Vulnerability and risk assessment of Transport Infrastructure of Navi Mumbai for Disaster Risk management and planning

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Abstract:

Vulnerability is the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure. However, in common use the word is often used more broadly to include the element's exposure.

Hazard, risk, vulnerability assessment (HVRA) is a critical, scientific process that serves as the foundation for Disaster Risk Management (DRM) planning and programming. By giving a clear picture of the risk profile of the transportation infrastructure of the metro city, disaster risk reduction plans can be developed such as emergency management plans, land use and urban development planning, construction and building, licensing, environmental management, social welfare, and other services.

By developing vulnerability and risk assessment and mapping for metro city of India, i.e. Navi Mumbai, it can be easy to evaluate and estimate the potential human and material losses, functional impacts (downtime of services and transportation infrastructure) and their spatial and sectoral distributions, impact on critical facilities and functions, identification of high risk areas or "hotspots", identification of evacuation roads and potential for fires, explosions and hazardous material release, and assessment of disaster "demands" versus the available "resources" for any natural disaster.

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Introduction

Transport represents one of the most important human activities worldwide. It is essential component of economy and plays an important role in maintaining spatial relationships between locations. Considering these points Transportation system's efficient and continuous working is mandatory. The operations will be negatively affected by natural disasters. Also, it will result in infrastructural, economic and socio-cultural losses. To minimize these negative effects, we require an effective Risk Management system in place.

The on-going development of Transport Infrastructure in and around Navi Mumbai calls for the need of quantitative and qualitative Risk Assessment to give guidelines for safe and viable investments and construction activities. The intention of this work was to provide with the information to decision makers for developing land and land use zoning, planning emergency response strategies, preparing infrastructure budgetary decisions, preparing guidelines for operation of existing infrastructure and general policy development at all levels.

Scope of the study

The present study covers municipal region of Navi Mumbai as shown in Fig. 1. Only roadways and railways and railway stations are considered as transportation infrastructure. Navi Mumbai has a 650 km-long road network that connects nodes and neighboring towns, besides 5 major bridges, 8 flyovers, 15 road-over bridges. The Trans-harbor and Harbor lines of central railways pass through the municipal region of Navi Mumbai with total 12 stations.

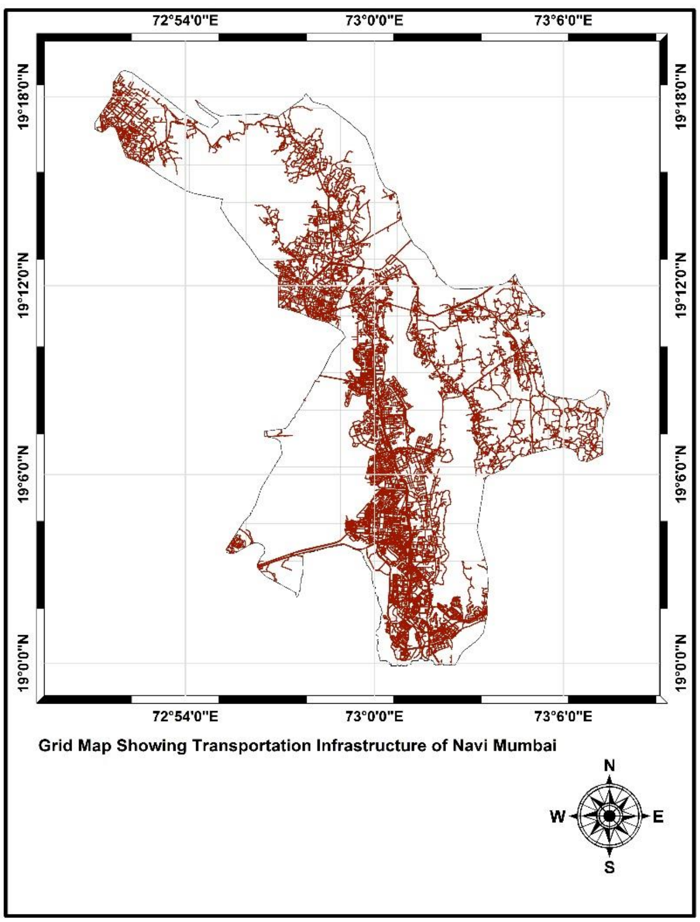

Fig: 1 Layout of Navi Mumbai city

Methodology

The study done for this report treats occurrence of the disaster such as earthquake and flood at a location independent of each other. The model also assumes that the occurrence of the disaster events will not overlap each other. This assumption is made to simplify the magnitude of complexity posed by simultaneous occurrences.

Grid Blocks

The study covers 344km^2 of municipal region of Navi Mumbai. The region is divided into smaller grid blocks of '1km x 1km'. The risk parameters for these grid blocks are calculated separately as mentioned in subsequent sections.

Risk Parameters

The Risk associated with a particular disaster mainly depends on three parameters which are hazard, vulnerability, and severity. Hazard is associated with probability of occurrence of disaster whereas vulnerability is susceptibility of asset under consideration to the effects of disaster and severity is intensity or extent of disaster.

Vulnerability Index

The vulnerability of roads and railways are calculated separately. Total length of roads and railway lines are calculated for each grid block and the grid blocks with maximum length of roads and railways are identified. The vulnerability for roads and railways is calculated as,

$$v_{rdi} = \frac{L_{rdi}}{L_{rdmax}} \qquad v_{rli} = \frac{L_{rli}}{L_{rlmax}} \qquad v_{sti} = \frac{N_{sti}}{N_{stmax}} \tag{1}$$

L_{rdi} = Total length of roadways in i'th grid (km)
L_{rdmax} = Maximum length of roadways identified in all grid blocks (km)
L_{rli} = Total length of railway in i'th grid (km)
L_{rlmax} = Maximum length of railway identified in all grid blocks (km)
N_{sti} = Number of railway stations in i'th grid
N_{stmax} = Maximum number of railway stations identified in all grid blocks
v_{rdi} = Vulnerability of roadways i'th grid
v_{rli} = Vulnerability of railways in i'th grid
v_{sti} = Vulnerability of stations in i'th grid

For each individual grid block, we have calculated a value of overall vulnerability given by taking average as,

$$VI_i = \frac{v_{rdi}+v_{rli}+v_{sti}}{3} \tag{2}$$

The vulnerability calculated by the mentioned expression represents the amount of transport infrastruc1ture susceptible to damage in a given grid. Special infrastructure is not necessary to board a bus where as in case of railways, the need for platform to board the train make Railway stations a critical structure. Thus, we have considered only railway station as terminals and not included bus stops as terminals in this study.

Hazard

Hazard (H_i) is calculated as probability of occurrence of natural disaster. The typical value of Hazard will range from 0 to 1.

Severity Index

Severity (s_i) indicates maximum amplitude of disaster recorded in i'th grid block. Severity Index will give a relative value of extent of disaster.

$$SI_i = \frac{s_i - s_{min}}{s_{max} - s_{min}} \quad (3)$$

s_{min} = Minimum value of severity amongst all grid blocks.
s_{max} = Maximum value of severity amongst all grid blocks.
The SI will typically range from 0 to 100.

Risk Index

As the three indices mentioned above are independent of each other, the risk index can be calculated simply by multiplying the three indices. Risk index for i'th grid block is given by,

$$RI_i = VI_i \times H_i \times SI_i \quad (4)$$

The risk index typically ranges 0 to 1.

GIS Mapping

GIS is one of the useful tools for hazards or risk analyses and mapping. In the present study, ArcGIS 10.5 software is used for all image preparation, spatial analysis and mapping. The data is stored in various layers as shapefiles (with extension .shp) and these layers or features are overlaid, intersected, clipped and spatially joined to produce a map for visual representation of the vulnerability of the transportation infrastructure of Navi Mumbai.

A uniform square grid layer having area of approximate 1sq.km is generated and is clipped with the digitized boundary map of Navi Mumbai city. A layer of square cells lie over the Mumbai city base map, dividing the whole city into 398 number of grid cells as shown in Fig. 1. The area, length are computed using the 'Calculate geometry' tool and 'Field Calculator' tool. It can also 'count' the number of features on the map by overlaying or combining the features. Thus, an additional data can be derived and stored in shapefiles.

Data Collection

In the present study, the transportation infrastructure data such as roads and railways are derived from volunteered geographical information (VGI) such as OpenStreetMap (OSM) that is obtained from online ArcGIS. In the recent literature, several studies have addressed the completeness of OpenStreetMap (OSM) by comparing it with other reference data sets (Haklay, 2010), (Zielstra and Zipf, 2010), (Girres and Touya, 2010), (Hecht et al., 2013). It is recommended that OSM data is fairly accurate and by using it the urban areas can be easily and better mapped. A total number of 398 data grid points are collected covering the whole of Navi Mumbai city as shown in Fig.1.

Results

Based on the Vulnerability indices calculated using the proposed expression as stated above in Equation (1) and (2), colour coded map for Navi Mumbai is prepared as shown in Fig. 2 indicating the grid wise vulnerability of the transportation infrastructure. It is observed that, though major transportation infrastructure of Navi Mumbai lies in low vulnerability zone, there are few areas having roads and railways that may be subjected to moderate to high vulnerability with VI from 0.25 to 0.75 while an area of 1sq.km towards the south of Navi Mumbai may be prone to critical vulnerability with VI ranging from 0.75 to 1.

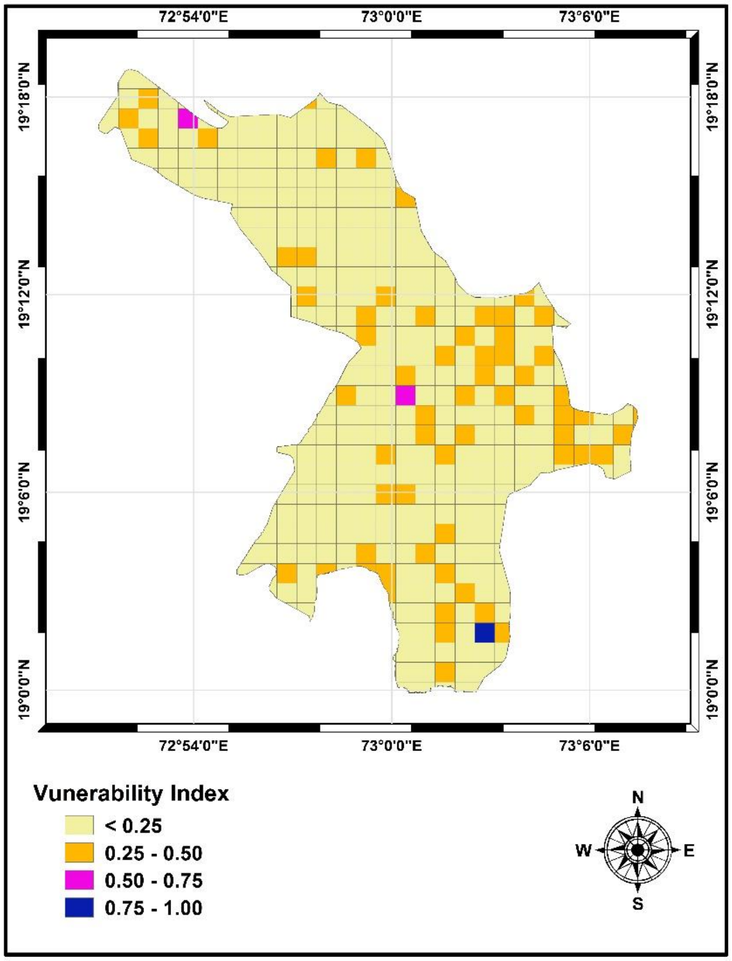

Fig: 2 Proposed Vulnerability Map for Navi Mumbai City

Conclusion

In the present study, transportation infrastructure vulnerability grid maps for Navi Mumbai city have been generated to project the use of ArcGIS for vulnerability assessment and mapping. The grid wise color maps showing the VI gives a fair idea about the impact of any disaster on the infrastructure and the need of hazard-vulnerability studies to be carried out for urban areas. These maps can be combined with the hazard maps to quantify the damages beforehand so that better disaster management plans can be framed for the city by the municipal authorities.

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