INDO-GERMAN Centre for SUSTAINABILITY

Workshop on Urban Resilience: Coastal Hazards and Coastal Water Management, Vulnerability and Sustainability

23-26 October 2017

Hall 1, IC&SR, IIT Madras

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Urban Resilience: Coastal Hazards and Coastal Water Management, Vulnerability and Sustainability IGCS Workshop, 23-26 October 2017, Chennai, India.

23-26 October 2017 **Venue: Hall I, IC&SR, IIT Madras, Chennai**

Tuesday 24th October	
10:00 - 12:30	Registration & Informal meetings & IIT Madras Campus Tour
12:30 - 13:30	Lunch
13:30 - 14:00	Workshop opening
Session I: 14:00 – 15:25 Chair: Prof. V. Sundar	
14:00 - 14:25	Climate Change Impacts on Coastal/Marine Sectors S.A. Sannasiraj (IIT Madras)
14:25 – 14:50	Coastal Hazards in Time and Space K. Reicherter (RWTH Aachen Univ.)
14:50 - 15:00	Engineering Geohazards - A new international M.Sc. programme N. Höbig (RWTH Aachen University)
15:00 - 15:25	Social Resilience from a cultural geographical perspective C. Pfaffenbach (RWTH Aachen Univ.)
15:25 – 16:00	Tea & Coffee
Session II: 16:00 – 18:05 Chair: Prof. Dr.-Ing. Holger Schüttrumpf	
16:00 - 16:25	Urban Coastal Floods with a case study of Chennai M.V. Ramana Murthy (ICMAM, Chennai)
16:25 - 16:50	Role of Vegetation in Coastal Flooding K. Murali (IIT Madras)
16:50 – 17:15	Geological evidence of Pre-1945 like tsunamis from Makran Subduction Zone, Arabian Sea: Should we expect the unexpected? S. Prizomwala (ISR)
17:15 – 17:40	Mangrove ecosystems as key to understand Holocene climate and sea level changes V. Decker (University of Bonn)
17:40 – 18:05	Coastal urbanisation, climate change and extreme wave events G. Hoffmann (University of Bonn)

Wednesday 25th October	
Session III: 09:00 – 10:45 Chair: Prof. Dr. K. Reicherter	
09:00 – 09:25	Coastal Hazards and Climate Change C. Sujatha (CUSAT)
09:25 –09:50	Risk potential of fine sediments in context of flood events and marine systems C. Ganal (RWTH Aachen University)
09:50 – 10:15	Coastal Risk Management in Germany H. Schüttrumpf (RWTH Aachen Univ.)
10:15-10:45	Fate and effects of highly hydrophobic substances: improving tools for a reliable environmental risk assessment F. Stibany (RWTH Aachen University)
10:45 – 11:15	Tea/Coffee
Session IV: 11:15 – 12:55 Chair:	
11:15 – 11:40	Impact of waterborne debri on the nearshore structures during extreme coastal floods V. Sriram (IIT Madras)
11:40 – 12:05	Geo-radar based subsurface investigations on paleo tsunami sediments along Indian coastal areas. V.J. Loveson (CSIR)
12:05 – 12:30	The past helping the present and future: sedimentological studies in water management in the Spanish Mediterranean coast J. Santisteban (Complutense Madrid)
12:30 - 12:55	Toxic Floods: Eco toxicological consequences of floods in urban environments S. Crawford (RWTH Aachen University)
12:55 – 14:00	Lunch Break
Session V: 14:00 – 15:15 Chair:	
14:00 – 14:25	Tracing the organic pollution of coastal areas in space and time with molecular indicators J. Schwarzbauer (RWTH Aachen University)
14:25 – 14:50	Environmental controls on microbial activity in coastal sediments - with special reference to methanogenesis S.G. Thanga (University of Kerala)
14:50 – 15:15	Toxic floods: Origin, distribution, timing and methodological approaches with examples from small river catchments in Central Europe F. Lehmkuhl (RWTHAachen University)
15:15 – 15:45	Tea & Coffee
Session VI: 15:45 – 17:00 Chair:	
15:45 – 16:10	Coastal Protection along Indian Coastline V. Sundar (IIT Madras)
16:10 – 16:35	Impacts of climate change and mitigation measures for small islands H. Schüttrumpf (RWTH Aachen Univ.)
16:35 – 17:00	Studying the effectiveness of coastal protection schemes against tsunami inundation Abhijit Chaudhuri (IIT Madras)

The past helping the present and future: sedimentological studies in water management in the Spanish Mediterranean coast.

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Spain is a dry land characterized by a high relief (most of the country is above 600 m.a.s.l.) but a considerable amount of richness is linked to the narrow coastal fringe. Infrastructures, highways, railways, airports, harbours, orchards, industries (like oil factories, nuclear power plants, etc.) and tourism concentrate in a stripe of less than 40 km-wide (and in some cases less than 5 km away) from the shore.

The high relief, isolation from the ocean influence and scarcity of rainfall reduce the area affected by coastal waves and great storms/tsunamis. However, the density of human settlements and infrastructures increases the economic magnitude of the potential damages.

However, these facts are also the main threats to the coastal area. Rainfall is scarce and uses to fall in short but intense storms (in many places 90% of the annual rainfall can fall in 1-2 storms); infiltration and evaporation plus increasing water abstraction for farming, industry and human use result in salinization and/or depletion of the groundwaters in the coastal area. In addition, retention of water and sediment by the widespread network of dams enhances the erosion of beaches and the destruction of natural coastal ecosystems.

In a future scenario of sea-level rise due to climate change, increasing aridity and increasing human pressure in the Mediterranean area, forecasting their effects could be crucial.

Sedimentology can help:

1) Forecasting of the saline wedge behaviour depending on sea-level change, tectonics, climate, water abstraction and sediment supply.
2) Defining the geometries of the fluid-bearing bodies and tracing the underground water paths.
3) Bounding the areas more sensitive to changes and, therefore, needed of special protection.

Mangrove ecosystems as a key to understand Holocene climate and sea-level changes

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The focus of the project is the reconstruction of the spatial distribution of mangrove ecosystems along the shores of the Arabian Sea during the Holocene. We follow the hypothesis that environmental changes - mainly changes in climate and sea-level – influences the ecology of mangrove swamps. Their variable spatial distribution possibly reflects changes in Asian monsoon circulation and intensity. Former mangrove swamps are Holocene analogues for ecosystem collapse, a process we would like to study.

Mangroves are important for various reasons. On the one hand they protect the coast from erosion, especially under storm surge and tsunami influence. On the other hand, they provide environmental services as they are fish nursery grounds and form very delicate and special ecological niches. Mangroves contribute organic litter to tropical waters which are commonly low in nutrients; they filter pollutants and prevent soil-salinisation. Besides these ecological benefits of mangrove ecosystems, they are also of socio-economic concern (e.g. for timber production).

Mangroves are sensitive to certain environmental factors, including changes in sea-level, temperature, CO_2, precipitation and storms. They occur only in certain latitudinal limits. The northern limit lies between 27-28°N. Our study areas are the Arabian Peninsula and the west coast of India, which are south of this limit.

We have three main aims: 1.) Decipher climate changes on a longer time scale; 2.) Reconstruct the site-specific relative sea-level development; 3.) Gain insight into the geoarchaeological context of mangrove and human population dynamics.

We will focus on geomorphological, sedimentological, geoarchaeological and palynological data to understand the Holocene mangrove dynamics, including their contraction and expansion phases. Indicative for former mangrove locations are for example shells of *Terebralia palustris*, a gastropod that lives predominantly in mangrove swamps. We will use stable isotopes on shells of a known species. By this it is possible to reconstruct environmental conditions like sea surface temperature, freshwater input, e.g. after heavy rain, in the estuarine environment. Combining this with a change in the so-called reservoir effect over time allows to interpret changing sea-level.

Environmental controls on microbial activity in coastal sediments - with special reference to methanogenesis (South West Coast of India)

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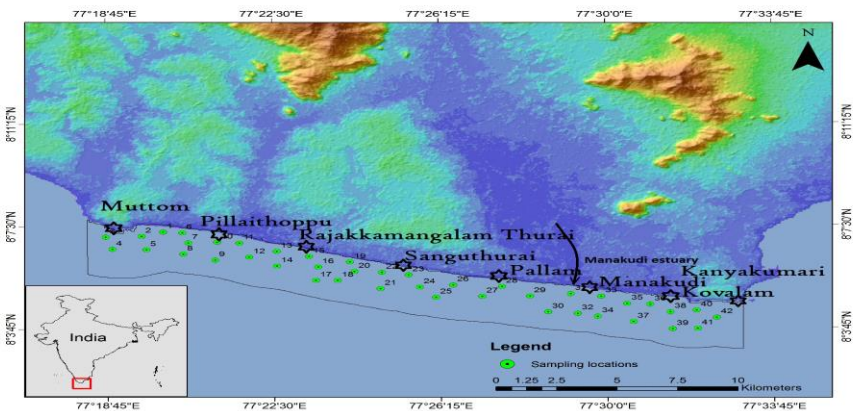
Increased nutrient inputs have implications on foodwebs and biogeochemical cycles of coastal areas, including the release of greenhouse gases. However, tropical coast with high population density and extensive agriculture display deviations from temperate and subtropical regions in this respect (Jennerjahn, 2012). Anaerobic decomposition of organic matter in coastal sediments is carried out by methanogenic archaea (MA) and sulphate reducing bacteria (SRB). SRB are the main competitors for MA because they use the substrate available for MA. Various environmental factors like temperature, salinity, quality and quantity of organic matter influence methanogenesis in marine sediments. Also, the **end product of methanogenic activity is methane**, a potent green house gas and hence, this process is of environmental importance. Nevertheless, human induced changes in coastal areas along with fluvial input from rivers alter the sedimentary conditions and inturn influence the microbial community structure of marine sediments. 42 sediment samples were collected from from Muttom to Kanyakumari of south west coast of Kanyakumari District using a VanVeen's grab sampler, transferred to sterilized sample bottles and stored at 4°C. The samples were analysed for various physico-chemical parameters. The quality and quantity of organic carbon as well as granulometry of the sediment samples were analysed. The abundance of MA was estimated by roll tube technique and methane production potential by analysing methane produced in the headspace of sediment microcosms using gas chromatography.

The abundance and activity of methanogenic archaea involved in the terminal phases of anaerobic organic matter mineralization, as well as the biogeochemical processes related to it, also showed distinct spatio-temporal variations. Abundance of MA in the sediment samples varied from 170 to 2660 CFUg-1 and the variation between sampling stations was significant ($p<0.05$). Similar to abundance, the methanogenic activity also varied significantly between sites ($p<0.05$) and methane production rate ranged from 0.096 to 1.009 mol/m3/day. Principal component analysis revealed that salinity and labile organic carbon were the principal components, which positively influenced methanogenesis, while sulphate showed a negative loading rate. Although marine sediments favour sulphate reduction due to the presence of sulphate, the present study results revealed that methanogenic activity dominated sulphate reduction during organic matter degradation.



Geological evidence of Pre-1945 like tsunamis from the Makran Subduction Zone, Arabian Sea: Should we expect the unexpected?

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Coastal areas around the world are densely populated and hence vulnerable to extreme wave events like tsunamis and storm surges. Assessment of coastal vulnerability to such marine high-energy marine events is vital as it helps reduce damage and loss of life in future. The study of geological evidences of past tsunami and storm surges is therefore vital however surprisingly limited from the western coast of India. Based on geochemical analysis, AMS ^{14}C chronology, sedimentary characteristics like erosive basal contact, presence of broken shell fragments, mud rip-up clasts, lack of sorting in sand layers and deep landward extent we conclude that a tsunami event occurred around AD 997 - 1107. The source of tsunami can none other be, but the Makran Subduction Zone (MSZ) in this case. Comparing it with regional records and its extent along the Kachchh coastline, we infer it to be the signatures of AD 1008 Strait of Hormuz earthquake. This gives us opportunity to compare the available palaeotsunami records of the MSZ viz., 4000 year old tsunami, BC 326 tsunami, AD 1008 tsunami and 1945 Makran tsunami. The palaeotsunami evidence studies suggest that the MSZ has produced major tsunamigenic earthquakes at a cycle of around 1000 years.

COASTAL HAZARDS AND CLIMATE CHANGE

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Climate change causing health impact is the greatest socioeconomic dispute of the present state of affairs facing worldwide. The dramatic cause has an immense capacity to effect adversely on the entire planet including human life. A variety of stress issues are being overlooked onto the subject of coastal hazards through climate change. A transformation in the pattern of coastal ecosystem are experienced due to the sea level rise which could erode and inundate these vulnerable realm. The warmer and more acidic oceans disrupt these fragile ecosystem abnormally. The variation in climate threatens the already hassled coastal areas owing to the anthropogenic activity like pollution effects through dumping waste materials directly from non point and point sources apart from other invasive species and natural processes like erosion, persistent storms, earthquakes etc. The human generated emissions as a by-product of rapid industrialization and urbanization are forcing and emitting the greenhouse gas and trigger the hydrological cycle and increase the shortage of rainfall annually and thereby increase the paucity of fresh water especially for the residents of the coastal province. It is a real time fact that incursion of saline water into fresh water aquifers, decline of coral reefs, mangrove forests and other aquatic life also massively affects the delicate coastal hinterland all over the world. In this scenario, adaptation efforts and measures have to plan through the planners and stakeholders of each local agencies for assessing the vulnerability to endure the changing outline or sketch of climate disparity.

Coastal urbanisation, climate change and extreme wave events

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The coastal zone is an important site of human settlement for millennia already. Benefits are the access to trade routes via ports, fertile soils, climate and availability of marine food resources. Demographic data reveal an accelerated global trend towards urbanisation as well as concentration of large cities along the coastlines.

Sustainable urban planning requires knowledge of the natural processes that act in the particular environment. This includes the extremes, e.g. maximum probable rainfall, maximum relative sea-level. Recent examples are Hurricane Irma (Caribbean and USA, 2017); Typhoon Haiyan (the Philippines 2013); the Tōhoku tsunami (Japan, 2011) and the Indian Ocean Tsunami (e.g. Indonesia, Thailand, India, 2004). The impact of the climatically forces global sea-level rise can only be evaluated for a specific site if the local isostatic and neotectonic processes are known. These need to be quantified which can only be done by geo-scientific field work. Some natural hazards – including storm surges and tsunamis – may have return periods that exceed a human lifetime. Historical records are often known to be incomplete and lack spatial completeness. Again sophisticated geo-scientific fieldwork is the key to quantify the processes. The intensity of storms is likely to increase in the future and the consequences need to be modelled in order to mitigate damages and control the risk.

The coastal zone of India is especially vulnerable as the it is densely populated including the megacity of Mumbai as one of the largest metropolitan regions of the world. Tropical cyclones are known to occur in the Indian Ocean as well as tsunamis.

We aim to quantify the various processes that control the coastal geomorphology, including the extreme events.

Geo-radar based subsurface investigations on paleo tsunami sediments along Indian coastal areas

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Coastal sedimentary records provide an acquiescent information on paleo extreme events. High-resolution mapping of shallow subsurface sedimentary features supports to unfold the geological flavour of paleo processes and its implications on paleogeomorphology. The sedimentological pattern due to the extreme events, especially tsunami, has been significant and a detailed mapping through GPR (Ground Penetrating Radar) up to 10 to 15 m depth in coastal areas helps to identify the spatial extension of paleo-tsunami deposits. Field investigations through trenching and laboratory analysis on sediments substantiate to indicate the characters of paleo-tsunami deposits. Moreover, OSL dating on selected samples reveals the period of a tsunami event. In this present study, three chosen areas along the coast of India were investigated and the time domain shallow profiles were digitally enhanced and subsequently interpreted. Based on the confirmation at field trenches on sedimentary layers and associated reflection signals in the GPR profiles, the extension of those layers was effectively mapped in and around the study areas. Site 1: GPR subsurface profiles on sedimentary layers at tsunami (2004) affected Karaikal beach (Tamil Nadu, east coast) was studied. Based on the momentous changes in the reflection amplitude, three different zones are identified. The buried erosional surface is observed at 1.5 m depth which represents the limit up to which the extreme event had acted. In other words, it is the depth to which the tsunami sediments have been piled up to about 1.5 m thickness. Three field test pits were made along the GPR transect, and sedimentary sequences were recorded. It is fairly clear that the lower zone located just below the erosional surface is comparatively more compact. The inferences from the GPR profile thus provided to trace the tsunami deposits all along the transects in the Karaikal beach. Site 2: The buried paleo-tsunami sediments were mapped in Guhagar beach (Maharashtra, westcoast) through subsurface profiles and correlated with mineralogy and OSL data. The destruction pattern and the run-off limits were assessed based on the disfigured geomorphic sand bodies buried under the present day sand sheet cover. Site 3: The tsunami sediments at Dive Agar beach (Maharashtra, west coast) has been mapped using 3D GPR approach. Subsurface data were collected in a closely designed grid profiles. The 3D transparency reflection models have been generated based on the reflection amplitude of sand mineral deposits of tsunamigenic origin. All the above-cited illustrations at three locations provide an insight to understand the dynamics of the study sites in detail and the capabilities of GPR approach, in understand and mapping the paleo extreme deposits.

Engineering Geohazards: A new international Masterprogramme

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Frequently, destructive natural forces hit our society all over the world. As a consequence we have to overcome high economic losses, the loss of human life and the threat to social structures on a regular base. In order to minimize those losses, we have to increase our effort to control these forces, in particular in time, space, and intensity. Increasing intensities of exogenous natural events (e.g., Storms, Monsoon) on one hand and on the other hand regularly endogenous natural events (e.g., Earthquakes, Volcanic Eruptions) inducing serious damages. An initial extreme event often triggers secondary hazards (e.g., Tsunamis, Mass movements) which tend to multiply effects and thus the damages. Our new international Masterprogramme “Engineering Geohazards” aims on understanding complex natural processes and strong interdisciplinary competences to evaluate consequences. In four semesters the students learn to think interdisciplinary and will contribute to a more sustainable society at least with respect to impact of natural hazards. Multidisciplinarity includes a portfolio of skills in Geoscience, Engineering, Ecotoxicology, and Economy which are supposed to be trained “hands-on”, e.g., in case studies guided by partners from industry/research institutions. Starting with a multi-method field survey to understand processes and train intercultural competences, the students gain a toolbox of basic principles and methods (Hazards, Disaster cases, GIS, Statistics, Ecotoxicology etc.). The next step would be training of integrative assessment that means application of field/lab/IT approaches to small own projects. After the second semester the students are supposed to settle their technical skills in scientific workshops. This period is also an integrated mobility phase. The third semester aims on training of risk management solutions, addressing preventive concepts (resilient buildings, infrastructure, communication/early-warning), management of losses (risk assessment, financial modelling, insurability), and follow-up care like remediation. The final step includes close contact to potential employers in form of internships and joint master theses which can be either in industry or academia.

Fate and effects of highly hydrophobic substances: improving tools for a reliable environmental risk assessment

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Highly hydrophobic chemicals (HOCs) are characterized by a log K_{OW} above 5.5, resulting in a low aqueous solubility in the lower µg/L-range. They are used in a broad range of applications ranging from personal care products to heavy industry. Due to the very high production volumes these chemicals enter the wastewater and the aquatic environment where they persist due to rapid and strong sorption to solid phases, i.e. (coastal) sediments, organisms, and particulate matter. Consequentially, these chemicals need to be considered as potential PBT-candidates due to their intrinsic properties. Therefore, a reliable assessments of the environmental fate and potential environmental toxicity are urgently needed for HOCs.

However, investigations into the environmental fate and toxicity of HOCs are by no means straightforward. The extensive sorption to solids complicates the application of standard tests that follow national and international guidelines for determining their toxicity or (bio)degradation. In particular, it can be challenging to provide defined and constant exposure concentrations in laboratory experiments but also to measure these concentrations. This is even more difficult when attempting to measure the exposure concentrations in the environment. The lack of consistent and reliable results due to these difficulties can lead to an improper assessment of their environmental risks.

Additionally, there are ongoing discussions about the presence of a general aqueous toxicity threshold (i.e., no toxicity below a certain concentration) or a general hydrophobicity toxicity cut-off (i.e., no toxicity above a certain Log K_{OW}). Reliable toxicity data in the high Log K_{OW} range are therefore urgently needed to clarify this issue, which in turn requires improved testing methods.

Impact of waterborne debris on the nearshore structures during extreme coastal floods

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Environmental impacts are the most significant in the areas closer to the points of impact of the extreme scenarios like a Tsunami. The stretch of the coastal housing, gas stations, important infra structures, industrial areas and more importantly nuclear power plant facilities (like Kudankulam nuclear power plant, constructed near Chennai coast, India) would be the most vulnerable due to potential contaminations from hazardous materials. The Fukushima accident during the catastrophic 2011 Japan tsunami is a standing example. Aquatic biomasses and its associated ecosystems along the coastlines are also vulnerable to the coastal flooding. In design aspects, there is currently no tools/methodology available to measure these impacts. Tsunami, one of such extreme event, consists of a series of highly violent energetic waves, i.e huge mass of water that impact the coast and persist over a long duration. Based on the past events, tsunami approaching the shore may broadly be classified as (a) A series of split waves (b) Non-breaking waves that act as a rapidly rising tide. (c) A large, turbulent wall- like wave.

This is collaborative research project between IITM and Nizhy Novgorod, Russia to determine the impact of water borne debris on the near shore structures during extreme events like tsunami and to develop a new method of coastal risk assessment taking into account of debris movement in the water flow. The objective also includes the study of bore characteristics in dam-break flow condition. The details of the impact tests with different weighed smart debris on the scaled model residential four storey building exposed to the action of different types of waves such as solitary waves, Elongated Single pulse waves, Symmetrical and Unsymmetrical N waves carried out in a 2m wide flume at IIT Madras are discussed. In the last part of the study, experiments using dam-break model for generating the hydraulic bore for exact resemblance of tsunami and its impact with the same debris and structure are presented and discussed.

Studying the effectiveness of coastal protection schemes against tsunami inundation

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Coastal protection schemes must be integral with the system in which they are positioned. Constructing seawall on the beach to protect important structures is one such scheme. The effectiveness of this protective measure should be quantified based on the reduction of impact force on the structure. The impact force is expected to depend on the height of the seawall, distance between seawall and building, slope of the beach, tsunami wave height etc.

A numerical study is being carried out for understanding the effectiveness of conventional seawalls in mitigating the impact forces due to high amplitude tsunami waves. Tsunami waves of prescribed wave height and wave celerity is generated numerically and allowed to propagate on a 1 in 40 sloped beach. Various parameters such as shape and geometry of the sea wall, presence of crown wall over the seawall, the promenade distance and position of seawall on the beach are also considered in the study. Trapezoidal shape of seawall with seaward and landward slopes of 1:4 and 1:2 are chosen for this study.

A two dimensional Reynolds Averaged Navier Stokes (RANS) equation with Shear Stress Transport (SST) k–ω turbulence model is used to solve the flow patterns. Volume of Fluid (VOF) method is used to track the free surface deformation of water. The commercially available CFD code FLUENT© is employed for this purpose. It is inferred from the present study that the position of seawall plays a significant role. So the seawall should be optimally positioned across the width of the beach to reduce the impact pressure on the building downstream.

Adaptation to Natural Coastal Hazards-A few case studies along the Indian coast

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The coastline of India has been experiencing a variety of environmental issues and problems, calling for an integrated coastal management and development as well as adaptation to coastal disasters. These include the coastal erosion, sand bar formation at the confluence of rivers/estuaries into Ocean, pollution from human settlement and industries resulting in unhygienic environment, loss of aesthetics in beaches affecting tourism and declining fishery resources.

The coast is highly vulnerable to disasters that are perennial at least once a year like cyclones, storm surge and also to the rare extreme events like the great Indian Ocean tsunami of 2004. The devastative effects of storm surge and tsunamis in the past have resulted in the loss of several lives and damage to private properties. The spatial distribution of a catastrophic event like the 2004 great Indian Ocean tsunami and its impact is of vital importance in recovery stages in case of emergency and in the planning for mitigation measures.

The coastal adaptation options, viz., protect, Accommodate and Retreat are highlighted with a few examples that covers both hard structural measures as well as soft measures like the application of geo-synthetic products and artificial reefs. The tsunami 2004 has really plantations as one of the mitigation measures and hence experimental results pertaining to plantations are highlighted through which empirical equations derived are discussed.

Through, efficient pre-planned mitigation measures based on the socio-economic aspects and geo-morphology of the coast, the loss of lives and property can be saved and environmental damage can be significantly reduced. Thus an SMP (shoreline management plan) fulfilling the desired and sustainable protection to the coast along with the consideration of the economical aspect in terms of implementation and maintenances is required. The details of stretches of coastal erosion, closure of river mouths, development of fisheries harbors, and effect of port structures on the adjoining shoreline are considered to draw the SMP. Further, the response of shoreline during extreme events through field measurements are highlighted.

CLIMATE CHANGE IMPACTS ON COASTAL/ MARINE SECTORS

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The mounting scientific evidence has well established that global warming is already occurring. The seasonal changes are evident in India and the long Indian coastline is particularly vulnerable to climate change due to sea level rise and the occurrences of extreme storms/ cyclones. A variety of marine strategies exist for adapting to climate change.

It is the basic understanding that any changes from an equilibrium might make chaotic behaviour in the system till an equilibrium is reached. Under this hypothesis, the global warming, an increase in the temperature of the ambience, makes an unbalance in the earth and ocean systems. Thus, the system might behave differently than the expected. These changes might be advantageous or disadvantageous to humans. Some of the potential impacts on the coastal/ marine sector due to global warming is listed below.

On the coastal and marine sectors, the following are the impacts due to global warming: Coastal habitats and coastal development; Water quality; Fisheries; Aquaculture, and Biodiversity. The above impact may be positive or negative depending on the consideration.

One who adapts to climate change is successful since natural climate change cycle in addition to manmade effects could not be controlled beyond certain extent due to the uncontrolled industrial growth worldwide. The adaptation can be due to private action, called autonomous adaptation and due to public action, called planned adaptation. The strategies for the above are reactive adaptation and anticipatory adaptation, respectively. The major four general adaptation strategies are:

a. Bear the losses, i.e., accept as it is and go ahead. This does not need any action.

b. In the first step of action, the losses are shared by community based mechanisms that share losses among different systems. It may be due to local taxation of centrally funded relief and rehabilitation measures.

c. The threat of global warming, more specifically sea level rise, could be modified (note *not reduced*) by minimizing other stresses to ecosystems.

d. A continuous learning exercises should be made effective about preparation for future changes in the environment.

ROLE OF VEGETATION ON ATTENUATION OF FORCES DUE TO CNOIDAL WAVES ON STRUCTURES

Prof. V. Sundar and Dr. K. Murali

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The recent tsunami has added a new dimension for the role of vegetation in minimizing the forces on structures in the coastal environment.

In the present work, an experimental study has been conducted on the understanding of the variation of forces on structures fronted by vegetation. Slender flexible cylindrical members that represent plantation have been adopted for the tests. The experiments have been conducted for different *G/B* ratios of 0, 0.5, 1 and 1.5. (Where *G* is the distance between front face of vegetation/ green belt and the sea side face of the building of width *B*). Experiments were repeated for three widths of Green belts (*BG*) and in each of the *BG* two different diameters were used. The forces on structure were measured in the presence and absence of green belt as shown in **Fig.1** and for the later. The measured results have been compared with existing results available in literature. Cnoidal waves with Ursell parameter ranging between 18 and 700 were employed for the experiments. The different non-dimensional vegetal and flow parameters have been identified. The variation of non-dimensionalised force over the slope in the presence and absence of vegetation as a function of the Ursell parameter, Relative rigidity and reduced velocity for different dimensionless *SP/D* of the green belt (where *SP* is the spacing between the stems and *D* its diameter) clearly indicates that there is significant reduction in the force. Prior to the experiments with the green belt, tests were carried out on the force measurements of waves over a plane slope and was compared with existing results for the purpose of validation. The details of the experimental set-up, procedure and analysis and discussion of the results are reported in this paper.

It has been found that,

- The non-dimensional Forces on the structure increases by about 80 %, when the distance *G* between the structure and the Green Belt is in the range of 0.5*B* to 1.5*B*.
- The most favorable location for the Structure is adjacent to the Green Belt (*G*=0*B*) or away from the Green Belt by more than 2*B*. For this configuration the forces can be reduced by a maximum of 90% and to a minimum of 50%.