Flood Risk Mapping of Kadalundi River Basin Using GIS

Sisir P, K Balan
Dept. of Civil Engineering
College of Engineering Trivandrum
sisir43@gmail.com , drkbalan@gmail.com

Abstract— **In recent years flood has become most common among the natural hazards. The study area, Kadalundi watershed, has thickly populated flood plains. The present study aims to prepare flood risk map of study area based on multi criteria analysis using Geographic Information System (GIS) and Remote Sensing. The flood intensity for different return period are arrived from historical rainfall extremes using Soil Conservation Service (SCS) Curve Number method with the help of GIS layers. The water shed was modelled and analysed in Hydrologic Engineering Center's River Analysis System (HEC-RAS). The floodplain maps for the different estimated discharges were generated. The important structures falling in flood plain area and also the high elevated safe zones within the flood plain are also mapped. The flood risk map can be used for planning control measures for future floods.**

Keywords—flood mapping; GIS; HEC RAS; scs curve number method

I. INTRODUCTION

Flood remains one of the major causes of natural disasters affecting societies. Flood has been ranked "first" out of sixteen natural disaster type responsible for either one million dollars damages or injuries after a study of the major natural hazards on worldwide. Since man is unable to control the basic atmospheric processes which produce most floods, he has attempted to adjust to the hazard by means of flood alleviation projects with land-based phase of the hydrological cycle. To achieve this flood risk maps is one of great help. It is stated that through the application of high technology and the massive capital investments, flood threats to human lives has decreased appreciably in most developed countries.

The management methods to decrease flood hazards are divided into structural and non-structural categories. Various types of structural as well as non-structural measures have been taken up to reduce the damages in the flood plains. The structural measures, such as the construction of embankments, levees, spurs, etc. have not proved to be effective in the long run. On the other hand, whereas, the non-structural measures such as flood forecasting and warning, flood plain mapping, flood hazard mapping, and flood plain zoning may prove to be quite effective in reducing losses from floods. Flood zoning using Geographic Information System as a non-structural method, is an efficient tool for flood damage mitigation management. GIS technology is a well-established tool used in hydrologic modelling, which facilitates processing, management, and interpretation of all available data. In addition, the concerned authorities can use the method as a legal tool to control and apply management and zoning of lands, plan development, decrease flood hazards and protect the environment.

The objective of the study is to identify the areas that are at risk of flooding, to identify the factors that are relevant to current and future flood risks and to prepare flood risk map.

II. LITERATURE REVIEW

A combined system for monitoring and evaluating a flood using geographic information system (GIS) and global positioning system (GPS) and other technologies has been developed in China [11]. Yaclin et al., provided Multi criteria evaluation method for analyzing the regions vulnerable to flood using ArcGIS software [2]. Sinnakaudan et al., discussed making a flood map in Pari River using Arcview software in the field of AVHEC-6 extension [8]. Hansson et al., provided a multi criteria analysis for designing the strategic assessment of flood damage using computerized models [4]. Surjit et al., assessed the risk and vulnerability of flood hazard in Ghaggar basin, India using GIS. The study attempted to propose a Flood Risk Index (FRI), based on factors such as hydrology, slope, soil type, drainage density, landform and land use [10]. Punithavathi et al., prepared a flood zone map for Thanjavur from drainage map prepared by survey of India toposheets by making reduction strategies [3]. Pieter et al., created a risk-based methodology to quantitatively assess flood risk based on hydrologic models, land use information and socio-economic data using a Geographic Information System [6]. Aditi Bhadra et al., mapped flood inundated areas using GIS for the Dikrong river basin of Arunachal Pradesh, India, corresponding to different return periods [1]. Ajin et al., prepared flood hazard risk zone maps of Vamanapuram River basin based on multi criteria assessment using remote sensing and GIS tools. Used factors such as rainfall distribution, drainage density, land use, soil type, size of micro watershed, slope, and roads per micro watershed, to prepare flood hazard risk zone map [7].

III. METHODOLOGY

The present study involves the preparation of flood risk map using land use priority setting map and flood hazard priority setting map. The detailed methodology adopted for preparation of flood risk map is discussed in subsequent sections.

A. Flood Risk Map Preperaton

To study the characteristics of the watershed the drainage network is to be delineated. After collecting the data Digital elevation model (DEM) was prepared from the Shuttle Radar Topographic Mission (SRTM) data. In Arc GIS platform the drainage network is derived using Arc hydro tools automatic delineation method. Toposheet can be used as base layer to compare the derived drainage network. The flow diagram of methodology is shown in Fig. 1.

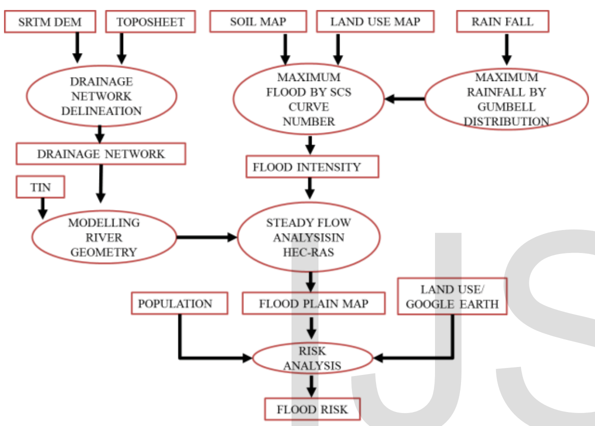

Fig. 1. Flow diagram of methodology

1) Maximum Rainfall intensity calculation : Statistical distributions can be used for probabilistic calculation of rainfall events. Gumbels Extreme Value Type-I distribution, is most commonly used for Intensity Duration Frequency (IDF) relationships. Gumbel distribution uses a probability distribution function,

$$f(x) = \frac{e^{\{-(x-\beta)/\{\propto - e^{\left[-\frac{(x-\beta)}{\propto}\right]}\}\}}}{\propto} \quad (1)$$

The precipitation depth is calculated for a given return period as

$$X = x\ mean + Kt * SD \quad (2)$$

Where, x mean is the mean of annual extreme rainfall events, SD is standard deviation, and Kt is the frequency factor for return period t.

$$\mathrm{Kt} = \frac{-\sqrt{6}}{\pi}\{\, 0.5772 + \ln\ [\ \ln \frac{\mathrm{T}}{(\mathrm{T}-1)}\ ]\,\} \quad (3)$$

Where T is the return period

Previous years extreme rain fall events are used to produce the precipitation data. Using Gumbels Distribution the precipitation for different return periods can be arrived.

2) Flood Estimation : Soil Conservation Service (SCS) curve number (CN) method can be used for flood estimation. The method uses parameters like land cover and soil type and provides the curve number for the basin. The SCS-CN model calculates direct runoff depth (Q) using the following equation

$$Q = \frac{(p - Ia)^2}{(p - Ia + S)} \qquad \text{for P > Ia} \quad (4)$$

Where P is the total depth of precipitation, Ia is the initial abstraction (mm), and S is potential maximum retention (mm).Q=0, for P ≤Ia. The initial abstraction is related to S by the equation

$$\mathrm{Ia} = \boldsymbol{\lambda}\,\mathrm{S} \quad (5)$$

Where, $\boldsymbol{\lambda}$ is an initial abstraction ratio. The values of $\boldsymbol{\lambda}$ varies in the range of 0.1 and 0.3. The value of $\boldsymbol{\lambda}$ has been developed for Indian conditions as 0.3 for Antecedent Moisture Condition, AMC-I and 0.1 for AMC-II & III (Hand book of Hydrology). In practice, the runoff Curve Number (CN) is used to compute potential maximum retention (S) in mm as

$$\mathrm{S} = \frac{254000}{\mathrm{CN}} - 254 \quad (6)$$

3) Hydraulic modelling : Hydraulic modelling can be done with the US Army Corps of Engineers (USACE) Hydrologic Engineering Centers River Analysis System (HEC-RAS). HEC Geo RAS Extension to Arc GIS enables exporting the river geometry from Arc GIS to HEC RAS. For creating the geometry, required data are Drainage network and Triangular Irregular Network (TIN) of the water shed. Along with the geometry data the computed flow data were added to HEC RAS and the analysis were done for different return periods. Post analysis data is exported back to RAS mapper for preparing flood plain map.

IV. ANALYSIS

Flood risk map were prepared as per the above methodology for the Kadalundi watershed, in Malappuram District of Kerala State, India and are discussed in detail below.

A. Study Area

The study area selected is the Kadalundi river basin, Malappuram district, Kerala state, India which is located between latitudes 10°55’38.3”N to 11°11’14.9”N and longitudes 75°50’19.8”E to76°25’32.4”E. The river originates from Western Ghats and meets Arabian Sea at a longitude 75°50’19”E and latitude 11°07’00”N. It is a sixth order river and it drains from an area of 1152square kilometer and has a length of 120 km. Fig. 2. shows the location of the Kadalundi River and its watershed.

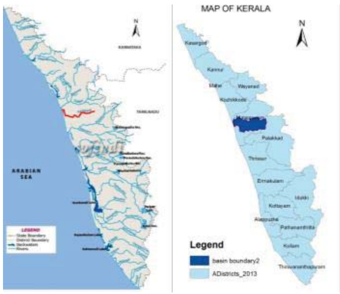

Fig. 2. Location of Study Area

B. *Data Used*

The data used for the flood risk map preparation are: (i) SRTM and Advanced Space-born Thermal Emission and (ASTER) elevation data (2000), (ii) Linear Imaging self-Scanning Sensor (LISS III) images, (iii) Moderate Resolution Imaging Spectroradiometer (MODIS) land cover type product (iv) Rainfall data (v) Kerala Soil map, and (vi) Survey Of India (SOI) toposheets.

SOI toposheets of scale 1:50000 are used as base layer. The study area were covered in toposheet numbers 49 M/16, 49 N/13, 58 A/4, 58 A/8, 58 B/1 and 58 B/5. The SRTM data has 90m and ASTER data has 30m resolution. These are used to create DEM of the study area. Land use map can be derived from LISS III satellite image with a resolution of 25.5m using method of supervised classification. MODIS land cover product directly provides land cover data of 315m resolution. Annual extreme rainfall data of 24hr duration were collected for the years 2005 to 2012.

C. *Preparation of flood plain map*

The preparation of flood risk map include two steps: (i) Hydrologic analysis for flood intensity calculation (ii) Modelling river network in ArcGIS platform (iii) Steady flow analysis in HEC RAS.

1) Flood intensity calculation : the probabilistic maximum precipitation for the watershed was calculated in order to estimate the flood discharge. For this, twenty four hour extreme rainfall events of the past 8 years (2005-2012) were collected. Gumbels distribution is fitted to the data and intensity of rain fall for a return period of 2, 5, 10, 50 and 100 years are arrived at. The rainfall for different durations are obtained from the rain gauge data. The rainfall data is converted to intensity by dividing the rainfall with duration (i = P/t). Table I shows the annual extreme rainfall events data. The mean and standard deviation of the data for all the selected durations is calculated.

The frequency factor (Kt) is calculated for all the selected return periods, based on the Gumbels distribution using (3) and are presented in Table II. The design rainfall intensity was calculated using (2) and are presented in Table III.

TABLE I. TABLE STYLES

SL NO	*year*	*max RF (mm)*		*RF intensity (mm/hr)*	
		24hr	48hr	24hr	48hr
1	2005	208.4	341.1	8.68	7.11
2	2006	166.2	292.1	6.93	6.09
3	2007	153.2	260.3	6.38	5.42
4	2008	233.6	383.1	9.73	7.98
5	2009	283.2	459.0	11.80	9.56
6	2010	17.3	168.7	0.72	3.51
7	2011	111.6	184.8	4.65	3.85
8	2012	78.6	135.2	3.28	2.82
			x mean	6.52	5.79
			SD (S)	3.60	2.35

TABLE II. FREQUENCY FACTOR

Return period (year)	2	5	10	50	100
Kt	-0.164	0.720	1.305	2.594	3.138

TABLE III. RAINFALL INTENSITY

	Return Period Year				
Duration	**2 year**	**5 year**	**10 year**	**50 year**	**100 year**
48hr	5.40	7.48	8.86	11.88	13.16
24hr	5.93	9.11	11.22	15.86	17.82

SCS Curve number method was used to calculate the flood discharge from the rainfall. The requirements for this method are rainfall amount and curve number. To create the Curve Number (CN) map, the hydrologic soil group and land use maps were uploaded to the Arc GIS platform. The hydrologic soil group field from the soil theme and the land use field from the land use map were selected for intersection. After intersection, a map with new polygons representing the merged soil hydrologic group and land use (soil-land map) was generated. The CN values for different land uses and hydrologic soil groups were adopted from Technical Release 55, USDA-NRCS. The appropriate CN value for each polygon of soil-land map was assigned and CN for each sub watershed is calculated. The calculated values are presented in Table IV.

The input hydrologic soil group map, land use map and the curve number map output are shown in Figs. 3, 4 and 5 respectively.

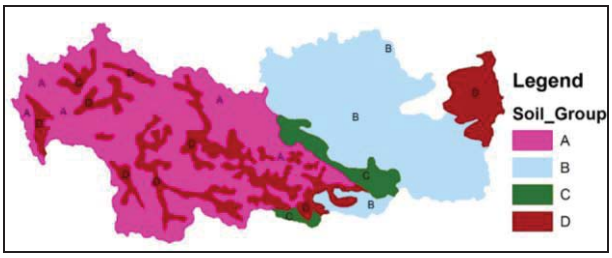

Fig. 3. Hydrologic soil group

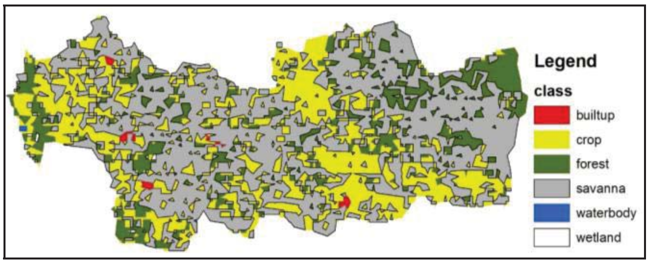

Fig. 4. Land use map

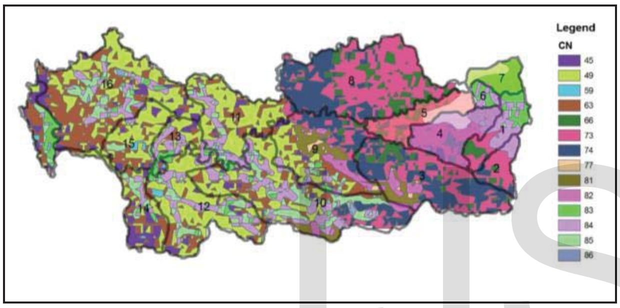

Fig. 5. Curve Number Map

Curve Number for each sub watershed was calculated as

$$CN = \frac{\sum CNi * Ai}{A} \quad (7)$$

Where CNi is the Curve Number of each polygon, Ai is the respective area of polygon and A is the total area of sub watershed. The curve number calculated for different sub watershed was shown in table 4. Flood discharge for sub watershed were calculated using (4), and is shown in Table V.

TABLE IV. CURVE NUMBER FOR SUB WATERSHEDS

sub basin	1	2	3	4	5	6	7	8
CN	76.9	69.2	75.2	66.7	73.2	83	83	74.1

sub basin	9	10	11	12	13	14	15	16
CN	73.0	73.3	65.2	67.5	63.8	72	65.1	67.5

TABLE V. FLOOD DISCHARGE FOR SUB WATERSHEDS

Sub basin	*Area (m2)*	*Flood Discharge q (m3/sec)*		
		100 YEAR	*50 YEAR*	*10 YEAR*
1	34746735.66	155.72	136.92	92.54
2	22514650.72	96.03	83.93	55.47
3	107060479.31	474.35	416.49	280.06
4	33347182.81	140.23	122.35	80.36
5	36929667.98	161.67	141.74	94.80
6	8948384.88	41.37	36.51	25.03
7	20873473.00	96.50	85.17	58.39
8	152329103.79	670.93	588.67	394.78
9	98234922.26	430.05	377.04	252.16
10	145510963.42	637.01	558.49	373.51
11	76815209.39	318.21	277.13	180.79
12	100201795.08	424.40	370.60	244.19
13	29128476.19	119.72	104.17	67.72
14	73361800.00	319.16	279.61	186.47
15	43886519.42	181.80	158.33	103.29
16	155431077.37	658.32	574.87	378.78

2) Modelling River Network : Geometric data is prepared using HEC GeoRAS extension to ArcGIS 9.3. The drainage network is deliniated from Digital Elevation Model. The flow direction map is first generated. Flow accumulation map is prepared from flow direction map, and stream network is deliniated. The delineated stream nework is compared with toposheet. Fig. 6.shows the drainage network.

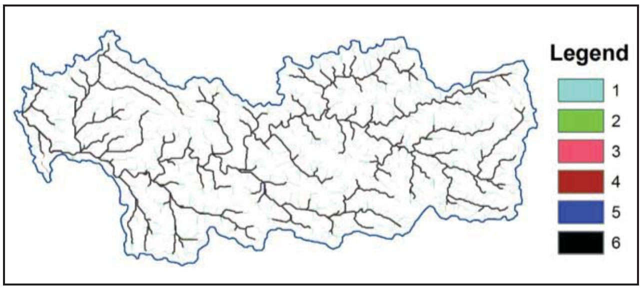

Fig. 6. River Network

TIN map of the watershed was used as the base map to extract the elevation for river cross sections. The entire watershed was divided into six sections based on the network pattern and the discharge on sub watershed were added up to calculate the discharges on each sections. The river geometry modelling is shown in Fig. 7.

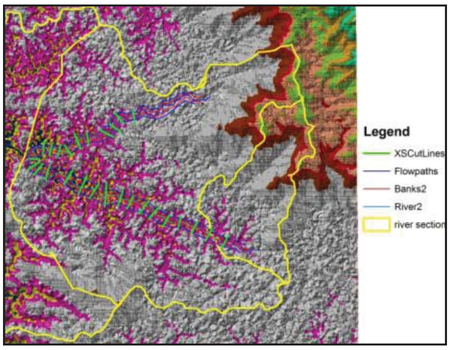

Fig. 7. Modelling the River Geometry

3) Steadyflow Analysis in HEC-RAS : Geometric data were exported to HEC-RAS. Flow data were prepared for three profiles namely 100 year 50 year and 10 year. The discharges added to the river model with the six sections as flowchange points. The data were added for all the three profiles. Steady flow analysis was run. Water surface profile is generated for the three flow profiles. The results are exported back to Arc GIS platform and the inundation area is mapped using RAS Mapper.

The flood risk map is derived by overlaying the slope map, land-use map and population distribution map over the flood plain map of the watershed. The slope map categories ranked from 1 to 5 such that high rank is given for low slope as presented in Table VI. Fig. 8. shows slope map.

TABLE VI. SLOPE CATEGORY AND RANK

Class	*Slope*	*Rank*
1	0-4.83	5
2	4.84-11.44	4
3	11.45-20.91	3
4	20.92-34.44	2
5	34.45-75.49	1

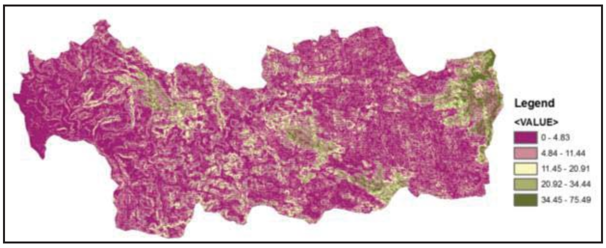

Fig. 8. Ranked Slope map

Ward wise population map were classified to five classes with most populated class having high rank as presented in Table VII. Fig. 9. shows the population map and ranks for each category.

TABLE VII. POPULATIONCATEGORY AND RANK

Class	*Population*	*Rank*
1	62781-41840	5
2	41840-33917	4
3	33917-28935	3
4	28935-23955	2
5	23955-15934	1

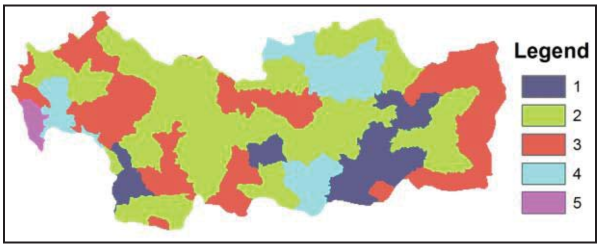

Fig. 9. Ranked Population map

V. RESULTS AND DISCUSSION

The flood plain map shows that 8.6%of the watershed area is inundated by a100 year flood, 6.9% area by 50 year flood and 3.4%area by 10 year flood. At the starting point of 6^{th} order river section the flood plain reaches far from the bank lines and inundates a large area. The floodplain spreads to the downstream end of the river. Figs. 10, 11 and 12 shows the flood plain maps of 10 year, 50 year and 100 year respectively.

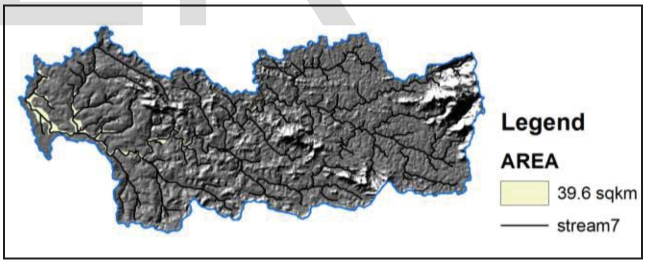

Fig. 10. Flood Plain Map of 10 year

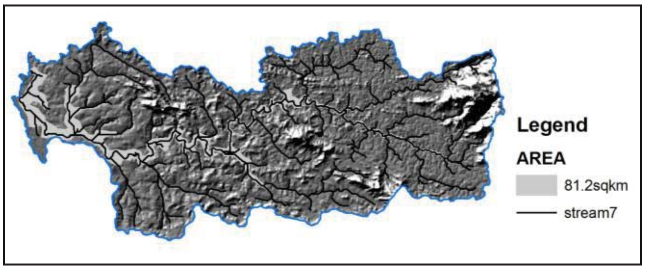

Fig. 11. Flood Plain Map of 50 year

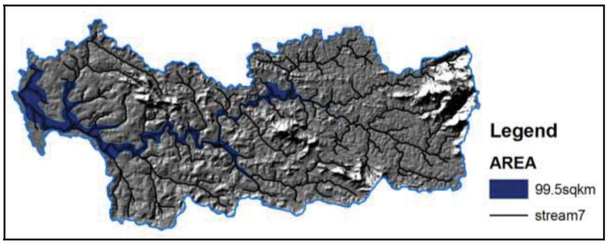

Fig. 12. Flood Plain Map of 100 year

The flood risk map for 10 year,50 year and 100 year flood were shown in Figs. 13, 14 and 15. It was seen from the 10 year flood risk map that 75.5sq km area is under high flood risk. This counts 6.6% of the total watershed area. In the case of 50 year flood, the high risk zone area is 184.1sqkm that is 15.7% of the water shed area. 251.9 sqkm of the watershed that is 21.8% falls under high risk zone of 100 year flood.

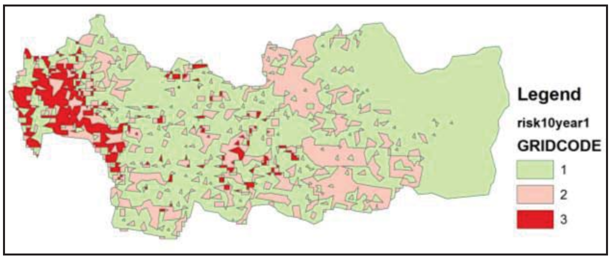

Fig. 13. Flood Risk Map for 10 year flood

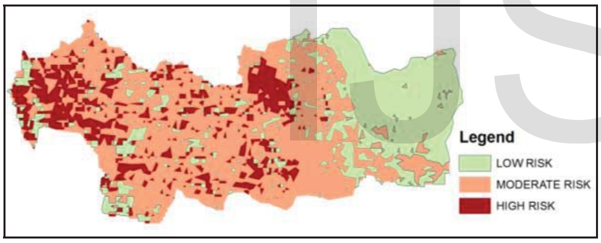

Fig. 14. Flood Risk Map for 50 year flood

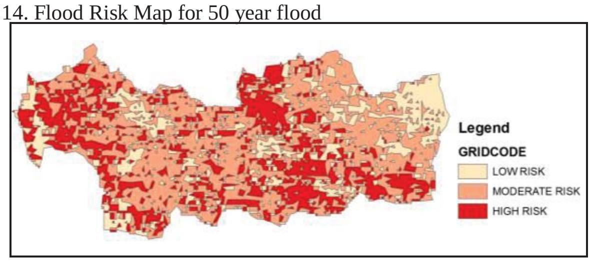

Fig. 15. Flood Risk Map for 100 year flood

VI. CONCLUTION

Having an overall look at the kadalundi watershed one can mention the necessity for the protection of the famous 'kandal' forests and reviving the vegitation that falls in the high risk flood zone. The watershed was found to be in urgent need of preparing evacuation planning and flood control measures. Proper awareness should be provided to the population in the high risk zone. These flood Risk Maps can be used and identified the structures vulnarable to flooding, to take protective measures and the safe structures inside the zone which can be used for immediate rehabilitation in case of flooding.

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