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Flood Inundation Modeling for Malir Watershed of Karachi Considering Future Mean Sea Level Rise

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Abstract

Karachi is the one of the largest coastal city of Asia & impacts of sea water level rise are worth studying for betterment of the inhabitants. It is the largest metropolitan of Pakistan with population over 16 million that is expected to reach 27 million by the year 2020. Heavy rainfalls of a high intensity are experienced on occasions with the average annual rainfall varying from 125-250 mm. The urban population along the coast line varies from 10 to more than 7000 persons/km^2 which is vulnerable to tropical cyclones as well as resulting floods. There is no fixed cycle for the occurrence of these occasional heavy down-pours. They are dependent upon the local atmospheric disturbances in the sea which occurs from time to time. Rain-storms, cyclones, floods and tidal bores are all natural phenomenon and their recurrence cannot be ruled out. Such natural hazards are responsible for the loss of millions of lives and damages to the properties. Man must therefore, learn to plan and build safely to counteract the devastation which can be caused by these forces of nature. This paper describes the simulation for the extent and depth of flooding in some portion of the Karachi city lying in the catchment area of Malir River due to rainfall event of the year 2007, change in the mean sea level at Karachi coast for the years 2025, 2050, 2075 & 2100 in accordance with the report of Intergovernmental Panel on Climate Change (IPCC) and due to rise of 6m in mean sea level and its backward flow through the estuary of Malir River. A distributed physically based hydrological model named "Institute of Industrial Sciences Distributed Hydrological Model" (IISDHM) was employed for the simulation of flooding. For the flood inundation modeling of a part of Karachi city lying in the catchment area of Malir River, a watershed having 1690 km^2 area was delineated. The calibration and validation of the model was carried out for the rainstorms of the year 2007 & 1977 and the maximum simulated flood inundation depths were computed as 2.89 m & 4.41 m on Super Highway Bridge and Haji Shah Ali Goth, respectively. Flood inundation maps for the years 2007, 2025, 2050, 2075 and 2100 were prepared. The results for the future scenario reveal that mean sea level rise in next hundred years will not cause any increase in the flood inundation depths within the simulated watershed boundary of Malir River. However the maximum simulated flood inundation depth for the scenario of 6m rise in mean sea level was computed as 4.41m.

Key Words: Climate Change, Mean Sea Level Rise, IISDHM, Flood Modeling, Flood Inundation Depths, River Malir, Karachi

1. Introduction

Climate change is expected to enhance the frequency of floods across the globe (Drogue, 2004). The economic assets located within flood-prone & coastal areas will be at higher risk of damages due to the enhanced flooding. There is eminent need to understand the risk of enhanced flooding for planning of possible mitigation strategy for the betterment of the population. Flooding is one of the most disturbing natural hazards because the number of population affected by the flooding outnumbers the population affected by the other natural hazards such as earthquake, land sliding, volcanoes, etc. Flooding devastates cities, roads and agriculture every year in various parts of the world. Numerous precious lives are lost due to this repeated menace. The estimate of indirect economic and social damages is even more difficult to asses. Need is there to comprehend the underlying causes of floodings, and to rationalize the distributed characteristics of this hazard. Quantifying flooding with distributed models will help in planning efficient mitigation and preventive measures to reduce the impacts of flooding. Intergovernmental Panel on Climate Change (IPCC, 2001) predicts, based on the intensive study, that mean sea level may rise as much as 88cm by the end of 21st century (Figure 1).

Sea level rise, also due to low & high tides, has many adverse impacts on the coastal population and environment such as saline water intrusion, erosion of shorelines, amplified intensity and frequency of coastal flood inundation. Coastal zones are expected to be highly vulnerable to climate change in future owing to the rapid urbanization and coastal zone development. The frequent extreme weather events are also expected to endanger human lives as well as dampen the economy of these coastal cities. Many of the low lying coastal cities in South-East Asia, which are located at the estuary of rivers and frequently affected by floods, are under greater threat of severe floods due to sea level rising. Karachi is one of the low lying coastal cities which is also located at the estuary of Malir River and is under greater threat of severe floods due to sea level rising and backward flow of sea water through the estuary.

Effect of climate change will be more prominent on the cities in the marginal areas like the coastal cities in the world. About 55% of the world's coastal cities with population between 1-10 million people are in Asia. And about 83% of the megacities (more than 10 million People) of the world are also in Asia. It is estimated that by 2015, half of the world's megacities will be in Asia, most of which will be coastal (APN, 2004).

Karachi is one of the highly populated cities of the Asia. It is the largest city and economical hub of Pakistan and is one of the ten most populous cities of the world. On the whole the weather of Karachi is pleasant though occasionally sultry. The coastal zone of Pakistan covers a length of about 1046 km in between 62°E to 68°E longitudes. The average January temperature is 18°C, whereas the June temperature varies from 27°-32°C, which is to be considered as the hottest month for the coastal area. The area has an arid climate with mild winter and hot summers Consequently its climate is marked with scanty and unreliable rainfalls. The average annual rainfall over the coast line varies from 125-250 mm. The winter rainfall varies from 25-125 mm, where the monsoon rainfall varies from 25-250 mm. The monsoon rainfall increases with the increase in longitude along the coast line, whereas, winter rainfall decreases with the increase in longitude. The urban population density along the coast line varies from 10 to more than 7000 persons/km^2 (APN, 2004).

In recorded history, the rainstorm which occurred on 30th June, 1977 has been of the highest intensity and the severest. In only a short duration of 7 hours 9.4 inches (235mm) of rainfall was recorded. It caused wide spread inundation in low lying settled areas. Unfortunately, the rainfall on 30th June 1977 occurred at a time when the bed of Malir River had already been saturated by the previous rain in the catchment. This unhappy synchronization coupled with high tide in the sea created worst possible condition. Thousands of buildings and ancillary structures particularly along Malir River were damaged /destroyed. In addition, the rainstorm took a heavy toll on life and left behind a trail of miseries.

This paper describes the effect of the global warming in terms of mean sea level rise at the flood conditions of the some part of the Karachi City lying in the simulated watershed boundary/catchment area of Malir River, using the Institute of Industrial Sciences Distributed Hydrological Model" (IISDHM).

Model Description

IISDHM is a physically based distributed hydrologic model integrating the overland flow and open channel flow components which was further modified by Dutta *et al.* (2000). A number of studies have employed the distributed hydraulic modeling for watersheds analysis. Dutta and Nakayama (2009) have analyzed the effects of grid resolution on channel flows while Zhang et al (2009) have linked the distributed model with the dynamic flow routing model. Hassan, Tanaka and Nobuyuki (2009) successfully employed the distributed water balance model for Arakawa River basin, in Japan. These applications of IISDHM model for various watersheds shows the general nature of the model, and its wise acceptability. The schematic representation of interlinking of various components of IISDHM is shown in Figure 2.

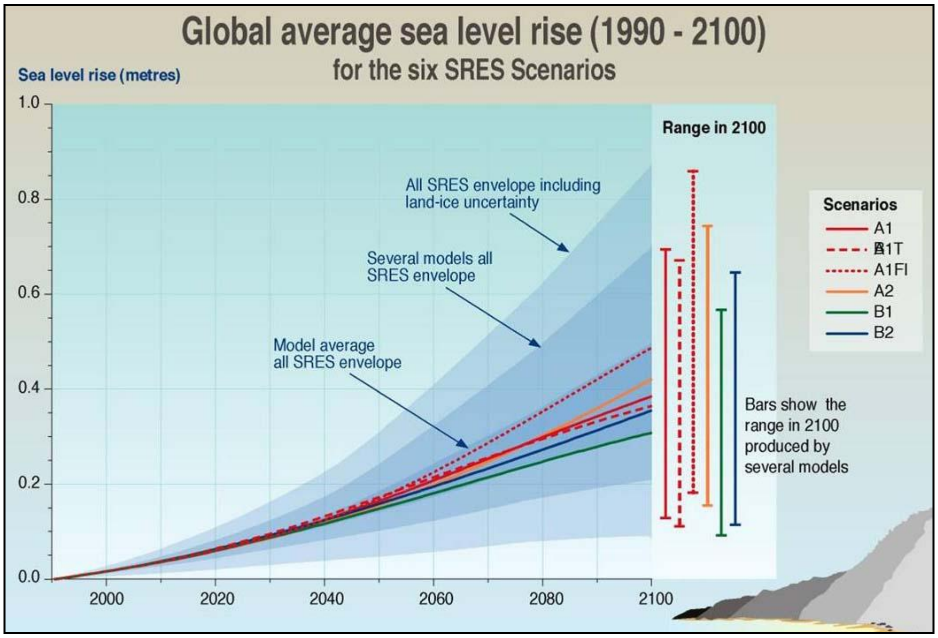

Figure 1: Possible increase in sea level rise due to global warming considering various scenarios (IPCC, 2001)

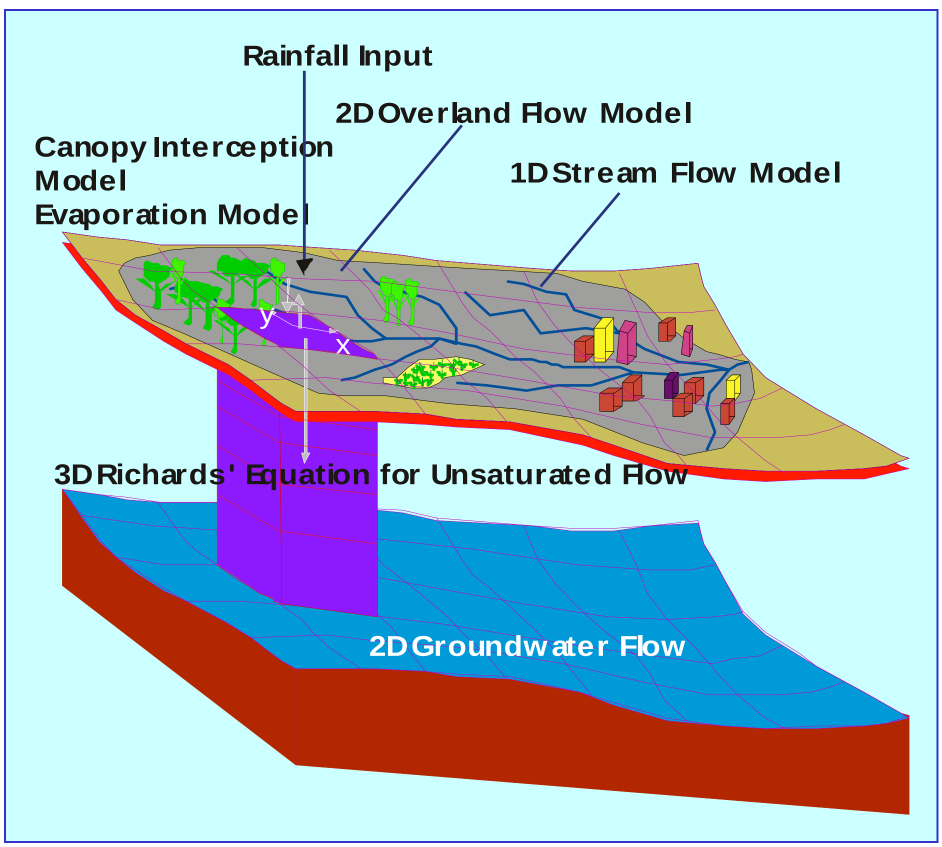

Figure 2: Interlinking of various components of IISDHM

The governing equations for the river flow and overland flow are 1-D Saint Venant's equation and 2-D Saint Venant's equations with diffusive wave approximation. Fully-implicit finite difference schemes were used to solve the governing equations of open channel and overland flow. This model is applicable in the case of converging river network. Water level and discharge in river and flood plain are calculated using explicit solution scheme. Mass conservation equation (continuity equation) is given below:

$$\frac{\partial Q}{\partial x}+\frac{\partial A}{\partial t}=q \tag{1}$$

Where Q is the discharge through the cross-sectional area A, x is the distance along longitudinal direction of flow, t is the time & q is the lateral inflow or out flow distributed along the x-axis of the waterway. Momentum equation in conservation form is given below:

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}[\frac{Q^2}{A}]=-g(\frac{\partial Z}{\partial x}+S_f) \tag{2}$$

Where Z is the water surface elevation with respect to datum, g is the gravitational acceleration constant and S_f is the frictional slope.

The governing equations for the two dimensional (2D) gradually varied-unsteady flow can be obtained from the conservation of mass equation and the momentum equation. Overland flow equations are the 2D version of 1D open channel flow Saint–Venant's Equation's and can be written as:

Mass conservation equation (continuity equation):

$$\frac{\partial uh}{\partial x}+\frac{\partial vh}{\partial y}+\frac{\partial h}{\partial t}=q \tag{3}$$

Momentum conservation equations are given below:

In the X-direction:

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+\frac{\partial u}{\partial t}=-g(\frac{\partial Z}{\partial x}+S_{fx}) \tag{4}$$

In the Y-Direction:

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+\frac{\partial v}{\partial t}=-g(\frac{\partial Z}{\partial x}+S_{fy}) \tag{5}$$

Where, u & v are velocities of flow in X and Y directions and S_{fx} and S_{fy} are friction slopes in X and Y directions, respectively.

Method of Diffusion analogy (G. Joos, 1950) based diffusive approximations of 1D and 2D Saint–Venant's Equations are used in river and surface flow routing by solving implicitly the grids respective equations through finite difference schemes with a uniform network of squares.

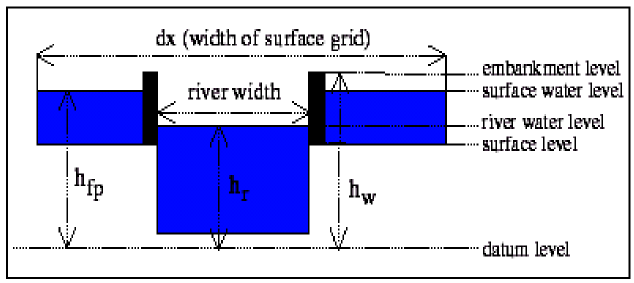

Figure 3: Concept of interaction between floodplain and river grid in IISDHM

Figure 3 is showing the concept of exchange of flow from channel network to/from the floodplains. It employs the compartment concept in which the floodplain is divided into number of compartments along the river network. The flow from the flood plain to river and vice versa is controlled through broad crested weir and depends on the water levels across the weir. One dimensional diffusive wave model is used for computation of water levels in river, while two dimensional diffusive model is employed for overland flow computations. Simple storage routing equation (6) is used for simulation of flow from/to the flood plain & the river network.

$$V_l^{t+1}=V_l^t+(I^{t+1}-O)\Delta t \tag{6}$$

where V_l is representing water volume in flood plain compartment at time $t+1$ or t depending on the water elevation, I represents inflow from the river to the adjacent floodplain compartment, and O is the outflow from the floodplain to the adjacent river network (Dutta et al., 2005).

In IISDHM the potential evapotranspiration is calculated by the Kristensen and Jensen Model (1975) using the land use data, incipient soil moisture, and local evaporation data,. If the rainfall exceeds the infiltration capacity of the soil or ground water level reaches to the surface level, the surface flow is generated. The surface flow is then routed by Saint Venant's equation (diffusion approximation) which supplies lateral flow to the river.

The subsurface flow in IISDHM is routed by Richard's equation. The space between ground level and ground water level is divided into number of layers for ground water modeling. The ground water flow thus modeled as quasi-three dimensional flow, where each cell in each layer can have its own distributed physical characteristics. Geographic Information System is extensively used for preparation of the input files and for presentation of the outcomes/results (Jha et al., 1997).

The inundation maps for the present scenario of the year 2007 and future scenario of rise in mean sea levels for the years 2025, 2050, 2075, 2100 and scenario when 6m rise in the mean sea level due to high tides, were prepared for the simulated watershed boundary of the Malir River. The GIS maps were prepared in the form of flood inundation depths and extents over the study area. The observed flow data/water levels at various locations of the streams were used for the calibration and validation of the flood model to predict flood inundation depths and extents with more confidence. Moreover, maps showing the flood inundation depths due to rainfall were developed.

3. Study Area

Karachi, the provincial capital of Sindh is the coastal city of Pakistan and is located on Arabian Sea at the extreme west end of the Indus delta between north latitude 29°-51' and east longitude 67°-04', out of the mighty Indus Basin which joins the Arabian Sea a few hundred kilometers South East of Karachi. It is famous in one of the top ten cities of the world with respect to size, population, social and economic importance. It is the largest and fastest growing mega city of Pakistan with a population of over 16 million (Population, 2006). The average population density of Karachi is 6666 persons/km^2 with the population growth rate of about 4%. Its geology consists of sedimentary rocks having two ranges known as Kirthar range and Pub range. The soil of Karachi city are classified into two types, the loamy sandy and gravelly soils of river valleys and alluvial cones near the coast line and shallow loamy gravelly soils and rock outcrops plateau. It lies in the semi-arid zone; consequently its climate is marked with scanty and unreliable rainfalls. But because of its location in the coastal belt over a length of about 1,046 kilometers in between 62°E to 68°E longitudes, heavy rainfalls of a high intensity are experienced on occasions. There are two non-perennial rivers crossing the thickly populated city areas before out falling into Arabian Sea., the Lyari River and the Malir River. Another river, the Hub River lies in western boundary of Karachi. New settlements are now reaching this boundary due to lack of land in the inner part of the city. Malir River crosses the thickly populated city areas consisting of Malir Zone i.e. Kashmir colony, Akhtar Colony, Azam Basti, Mehmood Abad, Manzoor Colony, Liaqat Ashraf colony, Darigh Colony No.1,2,3, Darigh colony (Azeempura), Darigh Colony (Millat Town) Malir, Haji Qasim Goth, Sammra Goth, Mullah Dad Goth, Lassi Goth, Rehmania Colony, Qayyum Abad, Gulzar Colony, Bilal Colony, Haji Muhammad Panwar Goth, Haji Shah Ali Goth, Kachhoor Colony, Sharafi Goth, Future Colony and Charagh Colony.

The Malir River, which has a catchment area of about 1974 km^2 traverses along the South -Eastern Boundary of the city of Karachi. The catchment area of Malir River is comparatively large and extends up to 112 kms towards North of Karachi as shown in Figure 4.

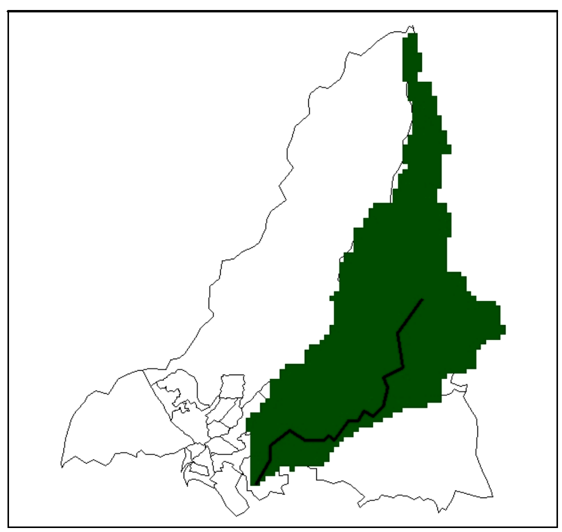

Figure 4: Map of Karachi city showing the River Malir and its watershed

Since the catchment of this river is located in the Karachi, the metropolitan city is facing with the threat of floods, soon after experiencing a rainstorm in the river catchment. The Malir River observed flooded during monsoon season and there are katchi abadies settled along the left and right banks of the river and some industrial units. After the occurrence of a torrential rainfall, rain water stays over the roads for few days due to insufficient drainage capacity of the storm sewer network slightly disturbing the daily life routines and causes slight damages to the road network etc. The width of river is about 200 m from upstream side at Super Highway Bridge and 1000m from the downstream side near Jam Sadiq Bridge. Length of reach between two sections is around 305m, its side slope was 70 degree, the maximum height of the 2007 flood was recorded here was around 3.9 m as shown in following graph describing the flashy nature of Malir River (Figure 5).

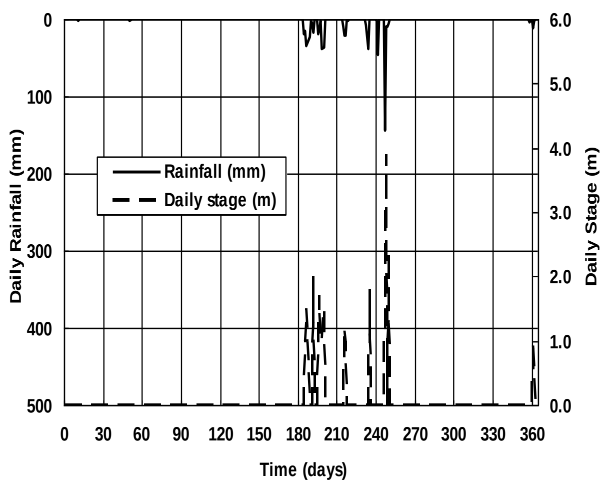

Figure 5: Stage hydrograph showing the flashy nature of the floods in Malir River at Super Highway Bridge for the Year 2007

The System of Malir River is made up of major streams i.e. Mol and Khaddeji and other tributaries ,Konkar,Thaddo and Sukhan join it in the lower reaches. The system having total catchment area of about 1690 km^2 flows southwards and westwards and passes through Gizri Greek tidal estuary and discharges finally into the Arabian Sea. The catchment of Malir River area has a rugged terrain. The middle part is made of sediment deposits comprising of coarse, conglomerate and sand stone, clay-stone and limestone, while the lower plain is composed of alluvial deposits. In the lower plain the River is wider and shallower and it gets braided. The basin comprises of rocky waste-land covered with sandy soil. The vegetation is in the form of shrub trees and bushes. The lower part has good grass cover which gradually diminishes towards south and is full of orchards and vegetable patches.

4. Data Sources

Two types of data were collected i.e. temporal data and spatial data. Temporal data consists of rainfall data, evaporation data, discharge / stage data, flood inundation depths and low & high tide data. Rainfall data at Model Observatory Station (MOS) Karachi Air Port for the years 2007 and 1977 were collected from Pakistan Meteorological Department, Regional Meteorological Centre Karachi. Automatic Weather System at Karachi Air Port operated by PMD as shown in Figure 6.

Figure 6: Automatic Weather System at Karachi Airport by PMD

However, hourly rainfall data was collected from a rain gauge at Model Observatory Station Karachi Air Port. Hourly data for the year 1977 was not available and hence it was generated keeping the same distribution as it is in hourly data. Pan evaporation data were collected from Pakistan Meteorological

Department and Sindh Irrigation Department, Karachi. Discharge/stage data for the years 2007 & 1977 were collected from Irrigation & Power Department Research Division Government of Sindh, Karachi. Flood inundation depths were identified from the past flood marks physically by visiting the Malir River site and senior citizens were interviewed to know the maximum estimated flood level in the area for the year 2007 & 1977 as shown in the Figure 7.

Figure 7: Stream Gauging Station at Super Highway Bridge across river Malir

Low & High Tide data (hourly) for the year 2007 and 1977 were collected from the National Institute of Oceanography at locations Lat 24º 48′ 00″ N & Long 066º 58′ 00″ E.

Topographical parameters were extracted by using the GTOPO30 (http://edcdaac.usgs.gov/topo30/topo30.html). GTOPO30 is a global Digital Elevation Model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). The land use data used for the modeling is USGS (United States Geographical Survey's) Earth Resources Observation System (EROS) Data Centre, the University of Nebraska-Lincoln (UNL) and Joint Research Centre of European Commission, of about 1 km resolutions. For Malir River watershed there are four land use types and the major land use is Shrub-land having 90.7% of the total area (Table 1).

The Soil type data of International Soil Reference and Information Centre (ISRIC) was used for the modelling. It consists of homogenized, global set of 1125 soil profiles. The data is available at relatively coarser resolutions of 5 minutes (about 10 km). For the study area the soil map was re-sampled to 1 km. There are total two soil types in the watershed. Soil codes with their textural classifications are presented in Table 2.

Table 1: Land use related Calibrating Parameters

Landuse Code	**Landuse Type**	Area (%)	**Leaf Area Index**	**Mann-ing's n**	**Root Depth (cm)**
1	Urban	**3.1**	0.0	0.015	0
2	Dry land & Pasture	**3.9**	1.5	0.030	0.5
8	Shrub land	**90.7**	2.0	0.045	1
19	Barren Land	**2.3**	0.0	0.015	0

Table 2: Textural Classification of Malir River Watershed

Soil Code	**Sand (%)**	**Silt (%)**	**Clay (%)**	**Textural Soil Type**	**Saturated water content**	**Hydraulic Conductivity (m/s)**	**d_{50} (μm)**
1	43	33	24	Loam	0.463	9.4d-07	1.17
2	44	35	21	Clay Loam	0.464	2.7d-07	1.29

The author collected the bed material samples from the Super Highway Bridge at Malir River to assess grain size distribution, Manning's 'n'& Hydraulic conductivity 'ks' of soil. The collected bed material sample was analyzed in the Geotechnical Engineering laboratory, and the obtained results of the grain size distribution are shown in Figure 8.

5. Methodology

Daily/hourly rainfall data, the daily discharge/stage data (water levels) were collected from their respective departments as discussed earlier. To obtain the highest flood marks achieved in the respective years, interviews were made from the senior citizens of the area. Using Digital Elevation Model 1000 x 1000 m grid resolutions, the flow direction and flow accumulation maps were prepared. Assuming some suitable value of the threshold, river network for the area was generated. A point coverage was generated for the stream gauging stations. For the Malir river, watershed was delineated by selecting the

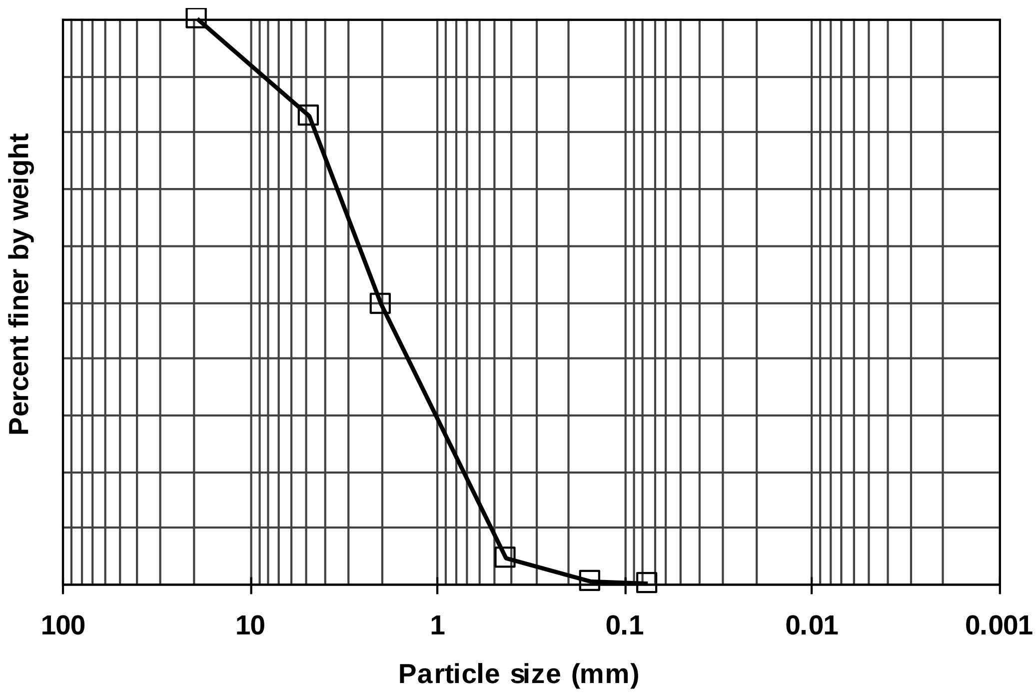

Figure 8: Particle Size Distribution Curve for bed material of river Malir at Super Highway Bridge

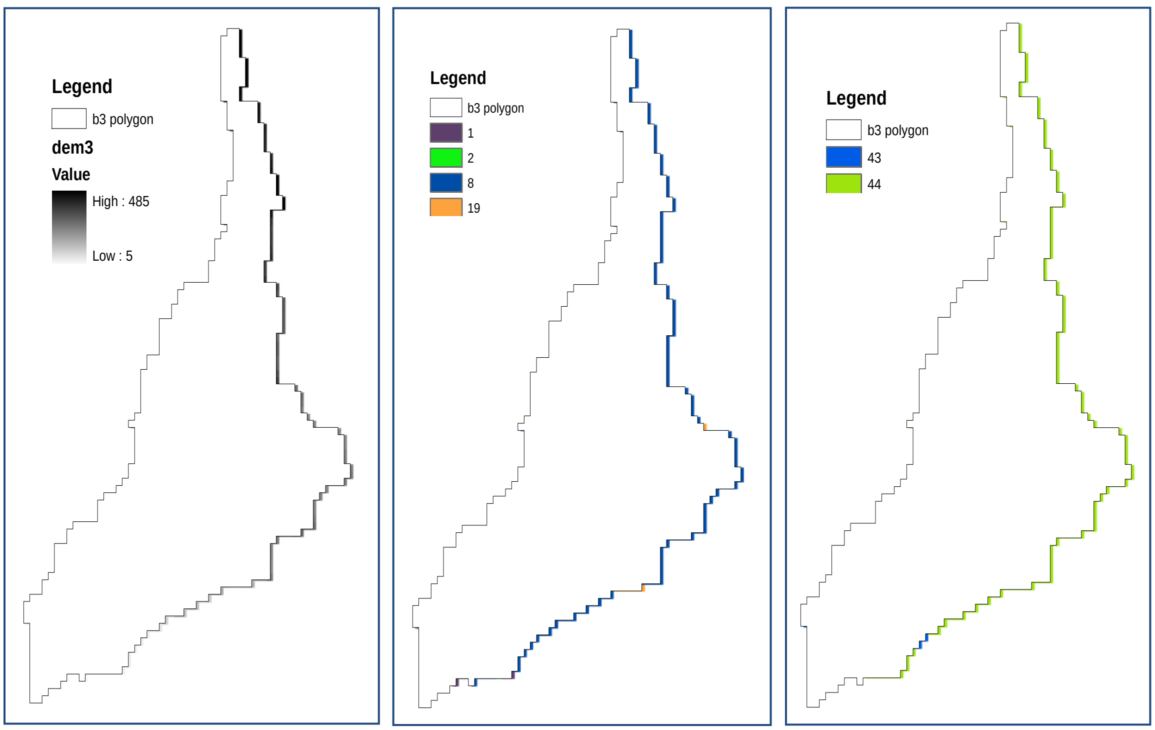

Figure 9: DEM, Land-use map and Soil map of the Malir watershed

pour point at the lowest possible location. A DEM map with river network, land-use map and soil map for the Malir River watershed were prepared and are shown in the Figure 9. After preparing the temporal and spatial data, setting up of the IISDHM Model for the Malir River watershed was carried out. It comprises of the four schematic steps i.e. Input data preparation, Model Calibration, Model Validation and Model Application.

6. Input Data Preparation

A flow diagram showing the setting up of the Model is presented in Figure 10. At this stage of setup, for flood inundation modelling spatial and temporal input dataset files in appropriate formats were prepared.

The major spatial dataset required were topographic, watershed boundary, land-uses, soil types, river network and geometric data. Spatial dataset files were prepared using GIS software. The temporal dataset consists mainly of rainfall, evaporation, leaf area index, root depth, root depth function, upstream and downstream boundary condition for the river etc.

7. Model Calibration

The Model was calibrated for the year 2007 flood inundation depths at location of Super Highway Bridge at the Malir River watershed. The rainfall distribution and oceanic tide levels on 9th and 10th August, 2007 were used as downstream boundary condition for the calibration of the IISDHM as shown in Figure 11. On the basis of the collected observed data, the highest flow/stage was observed in the 2nd week of August, 2007 in Malir River. Therefore, the flood simulation was carried out for two days i.e. from 9th to 10th August, 2007 using the actual rainfall data. The maximum intensity of rainfall was observed as 45 mm/hr and oceanic tide levels varied from 0.2 m to 2.89 m. The simulated inundation depths were compared with the observed flood depths in 2007.

8. Model Validation

After successful calibration of the Model, it was validated for the year 1977 at location of Haji Shah Ali Goth in the Malir River Watershed. The flood simulation was carried out using the actual rainfall for two days i.e. from 29th to 30th June, 1977. The rainfall distribution and oceanic tide levels on 29th and 30th June, 1977 were used as downstream boundary condition for the validation of the IISDHM as shown in Figure 12. On the basis of the collected observed data, the highest flow/stage was observed in the last week of June, 1977 in Malir River. Therefore, the flood simulation was carried out for two days i.e. from 29th to 30th June, 1977 using the actual rainfall. The maximum intensity of rainfall was observed as 50.6 mm/hr and oceanic tide levels varied from 0 m to 3.0 m. The results of the calibration and validation of the IISDHM Model are shown in Table 3.

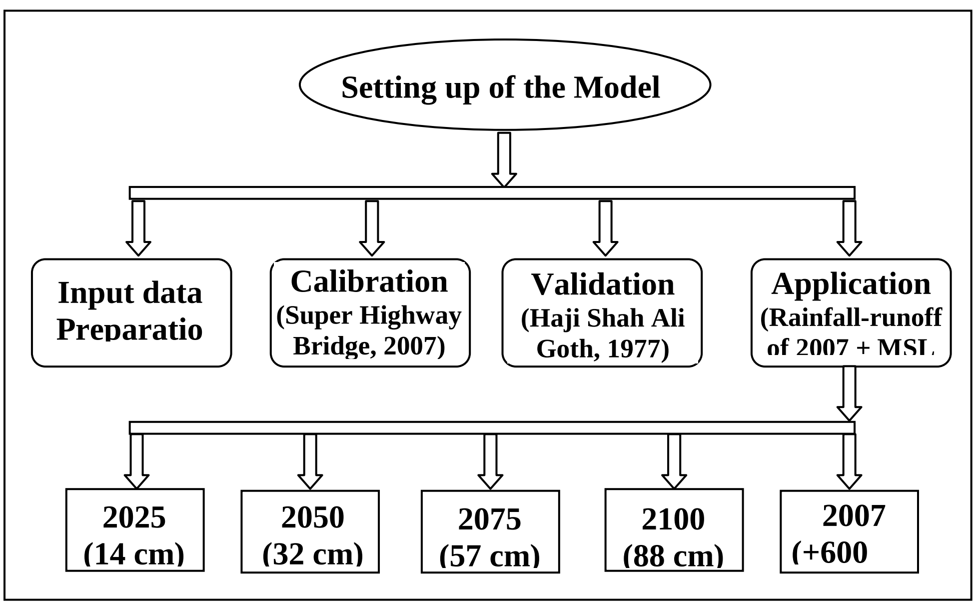

Figure 10: Flow diagram showing the Setting up of the Model for Malir watershed

Table 3: Calibration and Validation results of the IISDHM

Sr. No.	Simulation	Site Name	Rainstorm	Flood Depth (m)	
				Simulated	Observed
1	Calibration	Super Highway Bridge	9-10 Aug, 2007	2.89	2.89
2	Validation	Haji Shah Ali Goth	29-30 Jun, 1977	4.40	4.41

9. Model Applications

After calibration and validation, the Model was applied for future scenarios of possible mean sea level rise due to climate change in future. The change in downstream boundary condition (mean sea level rise) is considered according to IPCC (2001) and simulations were carried out. For the simulation, the observed mean sea level for the year 2007 was considered as present condition, and the mean sea levels were increased by 14, 32, 57, 88 cm for years 2025, 2050, 2075, 2100 and 600 cm, respectively**.** Finally, the flood inundation maps for the study area were developed for the year 2025, 2050, 2075, 2100 and for the scenario of 600 cm mean sea level rise within the delineated boundary of the watershed.

10. Results and Discussion

The results of the Model for calibration and validation are shown in the tabular form in Table 3. For calibration, the simulated inundation depth at Super Highway Bridge is 2.89 m, which is same as the observed at this location in the rainstorm of 2007. For validation, the simulated flood inundation depth at Haji Shah Ali Goth is 4.40 m which is very close to the observed at the site in 1977. These results show that Model was well calibrated and validated for the Malir River watershed and hence can be confidently used for the prediction of flood inundation depths for any possible climate change scenarios.

The simulated results of the Model for calibration and validation for years 2007 and 1977, respectively are also shown in the form of spatial distributions in Figure 13. The maximum simulated flood inundation depth due to August, 2007 rainfalls in Malir river watershed is 4.82 m. Whereas, the maximum simulated flood inundation depth due to August, 1979 rainstorm in Malir River Watershed is 4.85 m.

Figure 14 depicts the simulation results of the Model Application for years 2025 and 2050, respectively. The maximum simulated flood inundation depth in both cases is 482 cm. Figure 15 depicts the simulation results of the Model Application for years 2075 and 2100, respectively. The maximum simulated flood inundation depth in both cases is again 482 cm. It shows that increase in mean sea level due to the Global warming will not cause any additional inundation in the Malir watershed area.

Figure 16 presents the simulation results of the Model Application for year 2007 with an assumed increase in mean sea level by 600 cm. The maximum simulated flood inundation depth is 485 cm. It shows that such an increase in mean sea level due to the Global warming will result in additional inundation in the Malir River watershed area**.**

11. Conclusions

The Institute of Industrial Science Distributed Hydrological Model (IISDHM) can simulate well flood inundation depths for the Malir River watershed.

Mean sea level rise in the next hundred years will not cause any increase in flood inundation depths within the simulated watershed boundaries of the Malir River, hence area of Karachi city coming in the watershed of Malir River seems to be safe due to possible increase in mean sea level in the future 100 years. However, an increase in mean sea level by 600 cm will cause flood inundation in the southern part of the Malir river watershed.

12. Recommendations

Flood inundation modeling studies may be carried out by taking into consideration the increase in extremity of the rainfall pattern duo to Global warming.

It is further recommended that the climate change scenarios should be further studied using better resolution data, and the remedial measures should be proposed which must be the part of the policy documents of the country while planning future infrastructure of the Karachi city in the catchment area of Malir River.

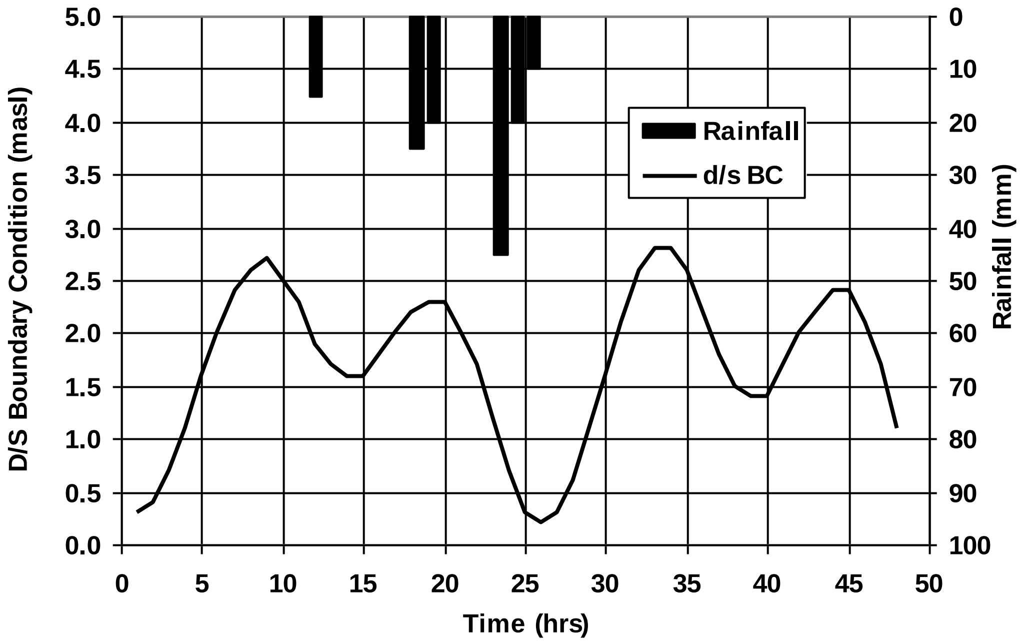

Figure 11: Rainfall distribution and oceanic tide levels on 9th &10th August, 2007 used for the calibration of the Model

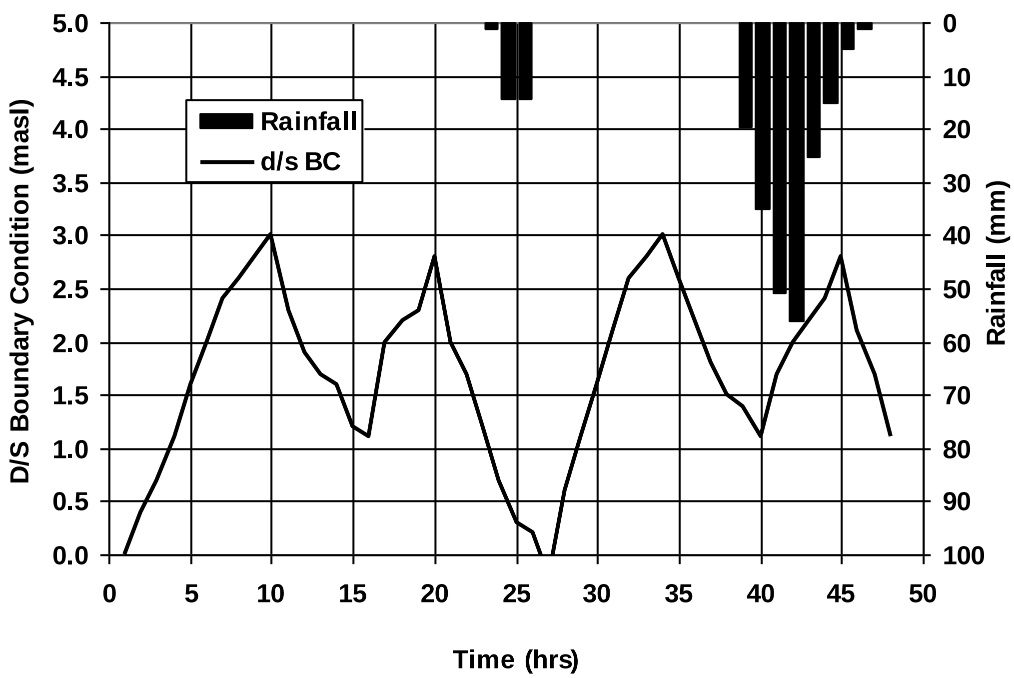

Figure 12: Rainfall distribution and oceanic tide levels on 29th & 30th June, 1977 used for the validation of the Model

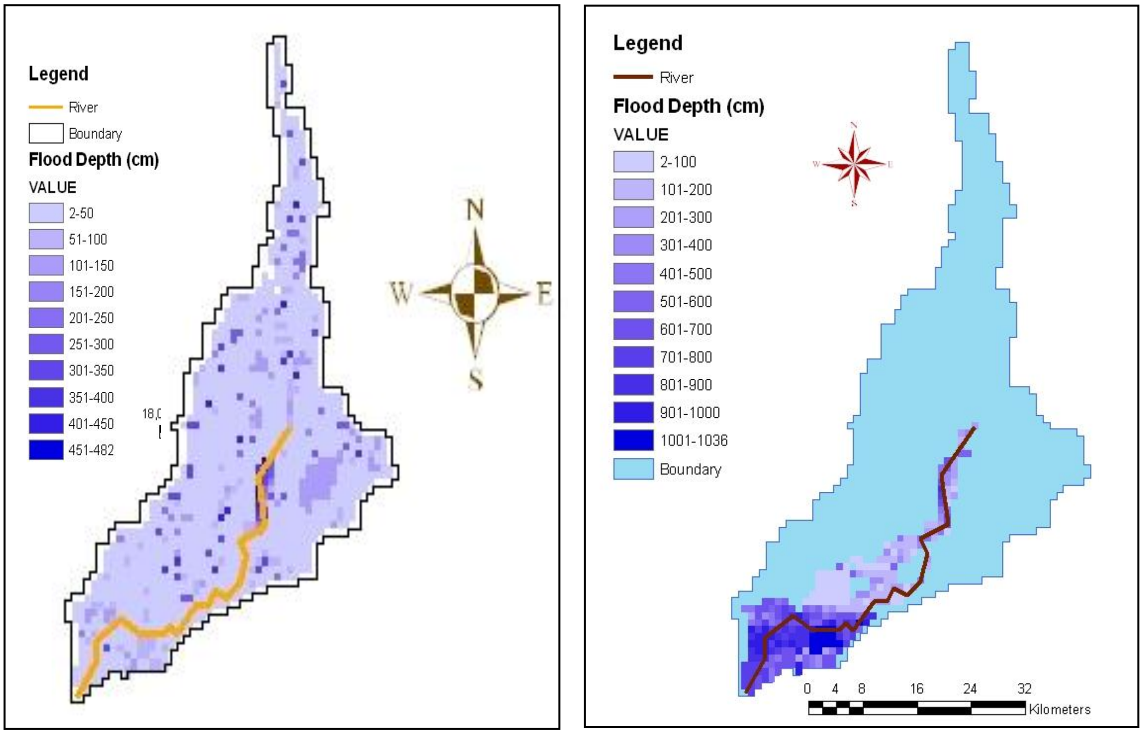

Figure 13: Results of the Model Calibration and Validation for years 2007 and 1976, respectively

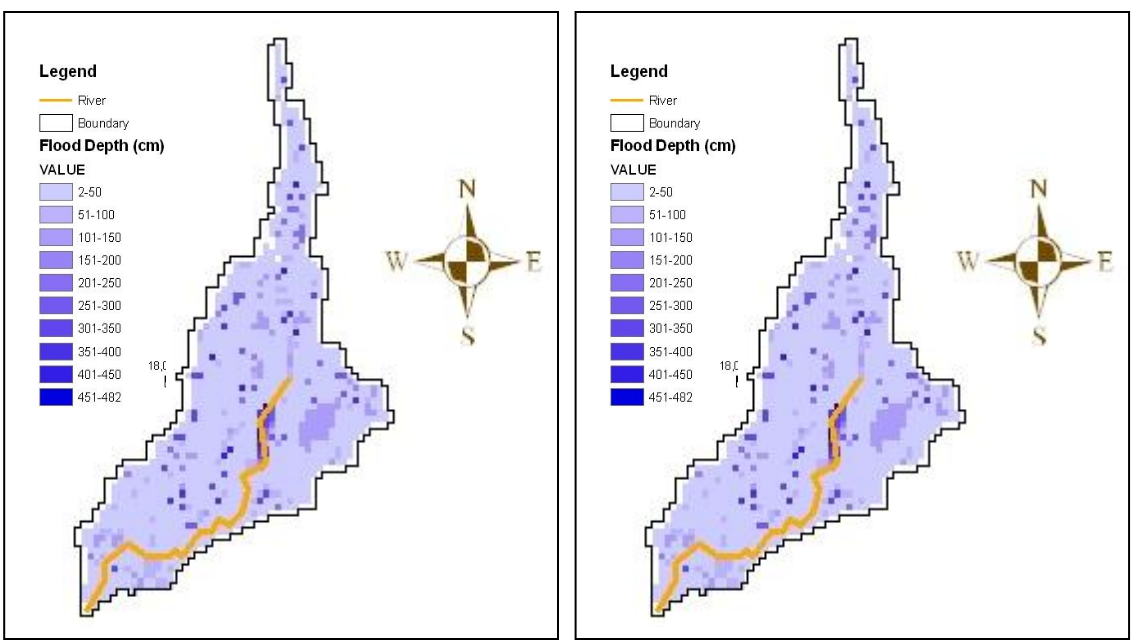

Figure 14: Results of the Model Application for years 2025 and 2050, respectively

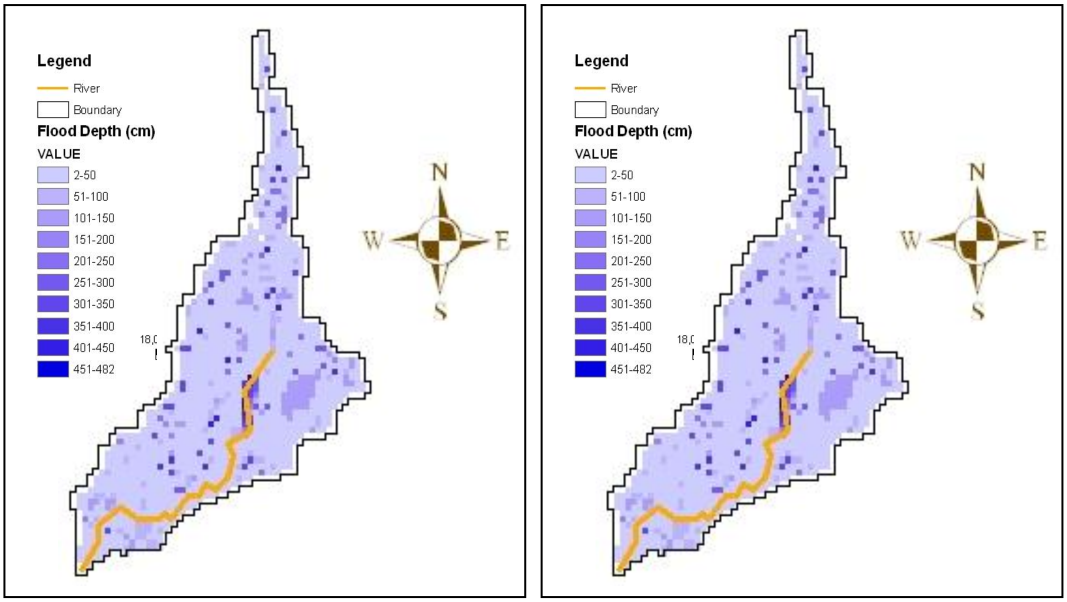

Figure 15: Results of the Model Application for years 2075 and 2100, respectively

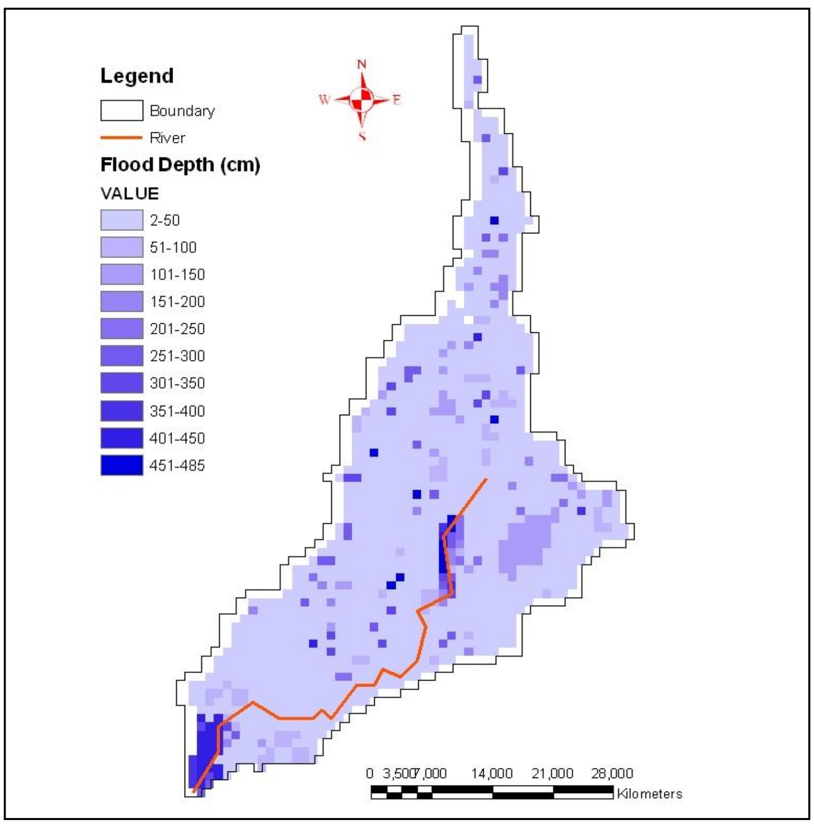

Figure 16: Results of the Model Application for year 2007 with increase in mean sea level by 600 cm

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