

## EVALUATING THE SPATIOTEMPORAL TRENDS IN FLOOD HAZARD ZONATION IN IMPHAL EAST AND IMPHAL WEST DISTRICT THROUGH GEOSPATIAL TECHNOLOGY

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**Abstract-** The northeastern part of India, in particular the Imphal Valley itself, is highly prone to recurrent flooding, which poses very substantial risks to life, property, and socio-economic development. In relation, this study aims to evaluate spatiotemporal trends in flood hazard zonation using advanced geospatial technology through integration with historical flood data, satellite imagery, and topographic information. Detailed flood hazard maps respecting the differing levels of risk were then produced, considering contributing factors such as land use changes, hydrological patterns, and climate variability. With variables like fill, contour, flow direction, slope, stream order, and land use/land cover, the weighted overlay method was applied with much efficiency in the identification of flood-prone locations. The results basically show that the locations prone to flood are characterized by low elevation, steep slope gradients, and certain land use patterns. These are valuable recommendations to reduce and control flood risks, hence providing policymakers options toward better flood-response and resilience-enhancing strategies. The detailed analysis of the dynamic spatiotemporal patterns of flood hazards in the Northeastern region, particularly in the Imphal Valley, covers the research gap identified in existing studies. In this regard, a weighted overlay method for flood zonation was found effective in identifying the dynamics of flood hazards and seeing how they have been changing with time through both the natural and anthropogenic process. Advanced modelling techniques integrated with real-time hydrological data will further enhance accuracy and predictability in future studies. Community-based flood preparedness and early warning systems are again very vital instruments to be taken against such impacts on vulnerable communities. The research will, therefore, increase our knowledge with regard to the dynamics of floods and aid in the formulation of sustainable flood management practices in relation to interdisciplinary collaboration and the use of geospatial technology.

**Keywords:** Remote Sensing, Flood Management, Land Use Land Cover(LULC), Digital Elevation Model(DEM), Weighted Overlay Analysis.

### **Introduction**

Floods are natural hazards that occur all over the world affecting all the continents and also millions of people in a year. Such catastrophic events results in large scale economic losses and ecological damages ,which in turn disrupt lives and livelihoods. Flooding has far-reaching impacts

that goes beyond its initial devastation, contributing to delayed rehabilitation and lasting recovery efforts for the affected communities. Economic activities are also frequently disrupted ,infrastructure can be severely damaged and significant changes in the ecosystems may occur. Climate change has further intensified the incidence and magnitude of floods, making flood a perpetual and an escalating global hazard.(Jonkman, 2005)

When flood events are framed at global scale, they are researched from several angles of hydrology, but also climatology, disaster management and other similar fields. Focussing on the flow, distribution and quality of water, which is hydrology helps us understand how floods move and behave. It becomes easy to know how emerging weather and climate issues could possibly influence floods by examining the association between floods and climatology. Disaster management includes an array of strategies and procedures intended to both anticipate the formation of floods, reduce the risk or the effects of floods and the response and recovery operations after a flood has occurred. In addition, floods contributes to numerous consequences on humanity and natural systems, the study of which is furthered by fields such as sociology, urban planning, and environmental science.(Merz et.al, 2014)

In India, flooding results most from severe monsoon, cyclonic storms, and overflowed rivers. The Monsoons, which sweep the Indian subcontinent from June to September every year, deliver about 75% of the country's total rainfall and represent a major period of flood risk. Heavy rainfall for a continuous period may cause severe flooding when the volume of the river system overtops. Besides, cyclonic storms originating in the Indian Ocean and the Bay of Bengal can cause torrential rainfall and strong storm surges that further worsen the situation. Thus, these natural phenomena result in periodic and severe flooding, affecting rural and urban settings. Likewise, the geographical diversity of India with its extensive river networks and diversified topographical features further enhances the magnitude and the complexity of these related flooding events.(Rajeevan et.al, 2010)

Flood is also an annual natural calamity with devastating effects, impacting large stretches of North-Eastern areas of India, which includes the states: Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura, and Sikkim. These regions are prone to flooding due to the presence of numerous rivers and their tributaries and torrential showers of monsoon that they receive. In Assam, the Brahmaputra and its tributaries in particular create significant floods that uproot thousands of people and hugely damage infrastructure and crops. The hilly topography of the area only intensifies the effects, causing flash floods and landslides. The Northeastern states still have a lot toil to be done regarding the post-management and recurrence of floods, despite extensive attempts to lessen its effects through projects like embankments and flood control. (Pradhan et.al, 2021)

The Northeast experiences two different seasons of flooding: pre-monsoon and monsoon, from May to September. The frequency of flooding in the region is intensified due to its geographical distinctiveness with the Brahmaputra and Barak river systems and abundant rainfall at these times. Causes that further intensify this flooding scenario and have catastrophic effects on the environment and socioeconomics include deforestation, rapid urbanisation, and poor drainage

systems. Urbanisation increases impermeable surfaces on the land, which increases the amount of runoff, while deforestation decreases the infiltration capacity of the soil. Flows surpass the capacity of poor drainage systems to take away the water and result in waterlogging and urban flooding. These problems highlight the pressing need for comprehensive plans for flood control in order to mitigate the catastrophic effects of floods in the Northeast. (Merz et.al, 2010)

The intensity and recurrence of floods have impacted infrastructure, crops, sources of living, and human lives in the Northeast. The most significant impact is seen with floods in the agricultural sector due to the fact that crops, cattle, and agricultural land are seriously affected by floods, which leads to long-term detrimental effects on the economy. Other repercussions are on the infrastructure, including roads, buildings, and bridges, through the destruction of networks of transportation and communication. These effects are intensified by the geography and heavy rainfall in the area, thus making flood susceptibility a significant concern. Some of the measures in place to minimize these impacts include sustainable land use practices, improvement in infrastructure, and early warning systems. However, its flooding is recurring, leading to the necessity of continued efforts to increase resilience and minimize vulnerabilities in the face of future floods.(Gupta, 2003).

### **Objectives**

- 1) To assess the role of topographic and hydrological features in flood hazard zonation.
- 2) To study the changes in flood-prone zones over different time periods in selected part of the northeast region.
- 3) To create detailed flood hazard maps indicating varying levels of flood risk.

### **Study Area**

For the state of Manipur, Imphal East and Imphal West, situated in the heart of the state of Manipur in northeastern India, geographically, constitutes the state capital of Imphal. The geographical location of these two districts falls approximately between latitudes 24.78°N and 24.81°N and longitudes 93.88°E and 93.95°E. They are divided by the Imphal River; to its west lies Imphal West and to its east, Imphal East. These districts are Valley regions surrounded by hills from all sides that keeps the valley cool, in a temperate climate with serene green surroundings. By road connectivity, Imphal East and Imphal West are well-linked and have considerable historical and cultural importance, with a number of historic sites, markets, and cultural festivals that draw visitors and researchers alike. The two districts were once a full district which was divided into the existing structure in the year 1997. The flow of the Imphal River, a main tributary of Manipur River, also adds to the rich agricultural productivity of these districts.

Though the Imphal river serves as a major source of water for numerous people residing along its river bank. It sometimes resembles a curse during flooding in the monsoon season, The Imphal river divides the two district of Imphal west and Imphal East, the river flows through the heart of the capital transversing the state's major area of demographic concentration. As a result of urbanization the river bank is gradually deposited by silts and the depth is thus reduce causing floods when faced with an adequate amount of rainfall. The Imphal river serves as a buffer between

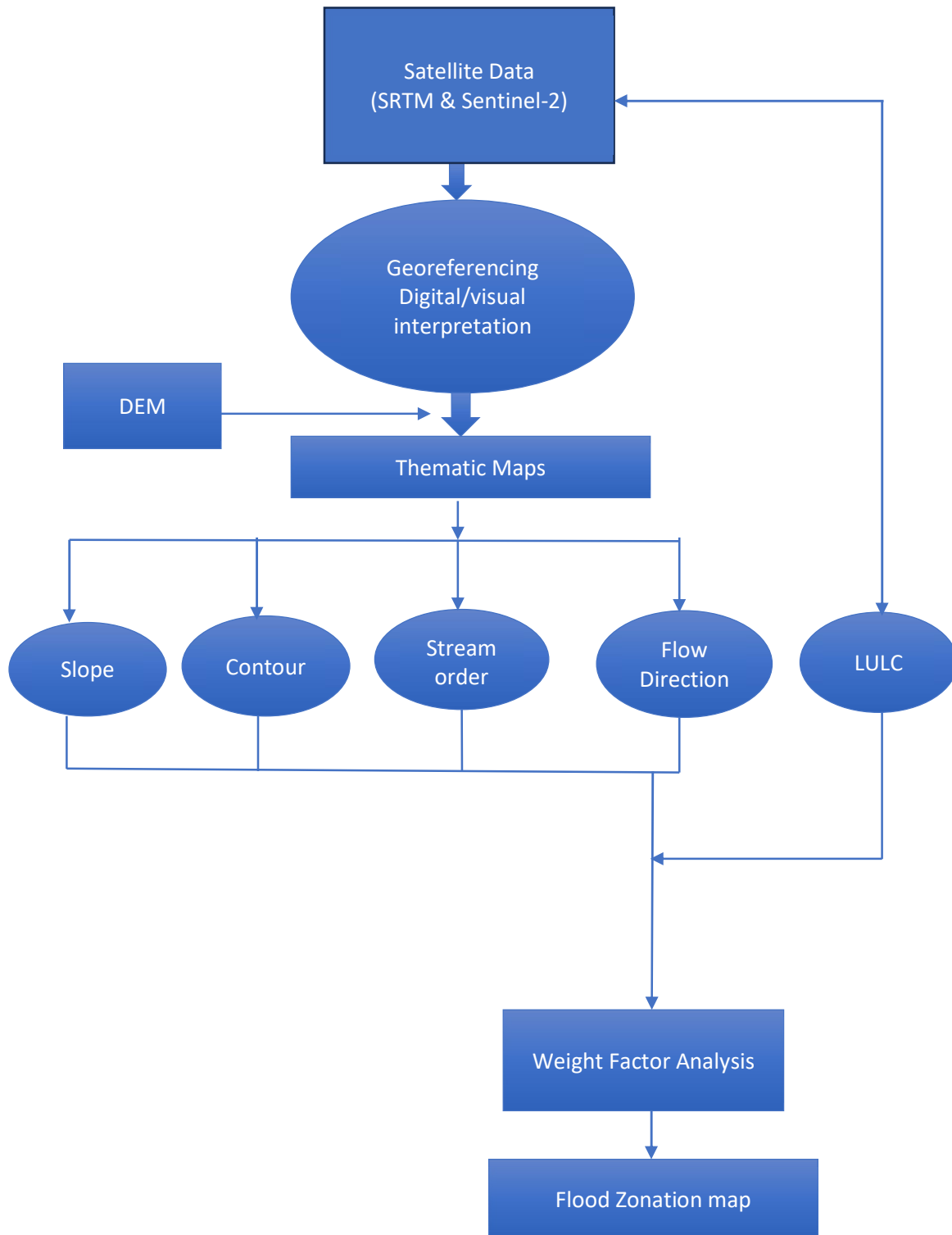
the two districts of Imphal west and east, it forms both a geographical as well as administrative boundary between the two. The flooding of the Imphal river is significant as it impacts both district and majorly impacts the periphery of the two district which is the area where all the major hub for all activity and functionaries of the state are located.

### **Methodology and Materials**

The following materials listed below have been used for my study area:

- Satellite images (IRS-1D, LISS-III, Sentinel-2, Google Earth images)
- Topographic (map scale), ESRI land use and land classification maps
- Survey of India Online maps, USGS Earth Explorer
- Thematic maps ( LULC, drainage network, slope, DEM, contours, etc.)
- Hydrogeological data and maps
- Geoinformatics software's ( Google Earth, ARCGIS)

The detailed methodology flow chart to be adopted for the study is as given below :



**Fig 1:** Methodological Flow Chart of the work

## Results & Discussion

### Generation of Data and Maps

The maps use in the work has been sourced from ESRI online site where LULC maps are readily available, the maps were of 10 meter resolution of Sentinel-2. For comparison of the difference in land use over temporal differences we have taken the maps which has a year gap of 6 years i.e. 2017 and 2023. Observing the spatial temporal difference of the same area will grant us the idea of what factors has induced the change in it's usage pattern, it will also show us the change in purpose allocated to particular area over the years and ultimately how flooding has been induced in prone areas.

For Dem maps, the raster file has been sourced from USGS Earth Explorer, the image is of 1 arcsecond or 30 meter resolution captured through Shuttle Radar Topography Mission.

### Assessment of the flood hazard zone

Assessment of flooding in the hazard zone of Imphal was done by considering certain relevant factors. Their significance has been indicated by weighting the class elements. The causative factors taken into account for this study included the following listed below:

- Slope
- LULC
- Flow Direction
- Stream Order
- Contour

Theoretically, there are still more causative factors, for example daily rainfall, the hydrograph of the main stream networks of the basin, etc.

The weight of each factor has been assigned keeping in mind the risk it carries and on the basis of its estimated significance in the process of causing flooding. The weight of each factor is as shown below in the Table1.

**Table 1: ASSIGNED WEIGHT FACTOR CLASSES**

Serial No.	Weight of the Factor	Assigned Weights
1	Flow Accumulation	9
2	Slope	8
3	Stream Order	7
4	Flow	6
5	Fill	5
6	Contour	3
7	LULC	1

Further each factor has been divided into a number of classes with each class being weighted according to the estimated significance for causing flooding. The maximum weight for each class of every factor is 9 whilst the minimum is 1.

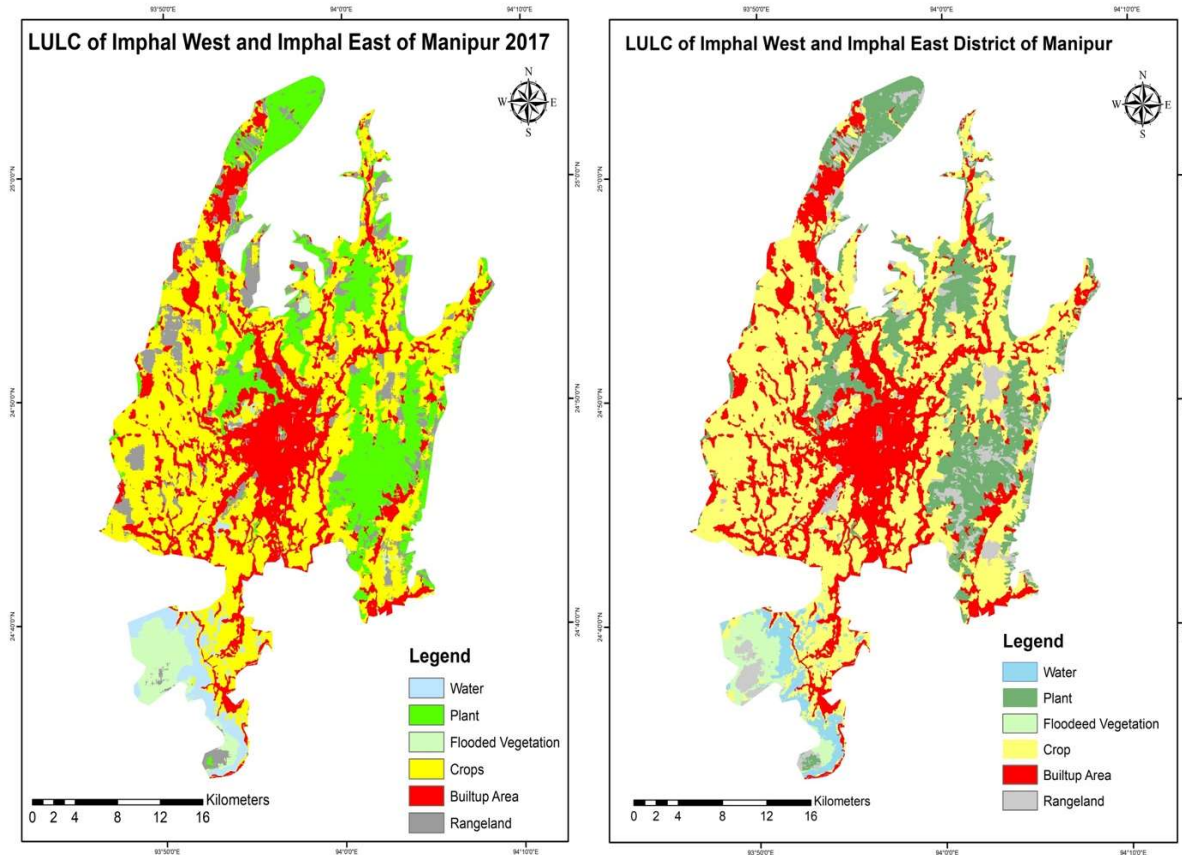
### LULC

Considering the land use map compiled from satellite imagery of the area the class and the weight of each land use classes is shown below in the table 2.

**Table 2: ASSIGNED WEIGHT FACTOR CLASSES of LULC**

Serial No.	Weighted Value	Assigned Weights
1	Water	9
2	Flooded Vegetation	8
3	Built-up Area	7
4	Crop	5
5	Plant	3
6	Rangeland	1

Given below are the images obtained after performing Land Use and Land Classification for the study area of Imphal Valley i.e. the Imphal West and Imphal East district, which is the main administrative centre of the state. From the image shown and the data obtained from the LULC map, we create charts to graphically represent how the share of lands have change over spatial change.



Fig

2: LULC of the Imphal Valley 2017 & 202

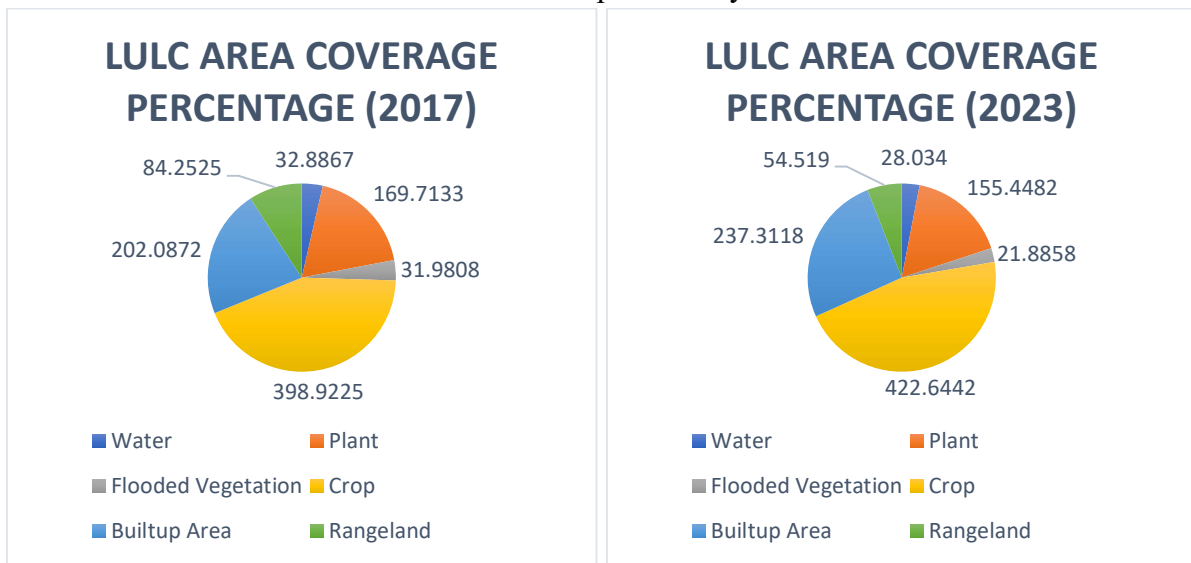
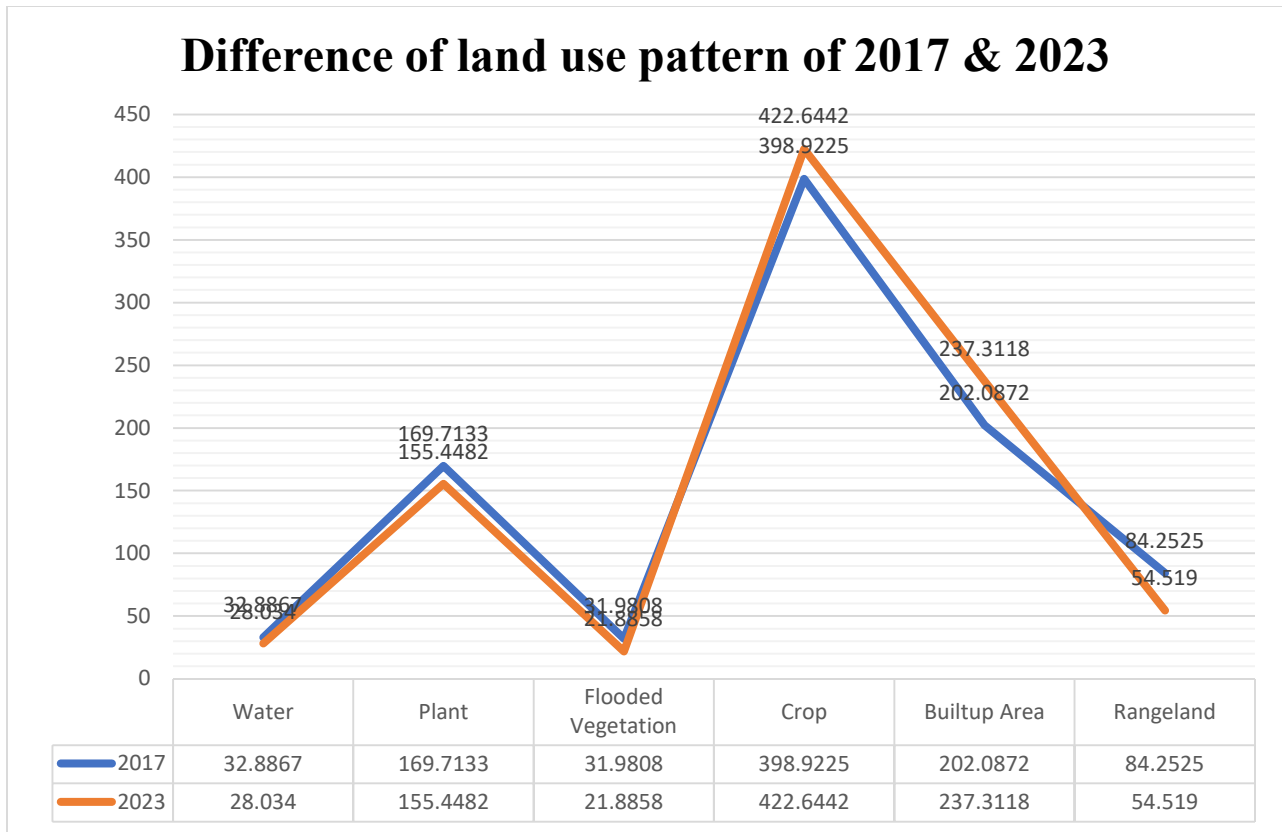


Fig 3: Percentage of area coverage of LULC 2017 & 2023

From the above charts we clearly observe that all aspects of land use have decrease except crop and built-up area, this is a clear sign that human activities have, is continuing and will continue to alter the topographical landscape that is with mother nature. Monitoring these two years have given

us a detailed insight of how urbanization have impacted on the morphology of our the city. Given below is the drastic change in various land use pattern.



**Fig 4:** Difference of land use pattern in Imphal (2017-2023)

### Slope

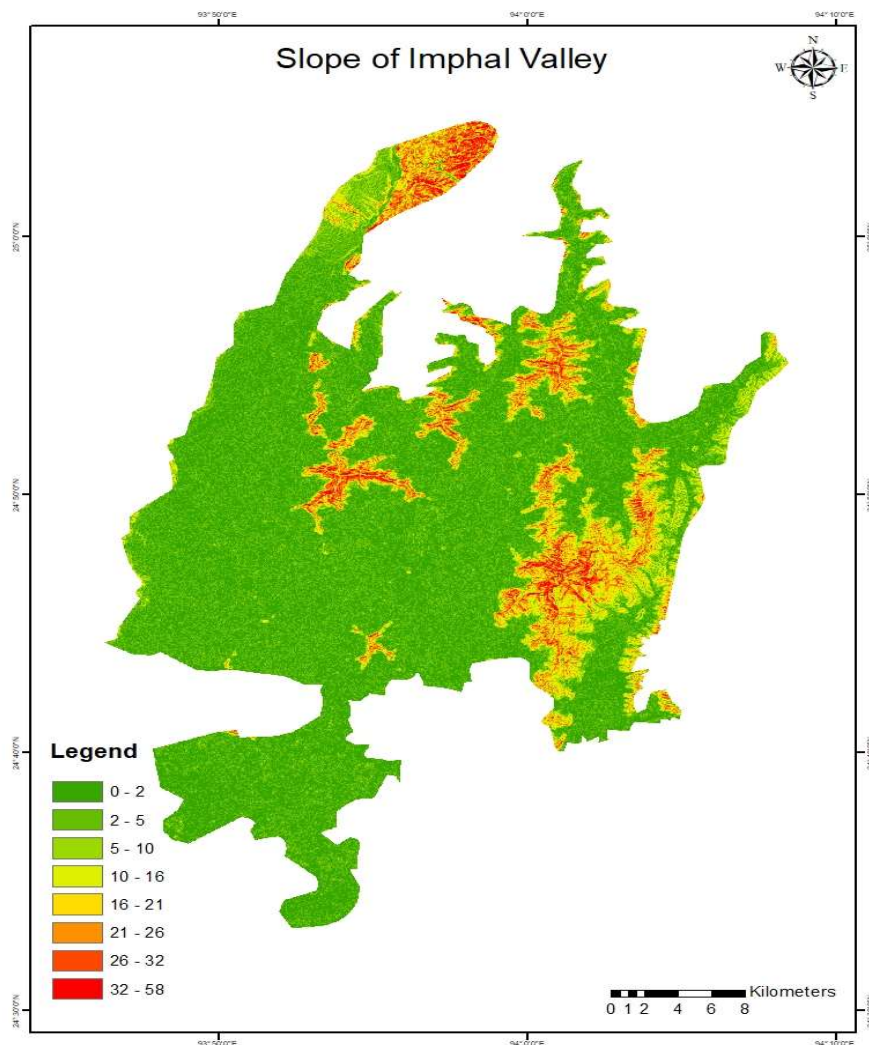
The weight of each factor has been assigned keeping in mind the risk it carries and on the basis of its estimated significance in causing flooding. The Values of the slope creates a situation for inducing flood based on the magnitude of its inclination. So the greater the slope greater the impact and susceptibility to flood. The weighted value of each of the above mentioned factors are shown in the Table 4.

**Table 3:** Assigned weight factor classes of slope

Serial No.	Weighted Class	Weighted Value
1	0-2	1
2	2-5	3
3	5-10	4
4	10-16	5
5	16-21	6
6	21-26	7
7	28-32	8
8	32-58	9

The Imphal Valley is centrally located and has unique topographical features. Slopes plays a very significant role in the dynamics of flooding in this region of Manipur, India. Comparatively, it has a quite flat valley amidst surrounding hills and hence the acquittance and flow of water is rather different as compared to other places during heavy rainfall and monsoon seasons. The surrounding intake capacity of the waterways is hugely dependent of the slope of the periphery juncture.

The mild slopes of the hills surrounding the Imphal Valley allows water to flow in slowly to the underlying areas. Because of the lower topography, the rainwater cascades down the hills to spread over the valley and collect at most places. This often leads to considerable waterlogging and flooding, mainly in areas where drainage infrastructure is poor and the waterways are narrow as a result of diminishing land.



**Fig 5:** Slope map of the Imphal Valley

## Contour

Contour lines show the elevation and slope of the land, which often influences the patterns of flooding at places such as the Imphal Valley. They form a very important topographical feature that impacts the flow and accumulation of water during intense rainfall events. Understanding the topography of Imphal Valley helps in learning the mechanics of floods at this particular place.

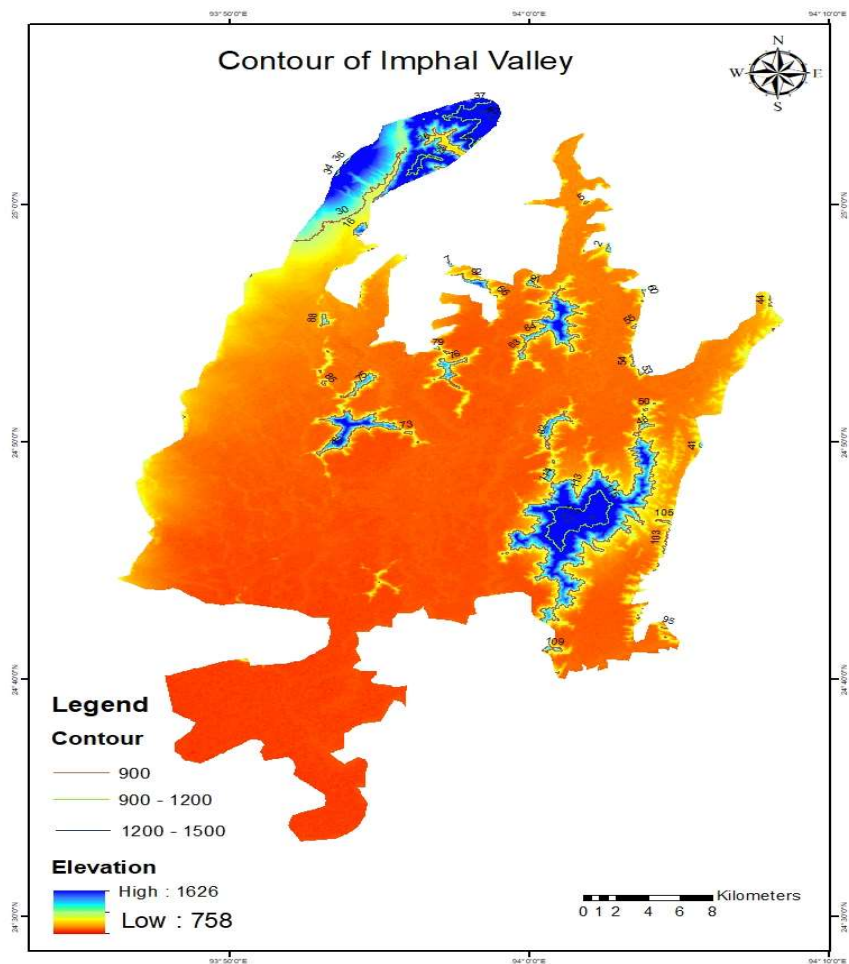
Firstly, it is the mountainous topography that surrounds the Imphal Valley, which determines the direction and velocity of the flow of the water. Heavy rainfall sends water from the adjoining hills rushing down the contour lines. This rapid runoff from the steep slopes of the hills reaches the comparatively flat valley below. The rapidity of the inflow of this water can easily overpower the artificial and natural drainage systems to cause extensive flooding. The moderately sloping valley, as shown by the wide spacing between contour lines, makes prolonged flooding much more likely. Water tends to spread out and remain rather than drain quickly.

It is also evident in the way that contours influence the way floodwaters are discharged over the valley. While widely spread contours indicate flatter terrain, where water tends to stagnate and pool, the areas with closely spaced contours would indicate a rather steep slope that allows faster circulation of water. Large areas with more level terrain are, therefore, more prone to longer periods of flooding and waterlogging. This is because the flatter areas—of which populations and agriculture are commonly based—do not have the natural gradient necessary to drain excess water. In effect, these low-lying areas may be subjected to prolonged periods of flooding, which impacts daily life, infrastructure, and crops.

Considering the risk factors given below is the table of weighted value:

**Table 4: ASSIGNED WEIGHT FACTOR CLASSES of CONTOUR**

Serial No.	Weighted Class	Weighted Value
1	900	1
2	900-1200	5
3	1200-1500	9



**Fig 6:** Contour map of the Imphal Valley

### Fill

Fill in Digital Elevation Models will help in understanding and controlling flooding in Imphal Valley. DEMs provide information of a proper concept about the landscape, like elevation and slope, that would help in predicting how water might flow across the environment. DEM filling thus involves enrichment of the elevation data to provide a continuous surface for topography in the real world. The procedure becomes very important for flood control and modelling within the Imphal Valley, where intricate topography and elevation changes can have a great effect on the behaviour of floods.

Filled DEMs provide more accurate hydrological modelling and flood prediction in the Imphal Valley. Accurate elevation data eases the simulation of the movement of precipitation and runoff across the terrain. This is vital in locating places vulnerable to floods and in inundation volume and level forecasts of floods. A full digital elevation model can be useful in understanding how water from heavy rains will flow from the hills into the valley in Imphal Valley, where both steep hills and gentler valley floors combine to potentially overflow drainage systems and produce floods. Accurate flood modelling, using a filled DEM—can enable proper design and emplacement

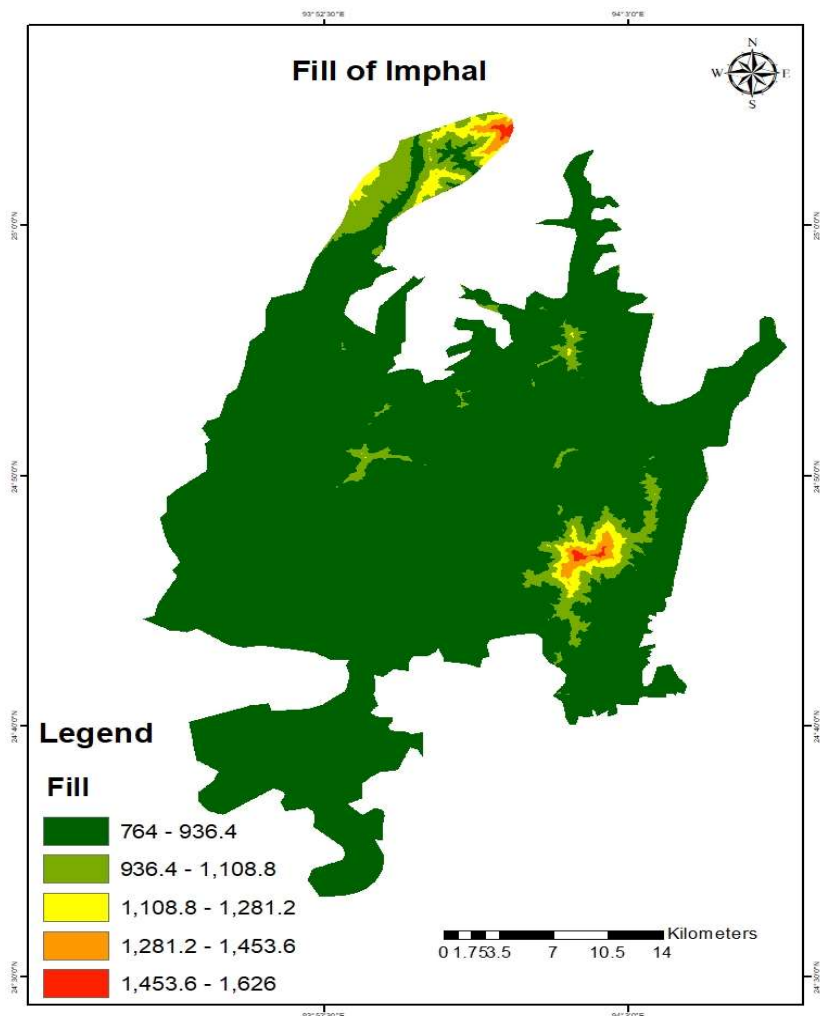
of infrastructure such as levees, drainage systems, and flood barriers to enhance flood preparedness and mitigation programs.

DEM filling can be very beneficial in finding out important topographical characteristics that eventually affect floods within the Imphal Valley. Through its use, mapping and studies of features like areas of drainage channels, natural depressions, or low-lying areas can be done. All these features get the first floods during intense rainfall periods. So, a complete and accurate DEM will allow for determining all such areas of vulnerability and formulation of solutions targeted toward these areas. This could involve the construction of buffer zones that will be capable of holding more water, improving the natural drainage channels, and building retention basins. Such targeted measures become extremely important in the Imphal Valley, where human growth and natural topography require special consideration with regard to appropriate management of flood risks. A high fill value will occur in areas where significant elevation adjustments were needed to eliminate deep sinks or depressions.

The weight of each factor has been assigned keeping in mind the risk it carries and on the basis of its estimated significance in causing flooding. The Values of the fill creates a situation for inducing flood based on the magnitude of its value. So the greater the value of fill greater the impact and susceptibility to flood. The weight of each factor is as shown in the table below:

**Table 5:** Assigned weight factor classes of fill

Serial No.	Weighted Class	Weighted Value
1	764 - 936.4	1
2	936.4 – 1108.8	3
3	1108.8 – 1281.2	5
4	1281.2 – 1453.6	7
5	1453.6 - 1626	9



**Fig 7:** Fill of Imphal

### Flow Direction

In the case of Imphal Valley, flow direction values become very sensitive components of a Digital Elevation Model, which may therefore influence much of the flooding pattern in the state capital of Manipur. The values describes the pathway water will take as it moves down the landscape; information very near and dear to predicting areas susceptible to flooding. The unique topography of the Imphal Valley itself is characterized by low-lying land with hills all around, so even small elevation differences may quite effectively influence water runoff. Accurate flow direction datasets help in understanding natural drainage paths and potential bottlenecks, which are areas where water will naturally get collected and cause localized flooding. Such knowledge will be useful in any flood risk management and mitigation strategies for ensuring that the vulnerability of an area can appropriately be safeguarded.

The flow direction values in the Imphal Valley are also important for urban planning and setting up of infrastructure. The valley receives heavy monsoon showers, and therefore, the water needs to flow efficiently through both natural and man-made channels. Hence, flow direction analysis will help set up drainage systems aligned to natural water movement, thereby decreasing the risk of urban flooding. Location of potential areas where water may settle and be oriented due to construction or natural barriers can help in preventing latent water settlement and reducing flood risk. Thus, on the whole basis, accurate flow direction analysis in DEMs can hardly be dispensed with for understanding the complex hydrological dynamics of Imphal Valley in improving its resilience against flooding.

Given below is the value of flow direction and it's corresponding direction which it Table represents:

**Table 6:** Values of flow direction with their corresponding direction.

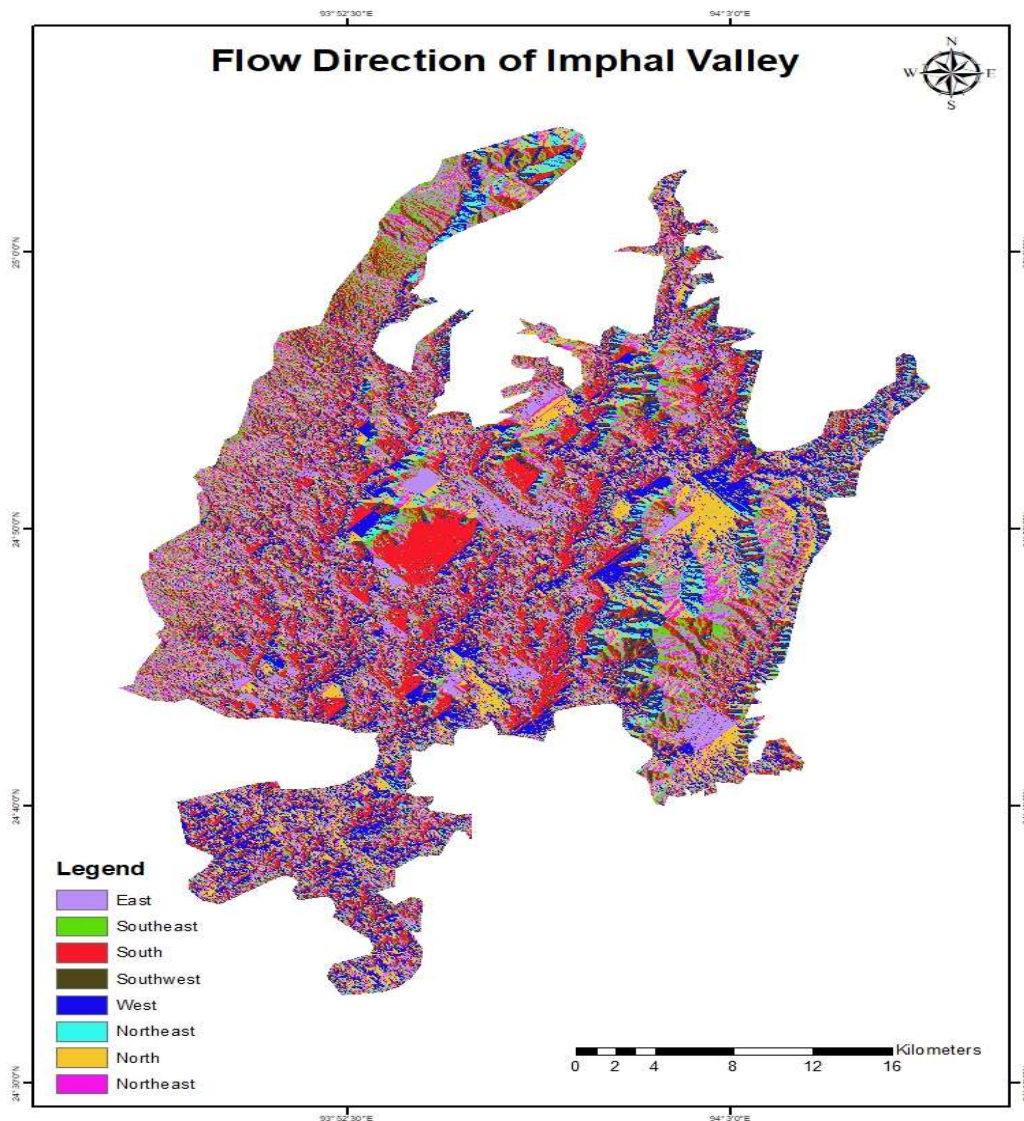
Direction	Direction Value
East	1
Southeast	2
South	4
Southwest	8
West	16
Northwest	32
North	64
Northeast	128

The weight of each factor has been assigned keeping in mind the risk it carries and on the basis of its estimated of flow direction and the significance in causing flooding. The Values of the flow direction creates a situation for inducing flood based on the direction of how the rivers flow when compared to the urban centres where activities are concentrated . The weighted value of each class is as shown in Table 7.

**Table 7:** Assigned weight factor classes of flow direction.

Serial No.	Weighted Class	Weighted Value
1	East(1)	5
2	Southeast(2)	7
3	South(4)	8
4	Southwest(8)	9
5	West(16)	4
6	Northwest(32)	3
7	North(64)	1

8	Northeast(128)	2
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**Fig 8:** Flow direction of water channel in the Imphal Valley

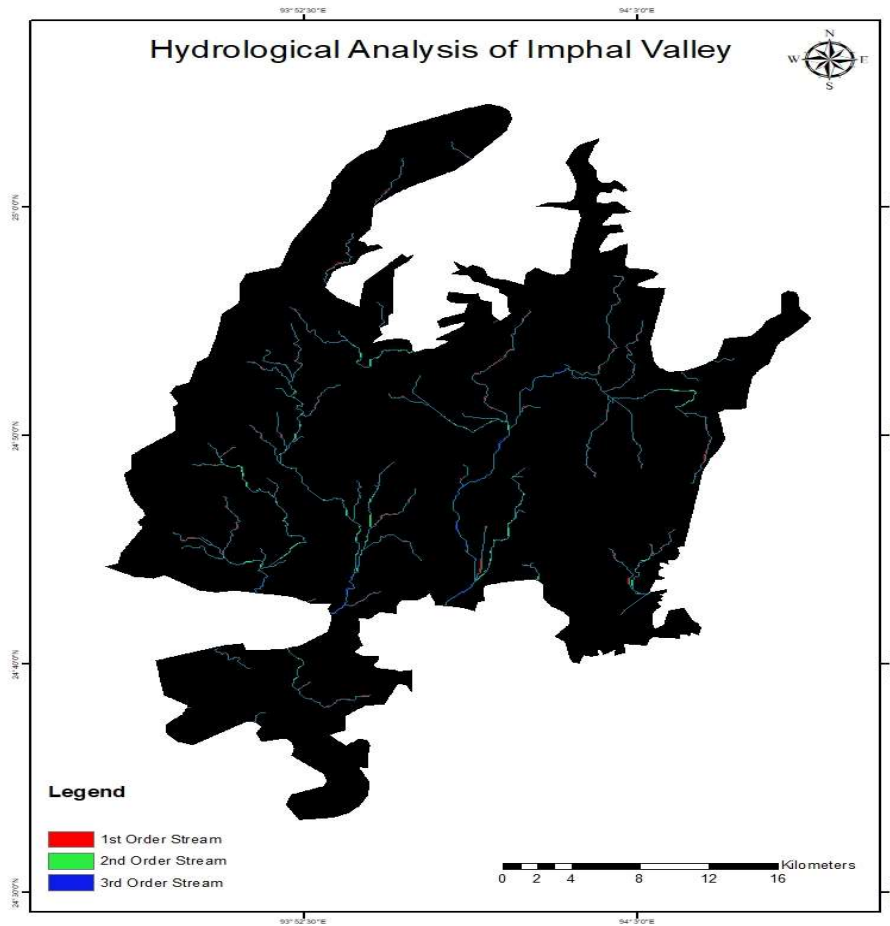
**Stream Order**

Stream order is one of the major controlling factors of flooding dynamics within the Imphal Valley. In this connection, it provides an idea about stream hierarchy within a watershed and explains apparently the complex nature of a given river network. Normally, a greater volume of water is conveyed by higher order streams, which are usually formed by the confluence of lower order streaming. Within the Imphal Valley, a system of rivers and a large number of tributaries, the higher-order streams, notably including the Imphal River, play a very major role in shaping flood behaviours. Heavy monsoon rains cause rapid swelling of these higher-order streams, which could result in wide inundation of the adjacent low-lying areas. One can understand stream order to get a better prediction of flood extents and prioritize areas for flood management interventions.

Stream order also has the power to influence the distribution and intensity of flooding within the Imphal Valley by changing the flow velocity and sediment transport capacity of rivers. Lower-order streams are generally steep and have higher flow velocity, hence they gain the capability to become very effective agents of erosion and sediment transport. However, with an increase in stream order, that is, when they merge down the slope to form higher-order streams characterized by gentler gradients, there is a gradual decrease in flow velocity leading to deposition. All this can build natural levees and raise the riverbed, which reduces the ability of channels to hold the current flow. Thus, during heavy rainfall in higher-order streams in the Imphal Valley, there are likely to be overflows, further increasing the risk of flooding. All of these dynamics explain why designing proper flood control measures that are based on dredging and the construction of levees requires deep scientific understanding in order to improve resilience against floods in any valley. Given below are the weighted value of stream order based on the tendency of volume it can contain:

**Table 8: ASSIGNED WEIGHT FACTOR CLASSES of Stream Order**

<b>Serial No.</b>	<b>Weighted Class</b>	<b>Weighted Value</b>
1	1 <sup>st</sup> Stream Order	1
2	2 <sup>nd</sup> Stream Order	5
3	3 <sup>rd</sup> Stream Order	9



**Fig 9:** Stream Order of water channel in the Imphal Valley

**Weighted Overlay Analysis**

By using weighted overlay analysis on all the above mention factors and reclassifying the targeted result into suitable number of classes based on the appropriate number of risk factors, we then assign the required interpretation of risk it carries and replaced them in their proper order based on the previously assigned weighted factors. We then assign the values with it’s risk factor as mention in the table below:

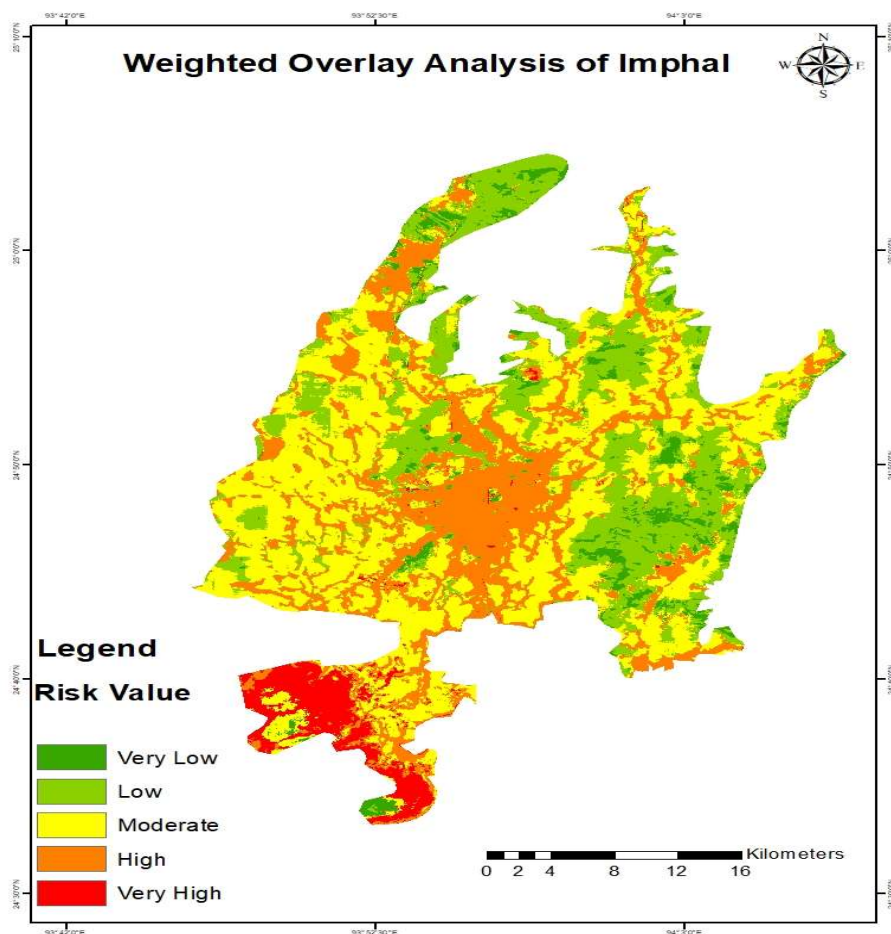
**Table 9:** Risk Factors with their weighted value

Weighted Class	Weighted Value
1	Very Low
2	Low
3	Moderate
4	High
5	Very High

From the figure below, we observe that the heart of the capital which is the centre of all activities in the state of Manipur fall under high or very high zone. This factors may be mainly due to the

facts that high capacity rivers like the Nambul river and Imphal River, which goes on to form the Manipur River ultimately falling into the Indian ocean through the Chindwin all passes through Imphal. The lack of proper infrastructure and the absence of sewage in the state capital can be an attributing factor. Another cause is the increase of built up area which is one prime suspect for diminishing waterways due to human encroachment which ultimately leads to great strain on the pre existing waterways creating havoc in case of urban flash flood.

As observe in the figure 4.11, Imphal is a flat lying area which is surrounded by mountains forming a slope which pass through the centre of the flat plains of Imphal, in case of heavy rainfall, which generally occur during the monsoon season it can lead to severe water intake failure by the narrow channels inside the state capital which would ultimately result in the whole valley flooding. The area observe to have the highest change or the greatest risk facing area seems to be the centre where urban population are concentrated while the outlying area or the rural area are relatively saffer.



**Fig 10:** Weighted Overlay Analysis of all parameters

## CONCLUSSION

The weighted overlay method has efficiently identified the flood-prone locations in the Imphal Valley, considering all the important variables like fill, contour, flow direction, slope, stream order,

and land use/land cover. Integration of these variables provided an integration of effective assessment of flood hazards and thus enabled efficient flood allocation. The findings indicate that low elevation, steep slope gradients, and certain land use patterns characterize areas that are prone to floods. In particular, high slopes and fill values indicated a higher possibility of floods. Flow direction and stream order analyses were used to further identify vulnerable zones by bringing out areas with remarkable potential for water build-up. The weighted overlay method proved to be an effective technique for flood zonation in Imphal Valley. In this present study, detailed flood-risk mapping was prepared by assigning the weights of each component based on their influencing factor of flood. This map could become a very useful tool to the local government functionaries and legislators for devising and implementing flood mitigation plans.

The imperative requirement pointed out by the study is to incorporate several topographic and environmental variables for determining the flood risk. In future studies, there is a necessity to focus on integrating state-of-the-art modelling techniques with real-time hydrological data so that accuracy and predictability related to flood zonation maps would increase. Community-based flood preparedness and early warning systems must also be planned for less vulnerable communities to reduce the consequences of floods.

The overall results of this research will improve and increase our understanding of the flood dynamics in the Imphal Valley, besides deeply anchoring risk-reduction/flood management techniques on a sound scientific platform.

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