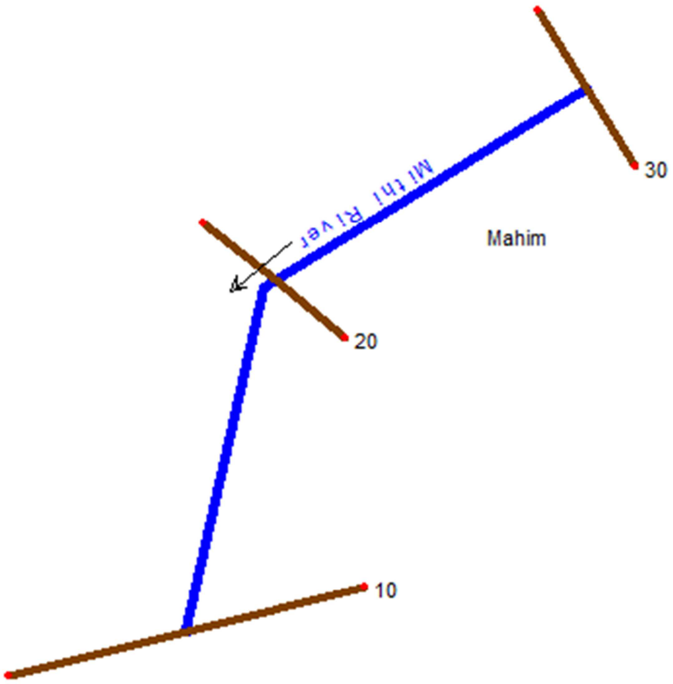

Figure m: River geometry prepared in HEC-RAS 4.1

7.3 Comparison of flood inundation map with and without mangroves

The past studies show that level of flood wave attenuation varied between 0.0014 /m and 0.011 /m. we assumed that attenuation in flood value will be 0.011/m. The flood map is prepared (Figure n) considering and neglecting the flood resilience effect of mangroves. The results obtained shows that area inundated by flood water considering mangroves is 1.45 sq km while it becomes 1.76 sq km when effect of mangroves are not considered. From results, it is found that there is almost 21 percentages decrease in flood inundation area when a mangrove comes in front of flood waves. The velocity of flood wave decreases due to obstruction caused by mangrove trees.

8.0 Conclusions

All studies have found that mangroves are able to attenuate wind and swell waves. The level of wave attenuation varies between 0.0014 /m and 0.011 /m per research. Wave height reduction within a mangrove forest depends on the width of the forest, mangrove tree morphology relative to water depth, topography and wave height. Mangrove species with aerial roots are more effective at attenuating waves in shallow water, when the waves encounter the roots; species without aerial roots are more able to attenuate waves when the water level reaches the branches. By quantifying the relationship between mangrove forest characteristics and the level of protection provided under different wave conditions, mangrove forests can be restored and managed in ways that it can help in reducing flood. The study reveals that presence of mangroves reduces the flood affected area by 21 %. The research confirms the significance of mangroves forest at river bank. The study confirms the importance of mangroves forest around river bank. From this study, it can be concluded that mangroves have ecological, environmental and flood reduction benefits and hence it should be preserved around the banks of Mithi River. However it should be noted that mangrove tree can elevate the water level in river which may cause flooding on the other side of the river if proper flood protection measures not provided.

9.0 Acknowledgment

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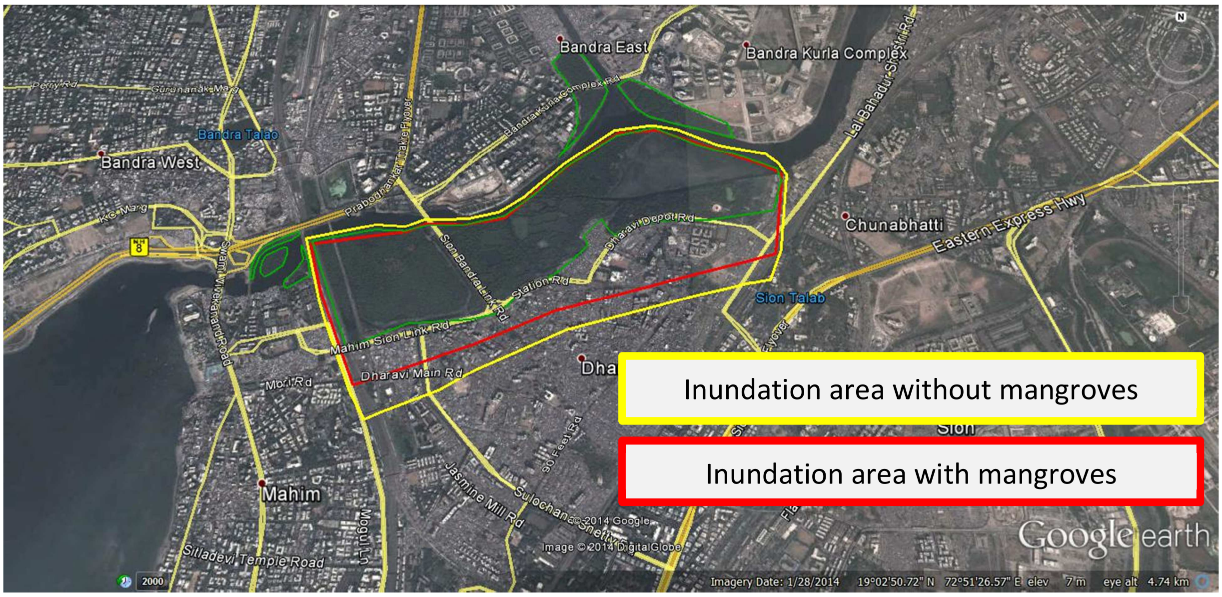

Figure n: Flood inundation map with and without mangroves (source: Google earth, 2014)

References

1) Alongi, D.M. (2008): Mangrove forests: resilience, protection from tsunamis, and responses to global climate change, Estuar. Coast. Shelf Sci., 76 (1), 1–13, doi:10.1016/j.ecss.2007.08.024.
2) Bao, T.Q. (2011): Effect of mangrove forest structures on wave attenuation in coastal Vietnam. Oceanologia 53, 807-818.
3) Brinkman, R.M., Massel, S.R., Ridd, P.V. and Furukawa, K. (1997): Surface wave attenuation in mangrove forests. Proceedings of the Combined Australasian Coastal Engineering and Ports Conference, Christchurch, 1997, 941-946.
4) Google earth. (2014): US department of state geographer, http://www.google.com/earth.
5) Granek, E.F. and Ruttenberg, B.I. (2007) Protective capacity of mangroves during tropical storms: a case study from 'Wilma' and 'Gamma' in Belize. Marine Ecology-Progress Series 343, 101-105.
6) Gupta, K. (2006): Extreme precipitation, multisource data measurement and uncertainty. 7th International workshop on precipitation in urban areas, 7-10 December, 2006, St Moriz, Switzerland
7) Gupta, K. (2007). "Challenges in modelling extremely heavy monsoon rainfall in a highly populated urban area, Mumbai, India". 7th International workshop on precipitation in urban areas, 7-10 December, 2006, St. Moritz, Switzerland.
8) Hong, Y. M. (2008). "Graphical estimation of detention pond volume for
9) Hong, P.N. and San H.T. (1993): Mangroves of *Vietnam*, IUCN, Bangkok, 158 pp.
10) Hong, P.N. and San, H.T. (1993): Mangroves of Vietnam. The IUCN Wetlands programme, IUCN, Bangkok, Thai, 173 pp.
11) India Lat & Lon Map. (2012): http://www.mapsofworld.com/lat_long/india-lat-long.html
12) Kathiresan, K. and Rajendran N. (2005): Coastal mangrove forests mitigated tsunami, Estuar. Coast. Shelf Sci., 65 (3), 601–606, doi:10.1016/j.ecss.2005.06.022.
13) Kishwar, and Madhu P. (2006): Three drown as heavy rain lashes Mumbai for the 3rd day. Daily News and Analysis (DNA) (Mumbai). Retrieved 15 June 2009.
14) Krauss, K.W., Doyle, T.W., Doyle, T.J. and Swarzenski, C.M., From, A.S., Day, R.H. and Conner,
15) W.H. (2009): Water level observations in mangrove swamps during two hurricanes in Florida. Wetlands 29(1), 142-149.
16) Kobayashi, N., Raichle A.W. and Asano T. (1993): *Wave attenuation by vegetation*, J. Waterw. Port C. Div., 119 (1), 30–48, doi: 10.1061/ (ASCE) 0733-950X (1993) 119:1(30).
17) Massel, S.R., Furukawa, K. and Brinkman, R.M. (1999): *Surface wave propagation in mangrove forests*, Fluid Dyn. Res., 24 (4), 219–249, doi: 10.1016/S0169- 5983(98)00024-0.
18) Mazda, Y., Kanazawa, N. and Wolanski, E. (1995): Tidal asymmetry in mangrove creeks. Hydrobiologia 295: 51–58.
19) Mazda, Y., Magi, M., Kogo, M. and Hong, P.N. (1997a): Mangroves as a coastal protection from waves in the Tong King delta, Vietnam. Mang. Salt Marsh. 1(2): 127–135.
20) McIvor, (2012): Reduction of wind and swell waves by mangroves. NCP Report 2012-01.
21) Mithi river image, http://en.wikipedia.org/wiki/File:Geographybombay.png.
22) Mumbai Mangroves, mumbaimangroves.wordpress.com
23) Mujib, K. (2012): Evaluation of flood control structures on Mithi River, Mumbai, India, thesis submitted for Master of technology, IIT Bombay.
24) Mumbai Plan. (2009): Department of Relief and Rehabilitation (Government of Maharashtra). Retrieved 29 April 2009.
25) Quartel, S., Kroon, A., Augustinus, P., Van Santen, P. and Tri, N.H. (2007): Wave attenuation in coastal mangroves in the Red River Delta, Vietnam. Journal of Asian Earth Sciences 29(4), 576-584.
26) Robertson, A.I. and Alongi, D.M. (1992): Tropical Mangrove Ecosystems. Coastal and Estuarine Studies 41, American Geophysical Union, Washington, DC, USA, 329 pp.
27) Sterling, J.E., Hurley, M.M., Minh, D. L. (2006): *Vietnam: a natural history*, Yale Univ. Press, 1–21 and 91–92.
28) Tarboton, D. G., RL, B., and Rodriguez-Iturbe. 1989. The analysis of river basins and channel networks using digital terrain data. TR 326. Massachusetts Institute of Technology: Boston.:

Department of Civil and Environmental Engineering.

29) Thompson, C., Thompson, T. (2008): *first contact in the Greater Mekong: new species discoveries*, WWF, Hanoi, 40 pp.
30) Thampanya, U., Vermaat, J.E., Sinsakul, S. and Panapitukkul, N. (2006): Coastal erosion and mangrove progradation of Southern Thailand. Estuarine, Coastal and Shelf Science 68(1-2), 75-85.
31) Vo-Luong, H.P., Massel, S.R. (2006): Experiments on wave motion and suspended sediment concentration at Nang Hai, Can Gio mangrove forest, Southern Vietnam, Oceanology, 48 (1), 23–40.
32) Vo-Luong, H.P., Massel, S.R. (2008): Energy dissipation in non-uniform mangrove forests of arbitrary depth, J. Marine Syst., 74 (2), 603–622, doi:10.1016/j.jmarsys.2008.05.004.
33) Zhang, K.Q., Liu, H., Li, Y., Hongzhou, X., Jian, S., Rhome, J. and Smith III, T.J. (2012): The role of mangroves in attenuating storm surges. Estuarine, Coastal and Shelf Science 102-103, 11-23.