Integrated Multi-parametric Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) based Spatial modelling for Flood and Water logging Susceptibility Mapping: A case study of English Bazar Municipality of Malda, West Bengal, India

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Abstract. Waterlogging as a perennial problem is deep rooted on the urban fabrics of English Bazar Municipality. The present
10 study pertains to vulnerability and risk assessment of flood and waterlogging susceptible areas in a micro or local scale, based on an integrated Analytic Hierarchy Process-Geographic information System (AHP-GIS) category model. For this purpose, a multi-criteria assessment of natural, quasi-natural and man-made factors have been performed. Criterion includes six parameters namely elevation, slope, soil, flow accumulation, land use land cover, density of digitized drain network which are responsible to initiate the waterlogged condition within municipality premises. The weights of all criterion are computed by
15 pair wise comparison decision matrix (AHP). According to their weightage, information of different parameters is superimposed for a final weighted overlay analysis following a spatial modelling, under ArcGIS 10.5 platform to delineate the flood and water logging susceptible zones. The result obtained from this study indicate 11.45%, 3.05% and 85.49% area of municipality corresponds with highly vulnerable, low and moderately vulnerable respectively. The major finding in the study reveals that unplanned urban expansion in the hazardous low-lying area by filling up of wetlands and depressions in association
20 with inadequate drainage gravity provisions in the newly built-up wards (3, 23, 24 and 25) are noteworthy for resultant waterlogging condition. The present paper also aims to suggest long-term mitigation measures to be well integrated for arriving at a well drafted and implementable comprehensive drainage plan of English Bazar municipality.

Keywords. Waterlogging; integrated AHP-GIS; weighted overlay; spatial analysis; drainage plan.

1. Introduction

25 Flood is considered a natural phenomenon, that exists when the discharge of river from its catchment cannot be accommodated within its normal channel (Starhler and Strahler, 2002)*,* i.e., it rises from bank full to flood stage, so spreading over its flood plain (Monkhouse, 1972). As a flood consequence, an area is said to be waterlogged, when it is wholly covered with water, through a temporary rise in the level of river. The water level rises to the extent, that the soil pores become saturated, resulting in the restriction of normal air circulation, decline in oxygen level and increase in the level of carbon-di-oxide (Hussain, 2011).
30 Being a quasi-natural manifestation of lowlands, flood and water logging are observed throughout the country (Bowonder et al., 1986) viz. Uttar Pradesh (Dwivedi, 1994); (Dash and Sar, 2020); Andhra Pradesh (Choubey, 1998); Gangetic West Bengal (Sanyal and Lu, 2005); (Sanyal and Lu, 2006); Indo Gangetic plain (Pandey et al., 2010); Karnataka, India (Ritzema et al., 2008); as well as the developing world Jiangsu, China (Huang et al., 2018); Ethiopia (Getahun and Gebre, 2015) and therefore is regarded as a global issue. Moreover, floods in urban areas intensify with the increase of impervious surfaces, which
35 eventually cause changes in run-off conveyance network (Dewan, 2013). Many cities (urban area) around the world, particularly in developing countries are exposed to disastrous flooding viz. Guwahati, (Barman and Goswami, 2009); Jorhat (Rajkumari, 2009); Kolkata (Roy and Dhali, 2016); Gujarat, India (Panchal et al., 2019); Bangladesh (Anisha and Hussain, 2014); (Atauzzaman et al., 2019); Kenya (Ouma and Tateishi, 2014); Ethiopia (Singh, 2016); China (Lin et al., 2017). In the

present study, being situated over the Mahananda flood plain, water logging has become an age-old problem of English Bazar
40   Municipality (Malda town) West Bengal, India, especially at times, when the river is at high level. The riverbed of the
Mahananda has been elevated during the recent past due to excessive silting and avulsion during the flood and flood withdrawal
phases. Moreover, changes in land use patterns, population explosion, and paving and water storage space, caused by
demographic, economic, political, and/or cultural mutations over the past few decades have had notable effects on rainstorms
and frequent water logging (Zening et al., 2019).

45   The present study pertains to identify and mapping of the water logging vulnerability and risk zones, which can perhaps be
tackled through an integrated GIS based spatial modelling using AHP in English Bazar Municipality, Malda. The paper has
been organized as follows:

The first section introduces the topic on which the work has been done followed by an introduction to the study area (2nd
section), i.e., English Bazar Municipality (Malda Town). In the third section materials and methods used in the current study
50   has been highlighted. Firstly, the parameters have been selected to analyze waterlogging vulnerability, followed by a decision-
making process using Analytical Hierarchy Process (AHP) and further checking the consistency of the evaluation. The fourth
section discusses the results of the various water-logging hazard parameters. The section that follows, discusses the results
obtained by using the tools (AHP and RS-GIS) in the study. The results in the next section has been used to map the water-
logging susceptibility and further some mitigation measures have also been suggested

55   **2.   Study area**

Malda district (24°40′20″ N to 25°32′08″ N and 87°45′50″ E to 88°28′10″ E) comprises about 3,733 sq. km area. The district
is situated keeping Jharkhand in the west, Bangladesh in the east, Murshidabad district in the south, and North Dinajpur district
in north whereas; the River Ganga delineates the western boundary of district (Fig. 1). Malda district has acquired a unique
combination with the fusion of physiography and crisscrossed with the principal rivers namely; Mahananda, Kalindri, Tangan,
60   Ganga, Fulahar and Punarbhaba. Along with the seasonal inundation, the entire Malda district is susceptible to seasonal
submergences. Physiographically, the district is divided into three well-defined parts namely; *Tal* (in north and north-west),
Diara (in south and south-west) and *Barind* (in east) (Sengupta, 1969). The English Bazar Municipality is situated along the
western boundary of the River Mahananda almost like a semi-circular fashion (Fig. 1) in *Diara* physiography, which is
replenished regularly by flood water and is created chiefly by the joint action of river deposits of Mahananda and Ganga,
65   during the Pleistocene-Holocene age (University of North Bengal, 2013). The River Mahananda is demarcated and separated
by the elevated Mahananda embankment for the entire course of the river within its trajectory along the township to save the
township at time of deluges and even the periods of seasonal inundations. However, with the growth of population and
urbanization, the municipality experiences lots of land use change that initially causes a significant increase in run-off
coefficients and subsequently make the flood occurrences inevitable and the low-lying area become precariously waterlogged
70   especially after heavy rainfall in the monsoon months (University of North Bengal, 2013).
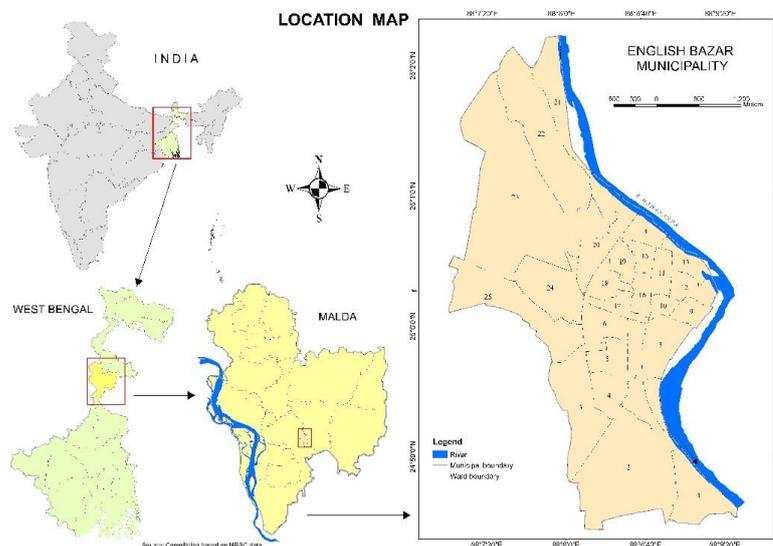
Fig. 1. Location map of the study area (compiled based on NRSC data)

3. Materials and methods

The science of flood and water logging vulnerability assessment is characterized by the development of a great number of
75   conceptual frameworks, which identify large number of indicators and therefore, implicitly proof the complex nature of
vulnerability assessment (Veerbeck, 2017). The frequency and magnitude of flood vis-à-vis water logging problem in the
municipal area is controlled by several natural, quasi-natural and man-made factors. To delineate the flood and water logging
susceptibility zonation in municipality, a multi-parametric data set comprising remotely sensed data and other conventional
maps are used. Six separate thematic raster layers (Fig. 3) are prepared using drainage and contour plan of English Bazar
80   Municipality, Sentinel 2A satellite image (ESA); Google Earth and soil map of National Bureau of Soil Survey and Land Use
Planning (Sahu, 2014).
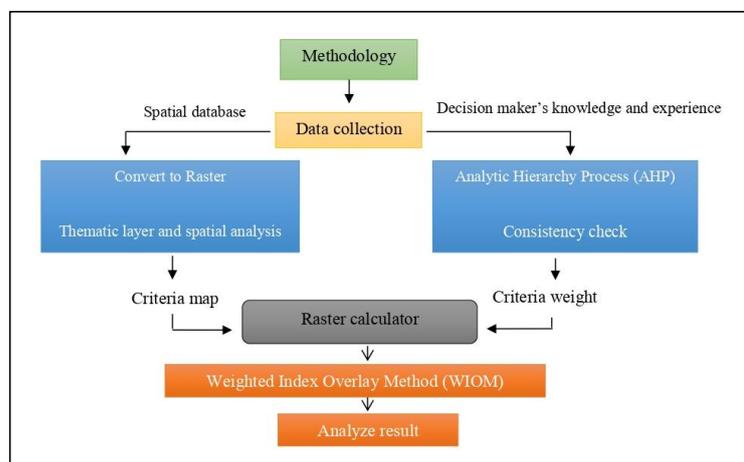
Fig. 2. Methodology integrating GIS based spatial modelling using AHP
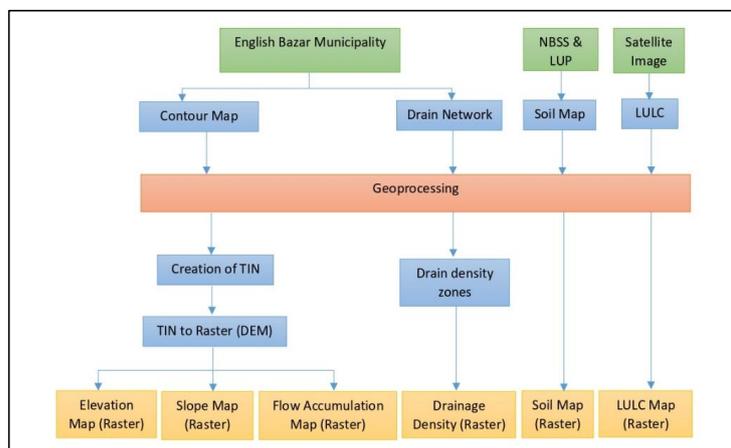
Fig. 3. Flow chart of GIS based spatial database

3.1. Selected parameters to analyse the water logging vulnerability.

The present study attempts to visualize the problem from all possible angles through GIS based spatial database (Fig. 2) and considers the parameters namely; elevation, slope, rainfall, soil, flow accumulation, land-use / land-cover (LULC), and drain density to be responsible for the initiation of waterlogged condition in English bazar municipality.

The elevation map has been generated using 3D Analyst extension in ArcGIS 10.5 from contour map collected from the municipal authority. The contour map was prepared in 2013 with an accuracy of 5 mm or 0.5 cm using precision Auto-level instrument. Both the handled and Differential Global Positioning System (DGPS) has simultaneously been used to capture the spatial and elevation data (University of North Bengal, 2013). From the same model, the slope map and flow accumulation map have also been prepared. The elevation, and slope map based on contour mapping, facilitates to incorporate the low land or upland points in order to have a true perspective of micro-topography, especially the waterlogged pockets in the municipality. The soil map has been collected as well as generated from National Bureau of Soil Survey and Land Use Planning, India, which has further been converted to raster layer using conversion tool on GIS platform. The land use land cover (LULC) mapping exercise has been carried out with the help of multi-temporal satellite data (Landsat 5 – TM, 1990; Sentinel 2A, 2018) and Google Earth (Table 1). Moreover, the drain network containing the alignment of master drains along with their respective outfall points, following the natural slopes has been procured (University of North Bengal, 2013) and a raster layer of drain density (Lingadevaru et al., 2015) is prepared by creating five density zones using Kernel density (Eq. 1) method (Silverman, 1986).

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} \left[\frac{3}{\pi} \cdot pop_i \left(1 - \left(\frac{dist_i}{radius} \right)^2 \right)^2 \right]$$ Eq. (1)

Where, i is 1…n are the input points, in the sum only those points within the radius distance of (x, y) location is considered; pop_i is the population field value of point 1 (here drain network); $dist_i$ is the distance between point i and the (x, y) location.

Table 1 Information of satellite image data

Satellite	Sensor	Tile no.	Path/Row	Date of acquisition	Spatial resolution (m)	Source
Sentinel 2A (ESA)	-	T45 R x H	-	17 October 2018	10	USGS
Landsat 5	TM	-	139/43	20 October, 1990	30	USGS

*ESA= European Space Agency, USGS= United States Geological Survey

3.2. Analytical Hierarchy Process (AHP) as a multi-criteria decision analyst tool

The present study proposes a multi-parametric approach for delineating the vulnerable water logging pockets within municipality through integrating Analytical Hierarchy Process (AHP), by reviewing the key documents (Saaty, 1990); (Saaty, 2008); (Zahedi, 1986); (Siddayao et al., 2014); (Ouma and Tateishi, 2014); (Kazakis et al., 2015); (Sar et al., 2015); (Ziaul and Pal, 2017); (Chakraborty and Mukhopadhyay, 2019). AHP as a potential, semi-quantitative decision-making process, provides a framework of assigning relative weightage in different criteria (water logging attributing factors) in order to identify the elements of a complex decision problem (Saaty, 1980), is delineated successively in following equations (Eq. 2-7). A pair-wise comparison matrix is formulated on the basis of established priorities for each criterion (Table 5). Sum the values in each column of the pair-wise matrix

$$C_{ij} = \sum_{i=1}^{n} c_{ij} \qquad \text{Eq. (2)}$$

Dividing each the element of the above matrix by its respective column sum ($\sum$), the resulting matrix is further normalized to formulate Normalized pair-wise matrix (Table 6).

$$X_{ij} = c_{ij} \Big/ \sum_{i=1}^{n} c_{ij} \qquad \text{Eq. (3)}$$

Dividing the sum of the normalized column of matrix by the number of criteria used (n) to generate weighted matrix (A2).

$$W_{ij} = \sum_{i=1}^{n} x_{ij} \Big/ n \qquad \text{Eq. (4)}$$

Moreover, the priority vector or eigenvector or criteria weight (the row average) indicates the weight for each criterion (A2 matrix), which is further multiplied with the elements of the initial matrix (Pair-wise comparison matrix) to get the weighted sum value (A3 matrix). The consistency vector (CV_{ij}) (A4 matrix) is generated by computing the ratio of A2 and A3 matrix.

3.2.1. Consistency check

In order to calculate and check the consistency of the evaluation, following equations are computed. λ_{max} is calculated by averaging the value of consistency vector.

$$\lambda_{max} = \sum_{i=1}^{n} CV_{ij} \qquad \text{Eq. (5)}$$

$$CI = \lambda_{max-n} \Big/ n - 1 \qquad \text{Eq. (6)}$$

Where, Ci is consistency index; λ_{max} is the maximum principal eigen value; n is no. of compared elements or size of matrix.

The final is the Consistency ratio (CR), computed as follows

$$CR = CI/RI \qquad \text{Eq. (7)}$$

Where, CR is consistency ratio and RI is random index for different n value, is displayed in Saaty, 1980.

3.3. Weighted Index Overlay Method (WIOM) in GIS platform

In order to merge the qualitative spatial database with quantitative assessment, all the respective thematic layers i.e., elevation, slope, soil, flow accumulation, land use land cover and density of drain network are reclassified to a common suitability scale to perform the ArcGIS Weighted Index Overlay Method (WIOM) (ESRI, 2020), to map the waterlogged susceptible zones in terms of highly vulnerable, moderately vulnerable and low vulnerable.

$$LC = \sum_{i=1}^{n} D_i W_i \qquad \text{Eq. (8)}$$

Where, LC is linear combination; D_i is decision parameter; W_i is AHP weight; n is no. of parameters. WIOM as a method of modelling suitability within a GIS mapping environment, is applied in considerable research article (Ajin et al., 2013); (Lingadevaru et al., 2015); (Kazakis et al., 2015); (Sar et al, 2015); (Chaudhari and Lal, 2018); (Karmokar and De, 2020).

Therefore, in the present study, a holistic methodology using AHP and weighted overlay techniques are applied in order to identify and mapping the waterlogged pockets and associated vulnerability within English Bazar municipality.

4. Results

150 The parameters considered for identifying the areas, prone to frequent water logging are mentioned earlier. The thematic maps illustrate the spatial distribution of parameters' values which has further been analysed through AHP-GIS model.

4.1. Water logging hazard parameters

4.1.1. Rainfall

The storm rainfall as meteorological aspect plays an important role in water logging within municipality premises, but the
155 spatial distribution of rainfall has been excluded as the area of the municipality is very small. Further, no such significant variations have been found in ward level analysis for the rainfall distribution still, the temporal aspect of mean annual rainfall for thirty-six years (1976-2012) is considered (Table 2). The general rainfall pattern clearly depicts that the geographical set-up of the area in the southern margin of the North Bengal plain has been an ideal place for the incidences of high intensity rainfall.

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Table 2

General rainfall pattern of English Bazar over the last 36 years

Years	Average Rainfall (mm)
1976-1980	1540.00
1981-1985	1640.40
1986-1990	1672.40
1991-1995	1844.80
1996-2000	1476.40
2001-2005	1368.63
2006-2010	1094.16
2010-2012	1026.55

Source: IMD, Govt. of India and I and Waterways Department, Govt. of West Bengal

165 #### 4.1.2. Elevation

The slope in association with elevation play an important role in governing the stability of terrain as well as influence the direction of and amount of surface runoff and sub – surface drainage (Ouma and Tateishi, 2014). The general slope of English Bazar municipality is from north to south and mostly lie well below 0.5 degree (Fig. 5) where the monotonous flatness cannot allow an efficient surface run-off and overland flow. The Mahananda embankment, lying along the eastern margin of
170 municipality in association with NH 34 and Eastern Railway track have altered the natural slope. The contour map, provided by the municipal authority, is used to generate the Digital Elevation Model (DEM). In the present study, the amplitude of the municipality is recorded 10.0 meter with highest altitude of 28.0 meter, identified in the north central highland, whereas lowest altitude of 18.0 meter, is identified along the Mahananda valley. However, the elevation map (Fig. 4) reveals that the municipality is dotted with number of depressions (basins), which is classified as: a) area along River Mahananda (18-20
175 meter); b) south-western lowland (20-22 meter); c) south-eastern lowlands (22-24 meter); d) east-central part (24-26 meter) and e) north-central part (26-28 meter) (Table 7). The entire western and south-western part along with some scattered pockets across the north-western and central portion of municipality with an elevation ranging from < 20 to 25 meter allows the rain

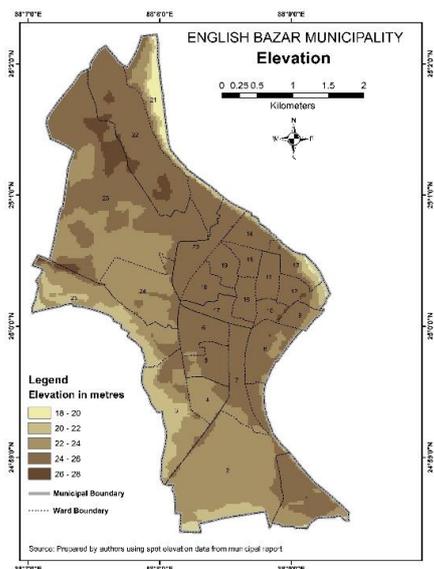
water to accumulate and without finding any natural way for draining out, it remains stagnant even for weeks unless and until it either evaporates or infiltrates.

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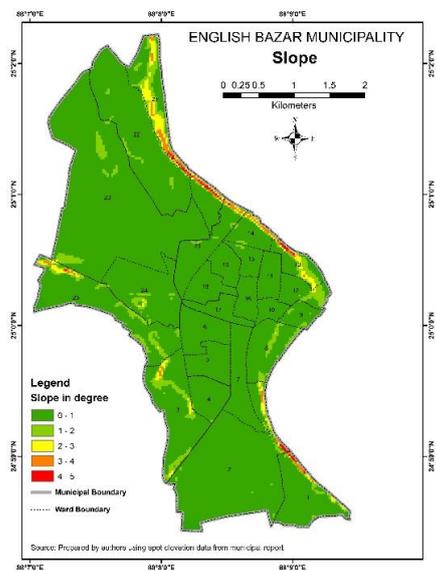
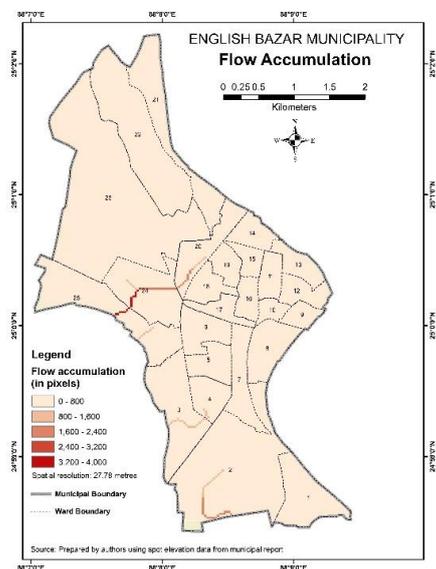
Fig. 4. Elevation map of English Bazar Municipality (based on spot elevation data from municipality report)

4.1.3. Slope

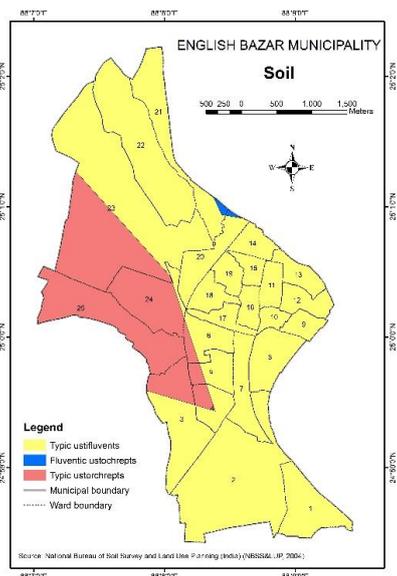
The slope map (Fig. 5) reveals 0 to 1° for maximum areas and then 1 to 2° stretch across south-west and north-central part; whereas 2 to 3° slope is identified in north-west and lastly a negligible stretch along river embankment records relatively high land ranging from 2 to 5° (Table 7). The high lands, appear within municipality along River Mahananda embankment is more susceptible to surface run-off thus slow down the flood response. Low gradient slopes (low-lying) are much susceptible to water logging as well.

190   **Fig. 5. Slope map of English Bazar Municipality** (based on spot elevation data from municipality report)

4.1.4. Flow accumulation

Flow accumulation is considered a relevant parameter of water logging which defines the cumulative flow downslope as well as reflects the ability to drain out excess rain water (Dash and Sar, 2020). As a significant part of the low-lying area within municipality is waterlogged due to insufficiency in water outflow, a raster flow accumulation map (Fig. 6) is generated from

195   the DEM file. Flow accumulation calculates accumulated flow as the accumulated weight (sum) of all cells flowing into each downslope cell in the output raster. The municipality records flow accumulation values to vary in a range between 0-4,139 (Table 7) with high values in the low elevated tracts which indicate areas of concentrated flow and resultant high flood hazard (Kazakis et al., 2015).

200   **Fig. 6. Flow accumulation map of English Bazar Municipality** (based on spot elevation data from municipality report)

4.1.5. Soil type

Flow accumulation is ascertained by the nature of soil in terms of its texture and moisture, which is considered another most important parameter in defining water logging hazard (Getahun and Gebre, 2015) (Lingadevaru et al., 2015).

205   **Fig. 7. Soil map of English Bazar Municipality** (based on NBSS & LUP, 2004)

The soil vector map is being geo-processed to form a raster output (Fig. 7). However, the soil types found within the municipality are considered into three sub-groups: a) Typic ustifluvents (low infiltrated) (ward no. 1-23); b) Typic ustorchrepts (moderately infiltrated) (ward no. 3, 4, 5, 6, 23, 24, 25) and c) Fluventic ustochrepts (highly infiltrated) (ward no. 20, 21) (NBSS and LUP, 2004). Typic ustifluvents, under Entisols order is characterized with fine silty loamy soil, extensive along

210   River Mahananda and is considered dominant soil sub-group within municipality. Typic ustorchrepts under Inceptisols order is medium textured soil with sandy loam to sandy clay loam, is identified at nearly level to very gentle sloping ground (west) of municipality. Fluventic ustochrepts under Inceptisols order is flood plain soil of recent deposition with coarse textured, occur beyond the Mahananda levee. As per the water retention magnitude, Typic ustorchrepts is found most susceptible to water logging as well as denotes maximum flow accumulation within municipality. Further, the soil map is digitized as polygon

215   layer and corresponding soil type and value have been added to the Table 7.

4.1.6. Land use and land cover (LULC)

In the present analysis, another water logging risk forming factor is taken as land use land cover (LULC) which not only reflects the current use of the land, pattern and type of its use but even the importance of its use in relation to soil stability and infiltration (Ouma and Tateishi, 2014); (Quan, et al., 2010). The thematic map of LULC (Fig. 8 (b)) has been prepared based

220   on satellite image (Sentinel 2A, 2018), is further validated with the help of Google Earth image 2018 in order to gather detail information regarding the predominant urban/ rural land cover and other socio-economic attributes as well as is converted to raster layer. However, the entire municipality is classified into five major lulc units viz. water body, built-up area (ward no. 1-20; partly 21, 22, 23) arable land, mango orchard, open space (Table 7). Different spectral signatures of similar pixel samples

are collected from satellite imageries using the maximum likelihood method and are later on grouped with spectrally identical

225 signatures (Ganaie et al., 2018).

4.1.6.1. Change detection in LULC of municipality between 1990 and 2018

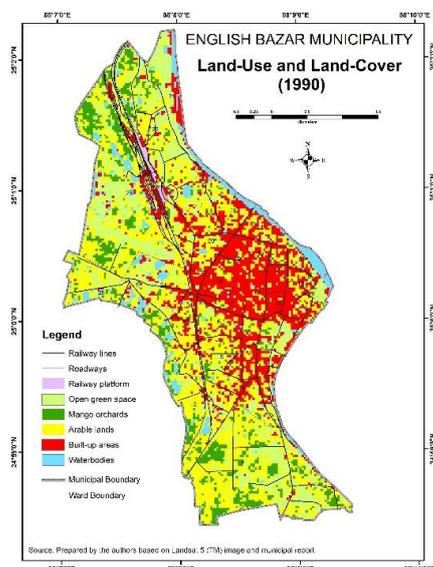
The land use land cover of 2018 is further compared with the year of 1990 (using maximum likelihood method) (Fig. 8 (a)), based on satellite image (Landsat 5 TM) in order to know the spatial expansion of built-up area over time in the municipal wards.

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Fig. 8 (a). Land use and land cover map of English Bazar Municipality (based on Landsat 5: TM data, October 1990)

The ever-increasing population growth and resultant urbanization has witnessed a dramatic land use/cover change (Fig. 8 (a) and (b)) in the form of built-up area which has increased from 2.86 sq. km in 1990 to 7.00 sq. km in 2018 i.e., an absolute change by 4.14 sq. km (144.76%), followed by mango orchard by 0.49 sq. km (36.57%) (Table 3) (Fig. 9) over past 30 years.

235 The huge in-migration during the liberation war of Bangladesh has caused a dramatic transformation of the natural and man-made sewerage system without paying any attention to the normal and storm water disposal waterways. With rapid urbanization, cities throughout the developing world struggle to meet the basic need of their growing populations (Baker, 2012); English Bazar municipality is of no exception. As a consequence, a number of localities, namely Krishnapally, Malanchapally under ward no. 03; Buraburitala under ward no. 25 etc. came up since 1970, have gradually been encroached

240 predominantly by the immigrants (service holders, workers of unorganized sectors, retail traders, land developers) (Table 4) (Fig. 10) specially from Bangladesh and other remotely located villages (Chattaraj and Sarkar, 2016). The filling of land by concretes, roads along with the construction of embankment by the neo-settlers in low-lands and former waterways ultimately hinders the natural overland flow during heavy showers which eventually become a perennial problem of water logging and drainage congestion on the urban fabrics of English Bazar municipality.

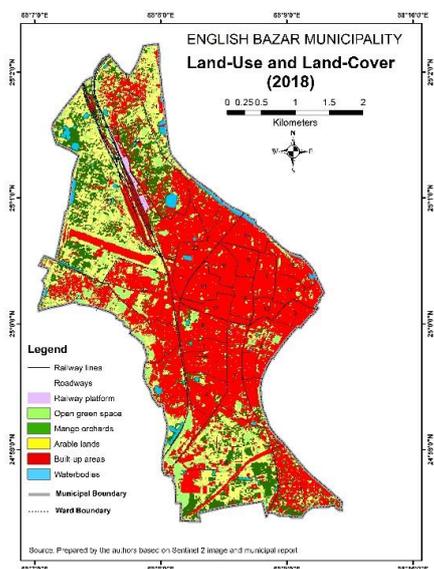



Fig. 8 (b). Land use and land cover map of English Bazar Municipality (based on Sentinel 2 A data, October 2018)

Table 3

Land use and land cover change in English Bazar Municipality between 1990 and 2018

Class name of LULC	Area (Sq. km)		% LULC		Absolute change of LULC	% Change of LULC	Status of change
	1990	2018	1990	2018			
Waterbodies	0.94	0.28	7.18	2.14	-0.66	-70.21	Decrease
Mango orchard	1.34	1.83	10.23	13.97	0.49	36.57	Increase
Arable land	5.2	2.8	39.69	21.37	-2.4	-46.15	Decrease
Open space	2.76	1.19	21.07	9.08	-1.57	-56.88	Decrease
Built-up area	2.86	7.00	21.83	53.44	4.14	144.76	Increase
Total	13.1	13.10	100.00	100.00			

Source: Calculated by the authors based on Landsat 5 TM data (1990) and Sentinel 2A data (2018), October

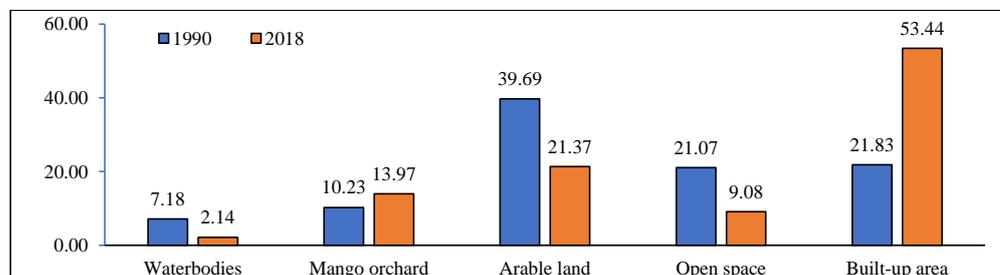



Fig. 9. Land use and land cover dynamics of English Bazar Municipality

Table 4

Growth of population in newly formed wards including newly emerged localities in English Bazar Municipality

Ward no.	Population			Decadal growth (%)		Localities
	1991	2001	2011	1991-2001	2001-11	
03	6735	9157	13097	35.96	43.03	Krishnapally, Malanchapally
23	8325	11375	14970	36.63	31.60	Subhaspally
24	7116	10230	14838	43.7	45.04	Regent park, Netaji park
25	NA	9454	13491	NA	42.70	

	Gandhi park, Buraburitala, Bank colony, Lake garden

255 *NA: Not available*

Source: Census of India 1991, 2001 and 2011; Field study; Chattaraj and Sarkar, 2016

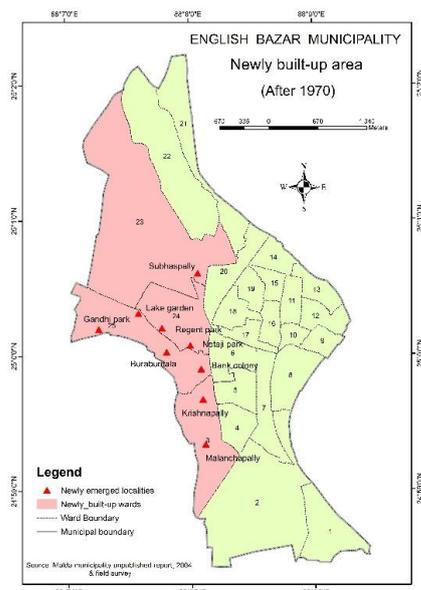
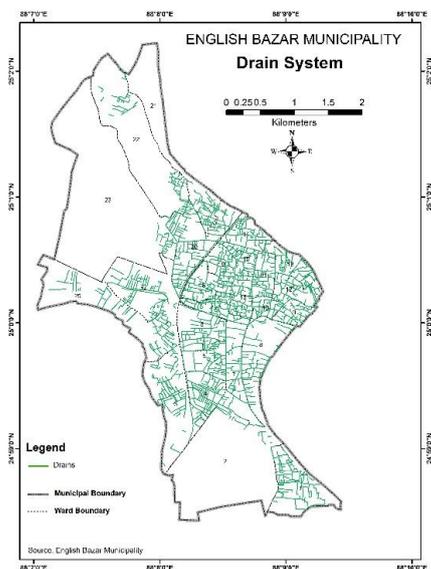



Fig. 10. Newly built-up areas of English Bazar Municipality (based on filed survey)

4.1.7. Density of drain network

260   In order to establish the spatial relation between the waterlogged area and the drain network (Fig.11 (a)), the density of drain (km/sq. km) has been generated using ArcGIS software which is considered another crucial determining factor for the initiation of flood event and waterlogging hazard. Thereafter, the drain density has been prepared by applying the density tool (Kernel density) in spatial analyst extension of ArcGIS (Eq. 1) as well as classified into five classes ranging from <1.86 km to >7.44 km/ sq. km (Fig. 11 (b)) depending on the waterlogged capacity. The vector map has further been geo-processed to form a
265   raster output. However, the drain density is considered as proxy for waterlogged mapping (Table 7), which indicates that less dense the drain network (<1.86 km/ sq. km) (ward no. 21, 22, 23; partly 1, 8, 25) emanates the capacity of an area to be more waterlogged, whereas the effect of this parameter decreases with well-dense drain network (>7.44 km/ sq. km) (Ward No. 4, 5, 10, 11, 15, 16, 17, 18, 19).

270   **Fig. 11 (a). Drain system of English Bazar Municipality** (based on municipality report)

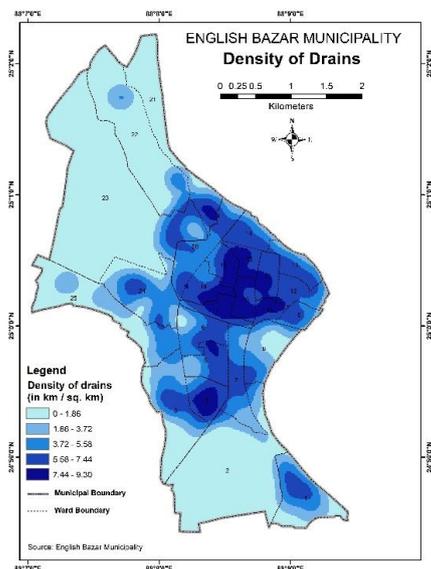



Fig. 11 (b). Drain density map of English Bazar Municipality (based on municipality report)

5.   Discussion

5.1.   *GIS based spatial modelling of susceptibility zonation through AHP*

275   In the present study, a multi-parametric approach through the integration of Analytical Hierarchical Process (AHP) as a multi-criteria decision making (MCDM) technique within a GIS mapping environment (Ouma and Tateishi, 2014) is applied for delineating flood vulnerability and associated water logging susceptibility zonation in English Bazar municipality. The aforementioned six different predictor maps have been used as the waterlogging hazard theme, are represented in the

280 hierarchical structure (Fig. 12), in order to know the control of influence of different criteria in the suitability model. The Analytic Hierarchy Process (AHP) (successively displayed in Table 5, 6 and following matrices), is calculated by assigning appropriate weight in pair-wise comparison, using a 6×6 matrix to establish priorities among the elements in hierarchy (Table 5).

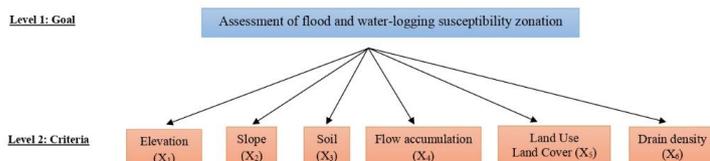



Fig. 12. AHP decision hierarchy structure of water logging susceptibility zonation

285 **Table 5**

Pair – wise comparison matrix for criteria

Criteria	X_1	X_2	X_3	X_4	X_5	X_6
X_1	1.000	1.000	2.000	3.000	3.000	4.000
X_2	1.000	1.000	2.000	3.000	3.000	4.000
X_3	0.500	0.500	1.000	2.000	2.000	3.000
X_4	0.333	0.333	0.50	1.000	0.50	2.000
X_5	0.333	0.333	0.500	2.000	1.000	2.000
X_6	0.250	0.250	0.333	0.500	0.5	1.000
Sum (Eq. 1)	**3.417**	**3.417**	**6.333**	**11.5**	**10**	**16**

Normalized pair-wise matrix (Table 6) is generated by computing Eq. 3.

Table 6

Criteria	X_1	X_2	X_3	X_4	X_5	X_6
X_1	0.293	0.293	0.316	0.261	0.3	0.25
X_2	0.293	0.293	0.316	0.261	0.3	0.25
X_3	0.146	0.146	0.158	0.174	0.2	0.188
X_4	0.098	0.098	0.079	0.087	0.05	0.125
X_5	0.098	0.098	0.079	0.174	0.1	0.125
X_6	0.073	0.073	0.053	0.043	0.05	0.063
Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

290 A2 matrix i.e., the normalized inputs as priority vectors are generated by computing Eq. 4.

A2 matrix	A3 matrix (Consistency vector)	A4 matrix
$\begin{bmatrix} 0.285 \\ 0.285 \\ 0.169 \\ 0.089 \\ 0.112 \\ 0.059 \end{bmatrix}$	$\begin{bmatrix} 1.749 \\ 1.749 \\ 1.034 \\ 0.538 \\ 0.684 \\ 0.359 \end{bmatrix}$	$\begin{bmatrix} 6.130 \\ 6.130 \\ 6.133 \\ 6.025 \\ 6.096 \\ 6.065 \end{bmatrix}$

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5.1.1. Consistency check and inference

In order to verify the consistency of assigned weight to the parameters, the above vector (A3 matrix) is divided by respective eigenvector (A2 matrix) to yield the ratio of consistency vector (A4 matrix). The maximum principal eigenvalue $\lambda_{max} = 6.097$
300 (Eq. 5). The Consistency index (CI) =0.019 (Eq. 6) and the final Consistency ratio (CR) is 0.016 (Eq. 7) i.e., <1. Since CR is less than 0.1, the comparison matrix is said to be reasonably consistent and thus acceptable.

5.2. GIS based spatial modelling through Weighted Overlay using AHP

Multi-criteria analysis is used for identifying the waterlogged pockets within municipality premises using weighted overlay analysis, which is considered the hallmark of ArcGIS as well as most required and common technique in geographic data
305 processing (Bhatta, 2011). Considering all the respective thematic layers i.e., elevation, slope, soil, land-use / land-cover (LULC), flow accumulation and drain density, which are initially converted into grid or raster format and subsequently are reclassified for making all the data layers unidirectional (Ziaul and Pal, 2017). In the raster overlay, the pixel or grid cell values in the thematic maps are combined using arithmetic and Boolean operators to produce a new value in the composite raster map (water logging susceptibility zonation), which affords a strong numerically modelling (quantitative analysis) capability
310 (Bhatta, 2011).

5.2.1. Weighting and rating of model parameters

Each class of the contributing factors (thematic layers) are assigned 5 points scale or rating (1 – 5) for reclassification; according to the assumed vulnerability (5 being the highest or more priority than others; 1 being lowest). Moreover, the weights are assigned for the influence of different parameters (thematic layers) based on AHP Importance Scale (Saaty, 1980) as well
315 as integrated on GIS platform by using raster calculator in ArcGIS spatial analyst tool (Eq. 8) to generate a spatial modelling on flood and waterlogging susceptibility zonation (Fig. 13). In the present study, a summary of the water logging causative parameters, their respective weights and how they are ranked according to their influence to water logging events is displayed in table 07. The factor weights, integrated with AHP reveals that the low-gradient (low-lying) area with high infiltrating soil cover in association with extended concreted structure accumulate maximum flow as well as have the highest weights,
320 implying that they are more susceptible to water logging than other factors.

6. Water logging susceptibility mapping for English Bazar municipality

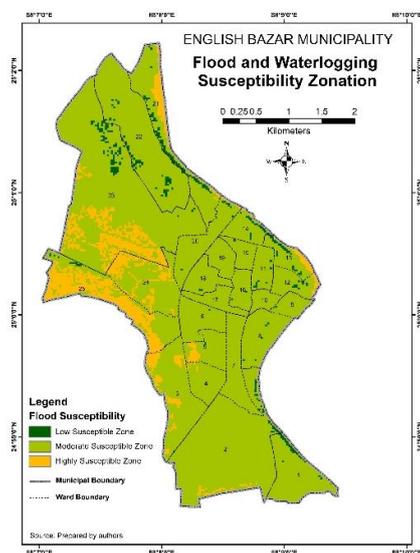
The composite raster map, using the weighted overlay has displayed three significant susceptible zones viz., low, moderate and high (Table 8), prone to flood and water logging. The susceptibility zonation map (Fig. 13) shows that 11.45% (1.50 sq. km) (entirely ward no. 24, 25; partly 2, 3, 13, 21, 23) of the total municipal area in the west and south-west is prone to highly
325 vulnerable zone, which is attributed to low elevation, entirely covered with built-up and paved region, especially after 1970. Conversely, 3.05% area (0.40 sq. km) under municipality is prone to low vulnerable (partly ward no. 1, 2, 8, 13, 14, 20, 21, 22, 23) at a stretch along River Mahananda embankment. Rest of the portion (rest of the wards) of municipality fall under moderately vulnerable zone (11.20 sq. km).

330   **Fig. 13. Flood and waterlogging susceptibility map of English Bazar Municipality** (prepared by authors)

Table 7

Classes of the parameters (raster thematic layers) according to weight

Parameters	Class	Rating	Weight
Elevation (m)	18-20	5	29
	20-22	4	
	22-24	3	
	24-26	2	
	26-28	1	
Slope (°)	0-1	5	28
	1-2	4	
	2-3	3	
	3-4	2	
	4-5	1	
Soil	Fluventic Ustochrepts	5	17
	Typic Ustorchrepts	3	
	Typic Ustifluvents	1	
Flow accumulation (pixels)	>3200	5	9
	2400-3200	4	
	1600-2400	3	
	800-1600	2	
	<800	1	
Land use and land cover	Built-up areas	5	11
	Arable lands	4	
	Mango orchards	3	
	Open space	2	
	Waterbodies	1	
Density of drains (km/sq.km.)	<1.86	5	6
	1.86-3.72	4	
	3.72-5.58	3	
	5.58-7.44	2	
	>7.44	1	

Table 8

335   Water logging susceptibility zones

Vulnerability zones and respective wards	Pixel counts	Area covered (sq.km.)	Percent (%) share
Low vulnerable zone	399	0.40	3.05
Moderate vulnerable zone	14513	11.20	85.49
Highly vulnerable zone	1896	1.50	11.45
Sum	**16808**	**13.10**	**100.00**

7. Further discussion and mitigating measures

The present study confirms that the integration of AHP and GIS technique allows a coherent and efficient use of spatial data as well as helps to better understand the multi-criteria evaluation in water logging risk assessment, providing useful information
340 on the influence of rating– weighting values assigned to each criterion (Kazakis et al., 2015). However, unplanned urban expansion in the hazardous low-lying area (filling up of wetlands and depressions), inadequate drainage gravity provisions and routes, drainage congestion with solid wastes along with growing weeds, lack of proper storm water disposal system and lack in social awareness (Anisha and Hussain, 2014) are noteworthy to have negative impact on the urban drainage system and resultant water logging condition. The long-term mitigation measures need to be well integrated with the existing development
345 plans and ongoing infrastructural improvements being carried out for arriving at a well drafted and implementable disaster management strategy (KMC, 2008). Therefore, it is very necessary to improve the existing drain capacity and sewerage system and to construct new high-standard rain drainage system, especially for the relatively flat areas. Further, introduction of public awareness of risk at community level and implementing disaster mitigation plans at the different levels of public administration are required on water logging risk control (Quan, et al., 2010).

350 ## 8. Conclusion

This paper presents an empirical approach through GIS-AHP based category model for mapping vulnerability to water logging and possible prediction in municipality. Moreover, the proposed approach provides essential information for the local government and administration to improve the water logging risk management and aids the decision and policy makers in the rapid assessment and evaluation of water logging phenomenon in urban municipalities. The present study adopts a holistic
355 approach by field verification, which shall value the age-old drainage problem and seasonal inundation induced inconvenience of the urban dwellers as well.

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