Multi-hazard Vulnerability of the Vernacular Houses of Supaul, Bihar, India

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Abstract

Supaul is a district town, located in the Kosi region, which due to its unique geographical location, is one of the most disaster-prone districts of Bihar, India. It faces several natural as well as manmade hazard challenges out of which natural hazards like; earthquakes, floods and high wind speeds create critical problems demanding immediate attention. However, there are a lot of vernacular houses in the region that survive all these hazards.

Vernacular settlements in Supaul are determined largely by the socio-economic conditions of the families and the houses are constructed utilizing the most commonly locally available materials i.e. bamboo, wood and bricks. In this paper, multi-hazard vulnerability of the vernacular houses of Supaul have been explored. Taking into account the large population at risk, it is calculated based on the latest available population data of the Census.

The study employs a qualitative approach. Building attributes have been gathered through a survey and a digital footprint map has been prepared to produce inventory maps. After the classification, the building and population vulnerability are assessed and risk is calculated accordingly.

It is found that in the absence of building bye-laws and guidelines, the houses have been built without any understanding of their exposure to the hazards. The research proposes how to reduce vulnerability against multi hazards in the region and recommends the procedures and criteria that can be adopted.

Keywords**:** Disaster-prone, Multi-hazards, Vernacular houses, Vulnerability, Risk assessment, Supaul, Bihar.

Introduction

India has its diversity from North to South and from East to West geographically as well as climatically and constitutes diverse vernacular house forms and building types (Dutta *et al.*, 2022). At present, due to the climate change, it has become necessary to carry out hazard risk and vulnerability assessments for the settlements, which are highly prone to multiple hazards. Whether it is an urban or a rural area, the vernacular settlements in particular must be given attention in these assessments. A vulnerability assessment can help the planners and policy makers to develop an appropriate emergency plan for settlement and allocate a budget and resources to mitigate the risk. Simultaneously, the preparedness of the community can also be enhanced (Sikkim State Disaster Management Authority, 2012).

"Vulnerability is one of the most important factors in the risk assessment. Namely, high vulnerability of some areas can result in severe losses during a low-intensity hazard, and low vulnerability can result in minor losses during a high-intensity hazard".

(Mladineo *et al.*, 2022:3),

Conventionally, impacts of hazards are more focused upon physical aspects of the settlements. However, social vulnerability is often neglected (Drakes and Tate, 2022). The vernacular house-forms are not just the physical abode of people, but the social aspects are also related here. Thus, the concern of 'building back better' should be the utmost priority. As part of the Agenda 21 for Sustainable Development of UNEP-1992, multi-hazard vulnerability and risk assessment has become an essential component of settlement planning (Kappes *et al.*, 2012). Interestingly, recent progress in the field of Remote Sensing and GIS have helped in the process of creating multi-hazard vulnerability maps for any settlement (Pal *et al.*, 2022).

This study examines the vernacular house-forms in the Supaul district of Bihar. The Supaul district has an area of 2,425 square kilometers (936 sq. mt.) and is a part of the Kosi division. The location of the study area is shown in Fig. 1. Kosi region is prone to different natural hazards like earthquakes, floods and high wind speeds. Supaul is part of the Kosi region which is named after the Kosi River, which is also regarded as the sorrow of Bihar, due to its changing water flow. This unstable behavior of the Kosi River is due to the heavy silt which it carries during the monsoons.

According to the 2011 census, the population of Supaul district is 2,228,397, and the district has a population density of 919 inhabitants per square kilometer (Census Department of India, GOI, 2011). Areas of district are under Seismic Zone V: 100%, Wind Speed Zone III (47 m/s):100% and Flood (FHZ):81.6% which makes it one of the major multi- hazard prone areas in Bihar, as mentioned in Table 1.

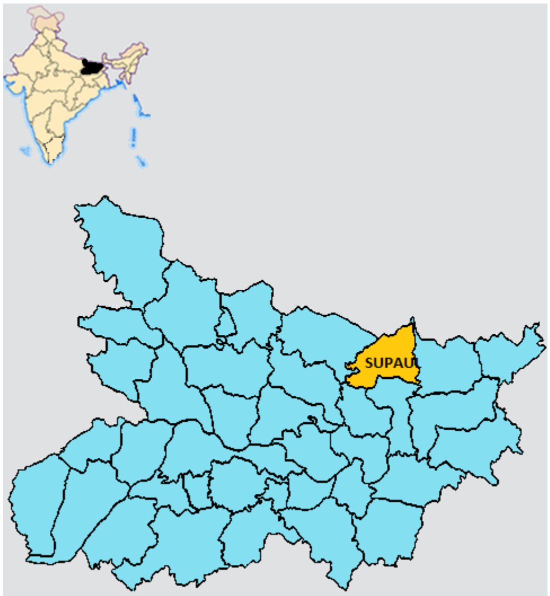

Fig. 1: Location of Supaul district
Source: www.wikimedia.org

Table 1: Natural Hazard Risk Zones of Supaul
Source: Vulnerability atlas of India

Seismic Zone	Wind Speed Zone	Flood Hazard Zone
V	III (47 m/s)	Applicable

The study aims to evaluate the vulnerability of the vernacular building types of Supul against the multi-hazards. Its objectives include the identification of vernacular housings types and risk analysis of vernacular settlements against the multi-hazardous situation of the region. Kosi region is one of the most disaster-prone areas of Bihar. There are several studies which talk about flood risk of the region and the Kosi River is identified as the "Sorrow of Bihar". However, there are very few studies and data available, which deal with the unique multi-hazardous situation of Supaul. The multi-hazard situation arises when more than one hazard event impacts the same area. These different hazard events may occur at the same time or may be spaced out in time. Data regarding building types was collected by the authors primarily by visiting Supaul.

Housing types were selected and categorized through visual sampling and survey. Vulnerability and risk assessment was done based upon the secondary data available in the form of the government of India's report for census and multi-hazard vulnerability atlas.

Theoretical Basis

Multi-Hazard Vulnerability of Building Types

Building materials and types of construction plays a major role in the performance of any building during the disasters (Folke, 2006). Risk of damage to various housing types based on their observed average damage levels during past occurrences of hazardous events is given below in the Tables 2 and 3.Vulnerability levels for the different types of buildings are based on the level which is given by the vulnerability atlas of India and the same methodology has been used for the assessment purpose (BMTPC, GOI, 2019).

Damage Risk Levels for Earthquakes

1. Very High Damage (VH): Total collapse of the structure.
2. High Damage (H): Gapes in walls, parts of building may collapse, parts of the building loss their cohesion and inner walls collapse.
3. Moderate Damage (M): deep and large cracks in walls, chimneys on roof may fall.
4. Low Damage (L): development of small cracks in walls, fairly large pieces of plaster may fall, pan tiles slip off, chimneys may be cracked and some part of it may fall down.
5. Very Low Damage (VL): Fine cracks in plaster may appear, small pieces of plaster may fall.

Damage Risk Levels for Cyclones/Wind Strom:

1. Very High Damage Risk (VH): This is similar to the "High Risk" but expected damage is greater in the case of a cyclone.
2. High Damage Risk (H): Walls overturns, walls of industrial structures and houses may fail, the roofs, roofing materials, and tiles fly, and semi engineered/non-engineered constructions may suffer heavy damage.
3. Moderate Damage Risk (M): Loose tiles may fly, roofing sheets fixed on battens fly, and there could be moderate damage to semi- engineered /non-engineered buildings.
4. Low Damage Risk (L): Loose sheets may fly, a few telephone/ lighting poles go out of alignment, hoardings and sign boards are damaged partially, well detailed semi-engineered /non-engineered buildings may have very little damage.
5. Very Low Damage Risk (VL): Generally similar to "Low Risk" but expected to vary the limit in extent.

Damage Risk Levels for Flood:

1. Very High Damage (VH): Total collapse of the buildings, floating away of thatch, sheets, etc., erosion in foundations; sever damage to life line systems and structures.
2. High Damage Risk (H): Gaps in walls, flowing water may punch holes in the walls, buildings may collapse partially, floating away of light roofs, erosion of foundations, tilting or sinking, undercutting of the floors.
3. Moderate Damage Risk (M): Deep and large cracks in the walls, bulging of walls, loss of belongings, electric fittings may get damaged.
4. Damage Risk (L): Small cracks in the walls may develop; large pieces of plaster may fall
5. Very Low Damage Risk (VL): Small pieces of plaster may fall, development of fine cracks in plaster could happen.

Table 2: Multi-hazard Vulnerability of Different Building Typologies by Wall Material
Source: Vulnerability atlas of India

Material	Category type of wall	Level of Risk					
		Earthquake			Wind velocity		Flood
		Zone V	Zone IV	Zone III	47m/s	39 m/s	
Bamboo	1.Bamboo with without plaster(A)	M	VL	VL	VH	M	VH
	2.Bamboo with mud plaster(B)	M	VL	VL	VH	M	VH
	3.Bamboo with cement plaster(C)	M	VL	VL	VH	M	VH
Mud	1.Mud walls(A)	VH	H	M	H	M	VH
	2.Mud walls with horizontal wood elements(B)	VH	H	M	H	M	VH
Unburned brick	1.Unreinforced unburned brick masonry in mud mortar (A)	VH	H	M	H	M	VH
	2.Unreinforced unburned brick masonry in cement/lime mortar (B)	VH	H	M	H	M	VH
Burnt brick	1.Unreinforced burnt brick masonry in mud/lime mortar (A)	H	M	L	M	L	H
	2.Unreinforced burnt brick masonry in cement mortar (B)	H	M	L	M	L	M
	3.Unreinforced burnt brick masonry in cement mortar with lintel bands (C)	H	M	L	M	L	M
	4.Reinforced burnt brick masonry in cement mortar (D)	H	M	L	M	L	M
	5.With reinforced concrete(E)	H	M	L	M	L	M
concrete	1.Brick fill in concrete frame	M	L	VL	VL	VL	L

Table 3: Multi-Hazard Vulnerability of Different Building Typologies by Roof Material
Source: Vulnerability atlas of India

Material	Category type of Roof	Level of Risk					
		Earthquake			Wind velocity		Flood
		Zone V	Zone IV	Zone III	47m/s	39 m/s	
Thatch, Mud Bamboo, Wood, GI& Asbestos sheet etc.	Light weight sloping roof(L)	M	M	L	VH	H	VH
Tiles, Slate etc.	Heavy weight sloping roof(H)	H	M	L	VH	M	H
Brick, Stone, Concrete	Flat roof(F)	As per that for the wall supporting it					

The differences in structural detailing, architectural planning, the number of stories, quality of construction and maintenance, and the damage performance of houses in each category could vary substantially from the observed average values.

Analysis and Findings

Vernacular Building Types in Supaul

Housing in the North Bihar is determined largely by the socio-economic conditions of the families, available materials and the hazards the region faces (Kumar, S. *et al.*, 2019). Thus, the vernacular houses (kachha house) in Supaul are made using locally available materials. They primarily use bamboo, bricks and mud. Thatch, earthen tiles and metal sheets are also used as roofing materials in most of the houses. New *pacca* houses are made using the modern construction materials like burnt bricks and concrete. In terms of the materials, the numbers of the existing houses in the study area are presented below in the Table 4.

Table 4: No. of Different Types of Houses w.r.t Building Material
Source: Census of India, 2011

No.	Material	2011 Census of Housing	
		No. of Houses	% of Total Houses
1	Mud & unburnt bricks	19,932	3.4
2	Burnt bricks	1,25,254	21.2
3	Stone	2,682	0.45
4	Wood wall	1,879	0.3
5	Concrete	1,713	0.3
6	Metal Sheets, Grass, leaves, Reeds, Bamboo or other materials	4,40,365	74.4
	Total number of Census Houses (Rural + Urban)	5,91,825	100

To analyze the vulnerability of the buildings of Supaul, firstly, a classification is required as it is almost not possible to analyze each and every building independently for such a populated district like Supaul. For this purpose, therefore, buildings have been classified into different types depending upon certain parameters as discussed below. Thus, the vulnerability analysis of the buildings can be performed accordingly, as detailed out in the Table 5.

- **Material Type:** All the buildings are classified based primarily on the material of construction like bamboo, mud, unburned brick, and burnt brick etc.
- **Height of the Building**: The building becomes more vulnerable to hazard changes with the increase in the number of stories. Hence, the number of stories is considered under this classification.
- **Irregularities:** Symmetrical buildings perform well in response to external forces. Thus, the irregularities become an important parameter.
- **Roof Type:** Roof weights and shapes play a vital role. They are categorized as light-weight, heavy-weight or flat respectively.
- **Quality of Construction:** To evaluate the local construction practices, quality of the construction with respect to codal compliances or visual assessment is taken into account.
  i. Code: Complied / Not Complied
  ii. Visual status of appearance or maintenance: Good/Poor

Table 5: Building Types in Supaul
Source: Author

	Material of wall	Parameters				Building Category
		No. of Stories	Irregularity	Roof Type/ Material of roof	Quality of Construction	
Bamboo (B)	Bamboo without plaster(A)	Number of stories in the building (01-10)	Horizontal and Vertical both (HV)	Light weight(L) Or Heavy weight(H) Or Flat(F)	CodeComplied and Good(CG) Code complied and Poor(CP) or Not code Complied and Good(NG) or Not code Complied and Poor (NP)	BA*******
	Bamboo with mud plaster(B)					BB*******
	Bamboo with cement plaster(C)					
Mud (M)	Mud walls(A)					
	Mud walls with horizontal wood elements(B)					
Unburnt Brick (UB)	Unreinforced unburnt brick masonry in mud mortar(A)					
	Unreinforced unburnt brick masonry in cement/lime mortar(B)					
Burnt Brick (BR)	Unreinforced burnt brick masonry in mud/lime mortar(A)					
	Unreinforced burnt brick masonry in cement mortar(B)					
	Unreinforced burnt brick masonry in cement mortar with lintel bands(C)					
	Reinforced burnt brick masonry in cement mortar (D)					
	With reinforced concrete(E)					
Concrete (C)	Brick fills in concrete frame					

Note: - Thatch (TH), CGI (GI), Asbestos (AS), Tiles (T), Brick (BR), Stone (S), Concrete(C)

Vulnerability Analysis of the Buildings

1. Typology BBGI1LNG:

Typical Building Specifications

- Wall: bamboo with mud plaster.
- Roof: CGI sheeting on purlins attached to rafters spanning from ridge beam to eave level walls with intermediate beams.

These types of houses are most common in the Supaul district. The plans of the buildings are generally square with centrally located rooms and verandahs on both sides making the structure symmetrical. Roofs are hipped shaped, as shown in the Fig. 2 & 3. Bamboo houses are more suitable to the local climatic conditions of the warm-humid areas. It is also an area where daily available and rapidly renewable building resources are abundant. These qualities of bamboo houses allow good living conditions and acceptance from the local communities in the aftermath of a hazard.

However, these buildings have the following risk levels.

Earthquakes: - Bamboo being a lighter material attracts less earthquake forces and therefore bamboo walls are safer from earthquakes. However, mud plasters may show cracks. These cracks will not cause any damage to the bamboo structure (Fig. 4). The cracked mud can be easily repaired with fresh mud plaster. Vulnerability level due to large cracks in mud plaster is therefore (M).
High wind/cyclones: -Due to the high tensile strength, the extreme light weight buildings have high range of elasticity and can withstand the strong forces. On the other hand, bamboo and CGI sheets being a light material can easily blow away if different components of a building are not tied with each other and into the ground. Walls in houses may fail; roofing fly, non-engineered/ semi engineered constructions may suffers heavy damage (VH)
Floods: Foundations are protected up to some extent. However, if scouring occurs or flood level is higher than the protection level, the bamboo walls with mud plaster may easily be damaged by the floods. This may lead to, erosion of foundation, roof and some walls collapse, floating away of sheets (VH). The total collapse of the buildings may also occur.

Fig. 2: Front Elevation of house typology BBGI1LNG
Source: Author

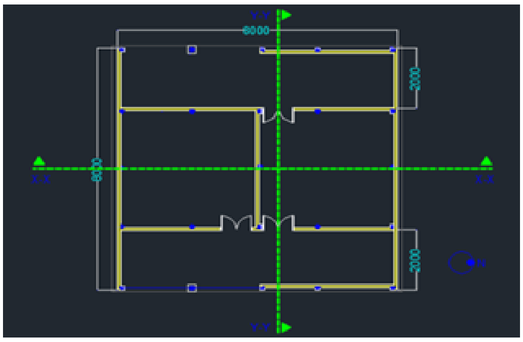

Fig. 3: Plan of house typology BBGI1LNG
Source: Author

2. Typology BBTH1LNP:

Typical Building Specifications

- Wall: bamboo with mud plaster
- Roof: Thatch on purlins attached to rafters spanning from ridge beam to eave level walls with intermediate beams.

These types of houses are very common in the Supaul district. The plans of the buildings are generally square with centrally located rooms and verandahs in front. Roofs are hipped shaped, as shown in the Fig. 5 & 6.

Fig. 4: Wall damage in house type BBGI1LNG
Source: Author

These buildings have the following risk levels

Earthquakes: - Large and deep cracks in mud plasters may occur due to the earthquakes. Walls may fail due to poor constructions (M).
High winds/cyclones: -Thatch roofs are very vulnerable to high winds as they are extremely light and are not properly tied down with the walls (Fig. 5). Walls in houses may fail, and whole roofs may fly (VH).
Floods: These may lead to the total collapse of the buildings floating away thatch, erosion of foundation; sever damage to life line structures and systems (VH)

Fig. 5: Front Elevation of house typeBBTH1LNP
Source: Author

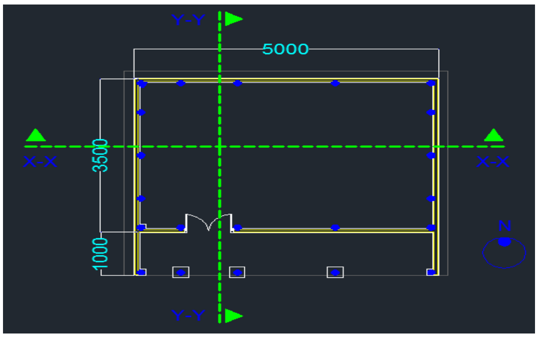

Fig. 6: Plan of the house type BBTH1LNP
Source: Author

3. The Type BRBGI1LNG:
Typical Building Specifications
- Wall: brick in cement mortar
- Roof: CGI sheeting on purlins attached to rafters spanning from ridge beam to eave level walls with intermediate beams.

These types of houses are also present in the Supaul district. The plans of the buildings are generally square with centrally located rooms and verandahs in front. Roofs are hipped shaped, as shown in the Figs. 7 & 8.

These buildings have the following risk levels

Earthquakes: The masonry walls are heavy and attract more earthquake forces. The out of plane behavior of the masonry walls are weak and can easily collapse in the absence of any reinforcement. The roof is light and hipped in shape. The, the roof will generate less static force if there is no gabble wall. Where gable walls are absent, the cracks may develop at the corners of the openings in the masonry walls. Gaps in walls may occur and parts of the buildings may collapse. Thus, the expected damage level is (H)

High winds/cyclones: In the absence of reinforcements, walls are weak against the lateral forces or the high wind loads and may fail. Roof is light and the whole roof can fly away if not tied well with the wall. Vulnerability level is very high (VH).

Floods: -As the walls are unprotected against the floods, large and deep cracks in the walls and bulging of walls can happen. Damage may occur to electric fittings. The vulnerability level is (M+)

Fig. 7: Side Elevation of the house type BRBGI1LNG
Source: Author

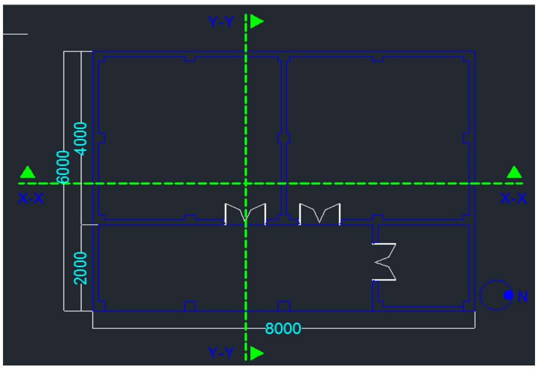

Fig.8: Plan of the house type BRBGI1LNG
Source: Author

4. **Typology BRAT1HNP:**

Typical Building Specifications

- Wall: brick in lime mortar
- Roof: earthen tiles on battens supported on rafters spanning from ridge beam to eave level walls with intermediate beams.

Many houses of these types are present in the district. The plans of the buildings are generally rectangle with centrally located rooms and verandahs in the front. Roof is hipped shaped, as shown in the Figs. 9 &10.

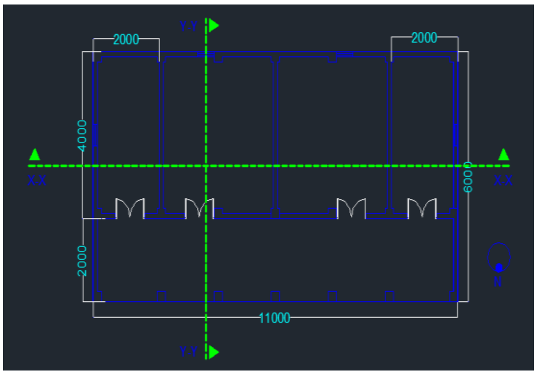

Fig. 9: Plan of the house type BRAT1HNP
Source: Author

Fig. 10: Side façade of the house typeBRAT1HNP
Source: Author

Fig. 11: Roof of the house type BRAT1HNP
Source: Author

These buildings have following risk levels.

Earthquakes: - The masonry walls are heavy and attract more earthquake forces. The out of plane behavior of the masonry walls in lime mortar is very week and can easily collapse in the absence of reinforcements. The roof is heavy and is hipped in shape. Thus, the roof will generate more static force. The absence of cross bracing makes it more vulnerable. Expected damage level is, Gaps in walls, parts of building may collapse, different parts of the building may lose their cohesion and the inner walls may collapse. The vulnerability level is (H+).
High winds/cyclones: Walls in the weak lime mortar in houses may fail, roof tiles fixed to the battens may fly or the whole roof may flyaway. Absence of cross bracing in roof trusses (Fig.11) makes them more vulnerable. The vulnerability level is (VH).
Floods: -The creation of gaps in the walls, flowing water may punch holes in walls, buildings may collapse partially, floating away of light roofs, erosion of foundations, tilting or sinking, undercutting of floors. The vulnerability level is (H).

On the basis of these above building types, as found from the field observations; the multi-hazard vulnerability of the vernacular houses in Supaul are presented below in the Table 6.

Table 6: Multi-hazard Vulnerability of Different Building Types of Supaul
Source: Author

Building Materials	Building Typology	% of houses	Level of Risks		
			Earthquake Zone V	**Wind velocity** 47m/s	**Flood**
Bamboo	BBTH1LNP	17	M	VH	VH
	BBGI1LNG	32	M	VH	VH
	BBGI1LNP	20	M	VH	VH
	BCAS1LNG	4	M	VH	VH
Burnt brick	BRBGI1LNG	8	H	VH	M
	BRCAS1LNG	3	H	VH	M
	BRBGI1LCP	3	H	VH	M
	BRDGI1HVLNG	1	H	VH	M
	BREC1FCG	2	H	M	M
	BRAT1HNP	4	H	VH	H
Mud	MATH1LNG	1	VH	VH	VH
	MBTH1LNG	1	H	VH	VH
Unburnt Brick (UB)	UBATH1LNP	1	VH	VH	VH
	UBBGI1LNG	1	H	H	VH
concrete	CC1FCG	1	M	VL	L

Criteria to be Adopted in the Design of Buildings

Based on the multi-hazard situation and vernacular building methods, the following criteria may be adopted in constructing the houses:

- **Foundations**

Against the erosion effects of flowing water, foundations should be resistant and remain stable under the liquefaction effects which can occur due to earthquake intensities MSK VIII or more. As it is known that during the floods, the rise of the water table reduces the bearing capacity of the soil by around 50%. Hence, the low bearing capacities should be considered (Sharma, *et al.*,2018).

- **Plinth**

Plinth level of a house should be above the prevalent flood level in the area and the natural drain level in the village. The plinth of the house must be made of non-erodible materials.

- **Superstructure**

The superstructure walls must behave stable under the earthquakes as well as high wind conditions. The wall material should not become soft and dissolve under water in case the inundation level rises (Arya, 2008). At the top level of the walls, a horizontal framework is required in case of the sloping roofs or an eave level band beam in integration with the superstructure walls/frame for providing integrity with all the enclosing wall system.

- **Roof**

The roof should be light and tightly anchored with the superstructure. Heavy roofs generate high static loads in case of earthquake forces which may lead to the damage of the structure. Light roofs can easily fly away if not anchored properly. A hipped or pyramidal roof is preferable to the gable type roof. As per the recommendations given by NDMA, the roof of houses in the flood prone areas should done in such a manner that it may act as the evacuation platform for the occupants during the high level of flooding i.e when flood water rises above the waist level (Ministry of Home Affairs, GOI, 2011).

Conclusion

Through the analysis of a number of case studies, it can be concluded that the risk level of different types of the vernacular houses depend upon several factors like, building forms, construction materials and maintenance etc. Vernacular architecture and construction practices may need to be transformed with respect to the vulnerability profile of the district to enhance their performance against the existing hazards.

Therefore, different retrofitting/modifying approaches have been recommended in accordance with three types of construction practices i.e. mud, bamboo and brick masonry. It is recommended that all the new constructions of habitats needs to have integral disaster resistant features with respect to the major hazards of the area. The buildings constructed without adequate disaster resistant elements may be retrofitted. The techniques suggested are also cohesive with the locally available labor and material. The multi-hazards make the situation more dangerous (Kappes, *et al.*, 2012) as seen in case of Supaul. Assessments for different combinations of hazards are needed. There are several building types which have different levels of risks against the different hazards (Kaushik, *et al.*, 2005). Here, the primary hazards were identified and possible mitigation approaches are explored.

Scope for Further Research

This research was aimed for the vulnerability analysis of the vernacular buildings of Bihar. One of the most hazard prone areas of Bihar, Supaul, was taken for the case study. Similar studies can be carried out for the other regions too. The parameters may vary with respect to the building types of the local context. The study found out the impact of disasters on different vernacular building type. Therefore, further research can be undertaken to explore the relationship of disasters specifically to changing building technologies.

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