CLIMATE RESPONSIVE DESIGN METHODS: CASE OF INDIAN INSTITUTE OF SCIENTIFIC RESEARCH AND EDUCATION, BHOPAL, MADHYA PRADESH, INDIA

Abstract

Over the past few decades, Climate change have created adverse impacts on environment where construction industry is one of the major contributors. According to a report generated by World Economic Forum in February 2022, buildings are contributing 40% of emissions globally. Therefore, it is a high time to adopt climate responsive design methods. It is extremely important to analyze different scales of climate in a region in the early phase of architectural design process and design accordingly. The climate should always be studied at three levels which includes macro-climate, meso-climate and micro-climate for in-depth understanding of climatic phenomena. Hence, this paper identifies the climate responsive design approaches for design of building clustersin institutional campuses with the case example of Indian Institute of Scientific Education and Research, Bhopal at all the three levels of climate. Microclimate analysis of the campus have been discussed in detail with the help of wind flow regimes between buildings , shadow analysis and topographic analysis including relief , slope , aspect and landform maps. The paper concludes with comprehensive landscape development solutions after identifying the issues from the analysis and adequate positioning of buildings with respect to each other to design with climate.

Keywords: Climate Responsive Design, Macro-climate, Micro-climate, Meso-climate,

Author

Mr. Manmeet Kaur
Assistant Professor
DIT University
Dehradun, Uttarakhand , India.

I. INTRODUCTION

Climate plays an important role in functioning of life on earth. Plants and animals have their own ways of building their shelters to protect themselves from excessive heat and cold.Human beings have always been adaptive and flexible to the climate change. There has been rapid transformation in the housing units and building materials in order to respond to climate change. Hence, Shelter has always played an important role in survival of the species. Therefore, shelter needs to be carefully designed by taking into account impacts of different climatic parameters.India has been divided into 8 climatic zones which are Tropical Savanna Climate Aw(winter dry), Tropical Savanna Climate As1(Summer Dry),Tropical Rainforest Climate Amw ,Hot Desert Climate BWhw,Semi-arid steppe climate BShw,,Warm Climate with dry winter Cwg, Cold humid winters Dfc (shorter summer) and Polar Climate Eas per Koppen climate classification system(Shaheer and et al, 2013) .Its characterization is based on the annual and monthly average of both temperature and precipitation.This classification of the climate is at the mostbroaderlevel . There are three scales of climate- macro-climate, meso-climate and microclimate.

Climate balanced house can be built by four major steps(Olgyay,1963). The first one includes analysis of the yearly characteristics of the variables like temperature, precipitation , radiation, wind effects etc. and the modified effects of the microclimatic conditions of a specific region.The second includes biological evolution which involves plotting the climate data on the bioclimatic chart at regular intervals showing the analysis of the region with relative importance of the climatic elements.The third step includes technological solutions which focusses on site selection, sun’s orientation, shading calculations, Housing forms and building shapes, air movements and Indoor temperature.The fourth step includes architectural application of the findings of the first three steps.

The paper covers the study of Indian Institute of Scientific Education and Research, Bhopal , Madhya Pradesh, India , campus at three levels of climate . This site was chosen because it has huge potential for climatic considerations in the design process of different building clusters. The large site area, positioning of different building blocks and its location in the city which experiences climatic extremes were the primary reasons for site selection.

The site was thoroughly studied at three climatic levels. The macroclimate level discusses the overall climate ofthe climatic zone under which the Bhopal falls . Meso-climate level talks about the climate of Bhopal city. and microclimate discusses climatic variations in terms of wind speed and direction,temperature , rainfall, softscape and hardscape zones within the campus.Micro-climate also discusses the site introduction , different wind flow regimes and their impacts on ventilation in buildings placed in clusters, shadow analysis around the buildings and open spaces and topographic Analysis that includes analysis of relief , slope, aspect and landform maps.

The entire research has been divided into four major sections. Beginning with the introduction about climatic zones and scales of climates. Introduction is being followed by research methodology which differentiates between all the three levels of climate. Analysis forms the third component of research . Different maps have been generated with the help of softwares to carry micro-climatic studies as part of Analysis. Yearly averages of rainfall, precipitation, temperature and wind speed and direction constitutes meso-climatic

component. Topographic Analysis including relief, slope , aspect and landform maps and shadow analysis in both the seasons constitutes micro-climatic component . The last section constitutes conclusion and inferences of the entire research. It highlights the important considerations for climate responsive design(Sharma,S,2019).

II. RESEARCH METHODOLOGY

The methodology for carrying this research involved segregating the study into three levels namely macro-climate , meso-climate and micro-climate study and their impacts on design decisions. Macroclimate focusses on the climate at regional level governed by atmospheric phenomena. Macroclimate is often influenced by natural calamities like cyclones , floods , droughts, hurricanes , earthquakes etc. It is impacted by disturbances happening at a range of thousands of kilometers(Sharma,2005)Meso-climate is the climate of a region that is at a scale of a city, town, district , large park , neighborhood etc. Physical characteristics of the region like vegetation cover , water bodies, cloud cover , air movement , temperature , rainfall, windspeed and direction etc influences meso-climate. It is impacted by the disturbances happening at a range of hundreds of kilometers.

Microclimate is the climatic condition in a small region which is often influenced by variables like location of site, shadow analysis of the buildings on its surroundings , building heights(Praveen,B. etal, 2020) , temperature, precipitation , solar radiation , wind speed and direction , building materials , softscape and hardscape zonesetc.(Oliver,J.E. and Hidore,J.J.,1993).It is impacted by the disturbances happening at a range of tens of kilometers. (Knight,J. 2018). The climate responsive approach adopted for this research is shown in Figure-1.

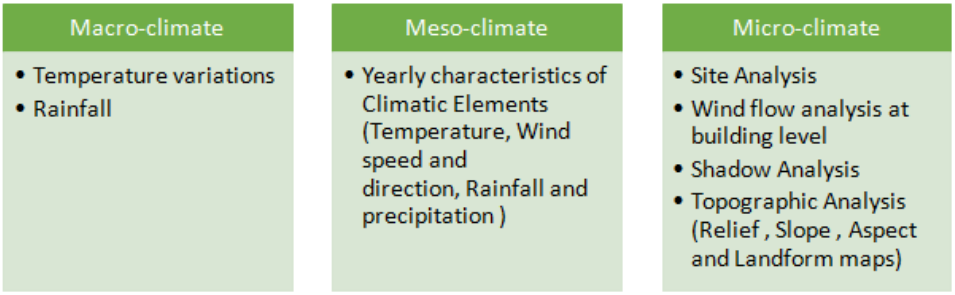

Figure 1: Flow Chart for Research Methodology Source - Author

Yearly characteristics of Climatic Elements includes identification of maximum and minimum temperature , rainfall, precipitation and wind speed ranges obtained from Indian meteorological department.Site Analysis was carried on site through interviews , surveys and group discussions. Shadow Analysis of different building clusters on sites have been prepared by taking different time durations in both summers and winters. For topographic analysis,the first and foremost step is to generate contour map. The topographic contour map comprises of lines which are formed by connecting points of equal elevation. The contours can be generated through aerial photography and surveying .However , in this case study they were generated through a remote sensing software called Geographic Information System .After generating contours , the inclination of a slope can be calculated by measuring the elevation

change from one contour to next often known as Contour Interval. The formula for the same as given by renowned landscape planner is

$$\text{Percent slope} = \frac{\text{Change in elevation}}{\text{Change in distance}} \times 100$$

Slope is also measured in degrees. For instance 100% slope is equal to 45 degrees, 70% equals 35 degrees, 47% equals 25degrees , 27 % equals 15 degrees and so on. The slopes can be classified into four categories namely-Very steep slopes(greater than 25 degrees), Steep Slopes (15 to 25 degrees), Moderate (5-15 degrees) and Gentle Slopes(less than 5 degrees). The classification can be more elaborate if the site area is large as in this case study. Hence , slope classification is done into six categories. These slope variations results in a unique terrain of a site which carves different landforms. Landforms are natural entities (Chang,1991) that includes ridges, valleys, watersheds, river basins, hills, plateaus, mountains , concave slopes , convex slopes etc. (Ferguson et al,2022)

The landform plan in this case study majorly comprised of identification of ridges , valleys, concave and convex slopes for measuring erosion levels in the soil and storm water drainage. Aspect mapping and Slope Analysis are important considerations for analyzing landform characteristics (Chang and Tsai, 2013).Aspect analysis tells the direction of slopes and is useful for analyzing erosion susceptibility(Mokarram,2018).

III. ANALYSIS

Bhopal is the capital city of Indian state of Madhya Pradesh. It is often known as city of lakes. It lies in Latitude 23.2599° N, longitude 77.4126° E and located in the central part of India, Being positioned on the Malwa plateau, it is higher than the North Indian plains and the land rises towards the Vindhya Range to the south. The city has small hillocks within its boundaries. The research has been conducted at three different scales of climate. Due to time constraints , the first two scales have been covered at introductory levels while the third scale that is micro-climate has been detailed out .

1. **Macro-Climate:** The central part of India where Bhopal lies have Warm climate with dry winters. The region has transitional climate between tropical desert and humid sub-tropical. The temperatures here are not as extreme as deserts. The annual rainfall is erratic and occurs mostly during summer monsoon season that is from June to September.The maximum temperature reaches as far as 45 degree Celsius.

2. **Meso-Climate:** Temperature ranges between 9-44 degree Celsius on an yearly average basis. The wind is a medium of transportation of heat and moisture to the atmosphere. The direction of prevailing winds and their velocity in different seasons is of great significance in planning for cluster of buildings. The wind speed ranges from minimum of4m/s to a maximum of 12 m/s.Rainfall and precipitation are important components of climate and hydrological cycle. Any alteration in these two can affect the water resources and hence the meso-climate . This is one of the major concerning issues of climate change. (Mokarramand Sathyamoorthy,2018).Maximum rainfall and precipitation in Bhopal happens during four months that is June to September with a minimum of 180mm and maximum of 500 mm.

3. **Micro-Climate:** Microclimate is strongly associated with the terrain of the site , wind flow regime between buildings , temperature variations due to building materials , softscape and hardscape regions around the buildings(Dursun andYavaş,2018) , shaded and non-shaded regions . Incorporating microclimate considerations in early architectural design process results in enhancing thermal comfort in both in indoor and outdoor spaces. The three components studied in this research as part of micro-climate assessment includes, topographic , Wind and shadow Analysis.

4. **Site Introduction:** Indian Institute of Scientific Education and Research, Bhopal, is one of the few premium institutes which is having a biologically diverse landscape. The campus is bounded with hill on east and a manmade water reservoir towards north which makes it an experientially exceptional campus. The institute currently caters about 1800 students, 130 faculty and 200 office staff, who carry out various activities in and around the campus making it a lively space.The distribution of different blocks and the facilities provides students' the scope for study and research. The entire campus is divided into three zones which are Residential block for professors,faculties and staff ;Educational block including workshops, lecture rooms and offices ; and hostel block for students

Figure 2: Existing IISER Campus showing three blocks – Educational , Residential and Hostel
Source - Author

5. **Wind Flow Analysis at building cluster level:** Wind pressure on a building and its surroundings is often influenced by height of the buildings, the shape of the buildings, materials used on the surface of the building and distance of nearby buildings from the main building(Singh and Roy, 2019).

Figure 3: Prominent wind flow from NW to SE Source - Author

The average hourly wind speed at IISER experiences significant seasonal variation. Between 5 to 8 m/s, Whereas comfortable windspeed for a human is 5m/s. The wind flows from northeast to southwest during winter months from november to february , from northwest to southeast and west to east during summer months from march to june,from west and northwest to East and southeast during monsoon from July to september and from north and northeast to south and southwest during post monsoon season from october to november. The most prominent wind flow through the year is from northwest to southeast as shown in Figure 3 . The academic block of the campus has highest footfall of 2000 people per day for an average of 8 hours a day. Therefore , wind flow regimes at building cluster levels is studied in detail for this block as shown in Figure 4. The map shows windward and leeward zones formed between buildings (Hadianpour and etal.,2018). The sections through different building clusters showing variations in building spacings creates three types of windflow regimes as shown in Figures 5.a,5.b and 5.c. which are Skimming flow, Wake Interference , Isolated Roughness(Brown and Dekay,2001)

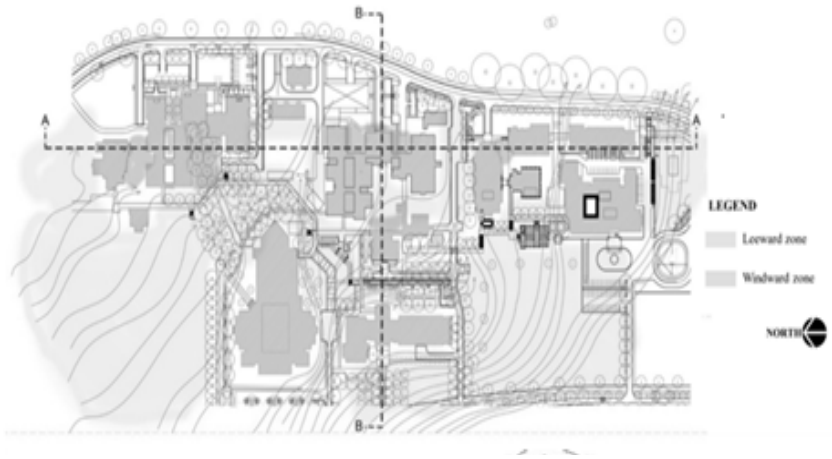

Figure 4: Wind Flow regimes between building clusters of an Academic block Source - Author

Figure5: a. Section through B-B'(Plan in Figure-4.)

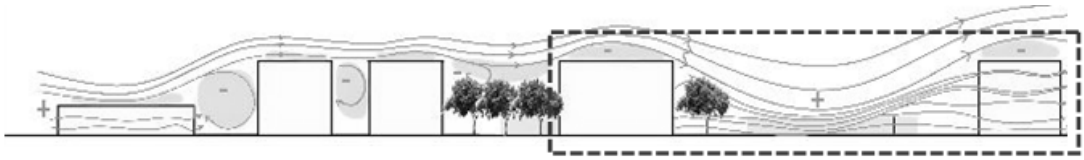

Figure 5: b. Section through A-A'(Plan in Figure-4.)

Figure 5: c. Section through C-C' (Plan in Figure-4.)

Skimming Flow is caused when buildings are organized in rows spaced closely together and oriented perpendicular to wind.(Mathew,S.,2006)as shown in figure 5.c.

When spacing is larger than that required to create a stable vortex between buildings , but smaller than the sum of the upwind and downwind eddies, a wake interference flow is induced as shown in figure 5c.

If spacing between buildings is larger than the sum of the wind and downward eddies ,wind will drop between the buildings in a pattern of isolated Roughness, which is good for ventilation as shown in figure-5.b.

Larger building spacing in the direction of wind flow, space between the ends of buildings and lower building heights minimize windspeed reduction. If the buildings are staggered , the wind flow around one building helps provide ventilation air for the adjacent building and along -wind spacing between buildings may be decreased.

6. **Shadow Analysis:** Shadow Analysis means identification of the extent and magnitude of the shadow casted by an object or a building on its surroundings at a particular time of the day (Knowles,2003).Depending on the sun's orientation different parts of buildings receive sunlight in different seasons. This constitutes one of the important factors in sustainable building design. The shadow analysis often involves the solar azimuth and solar angle. (Graham,2020)

Figure 6: Shadow Analysis during summers Source - Author

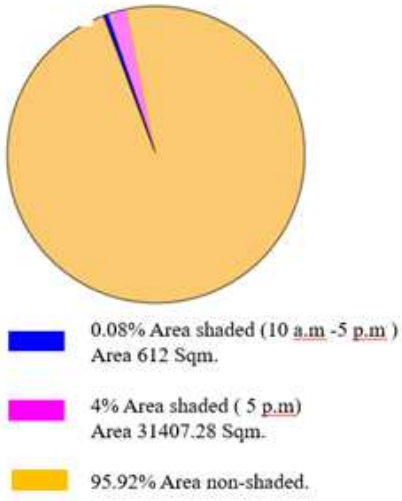

Figure 6: a Pie Chart showing distribution of shaded and non-shaded areas during summers Source - Author

Shadow analysis for all the three blocks -Residential , commercial and Academic is prepared at different times of the day . Three timings are taken for the study which are 10a.m. morning , 1p.m. afternoon and 5p.m evening . These timings are decided based on change in sun's orientation at different times of the day. The percentages are then calculated for shaded and non-shaded areas. 0.08% that is 612sqm of the area around the buildings are shaded throughout the day from 10.a.m to 5p.m. 4% of the area that is 31407.28 sqm around the buildings are shaded at 5p.m. Remaining 95.92% area is non shaded and needs design interventions for thermal comfort. This is the scenario during summers as shown in Figures-6 and 6-a. Similarly , the same procedure is carried during winters.

Figure 7: Shadow Analysis during winters Source - Author

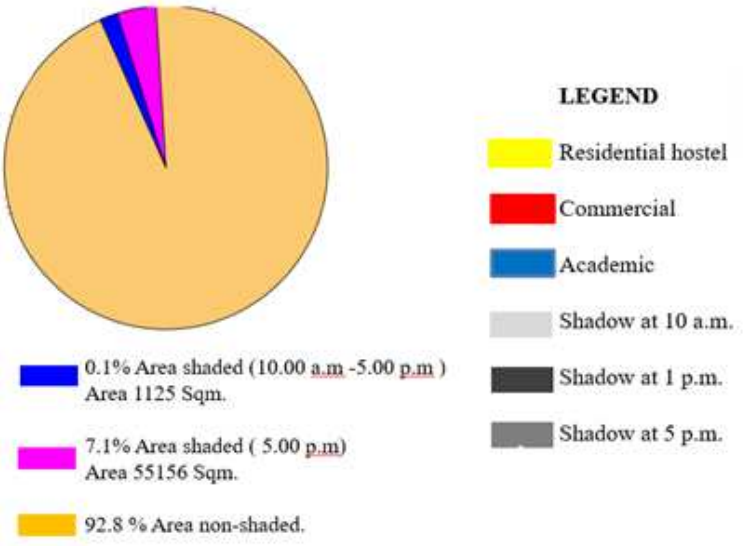

Figure 7:a Pie Chart showing distribution of shaded and non-shaded areas during winters Source - Author

There are minor differences in pattern of shadows around the buildings during winters as shown in figure 7. 0.1% of the total area that is 1125 sqm around the buildings is shaded from 10a.m morning to 5p.m. evening. 7.1% of the area that is 55156 sqm is shaded at 5p.m. Remaining 92.8 % of the area is non -shaded which needs design interventions as shown inn figure-7.a The common area which is non-shaded during all the seasons needs landscape design interventions to improve the quality of the spaces thermally. Passive cooling techniques such as introducing water bodies and planting material can improve the microclimatic conditions of these zones.

7. **Topographic Analysis:** Topographic maps are one of the best tools to understand the climatic components of environment (Kent and Hopfstock, 2019).Carrying a topographic survey of the site is extremely important .It includes the study of elevation , slope , aspects and landform maps.

8. **Relief Map:** Spatial variation in elevation produces different type of slopes and their orientation . Each of these have a substantial influence on land planning and design decisions.The elevation map shows the highest and lowest levels on the site which are potential locations to develop vantage points as shown in Figure 8.

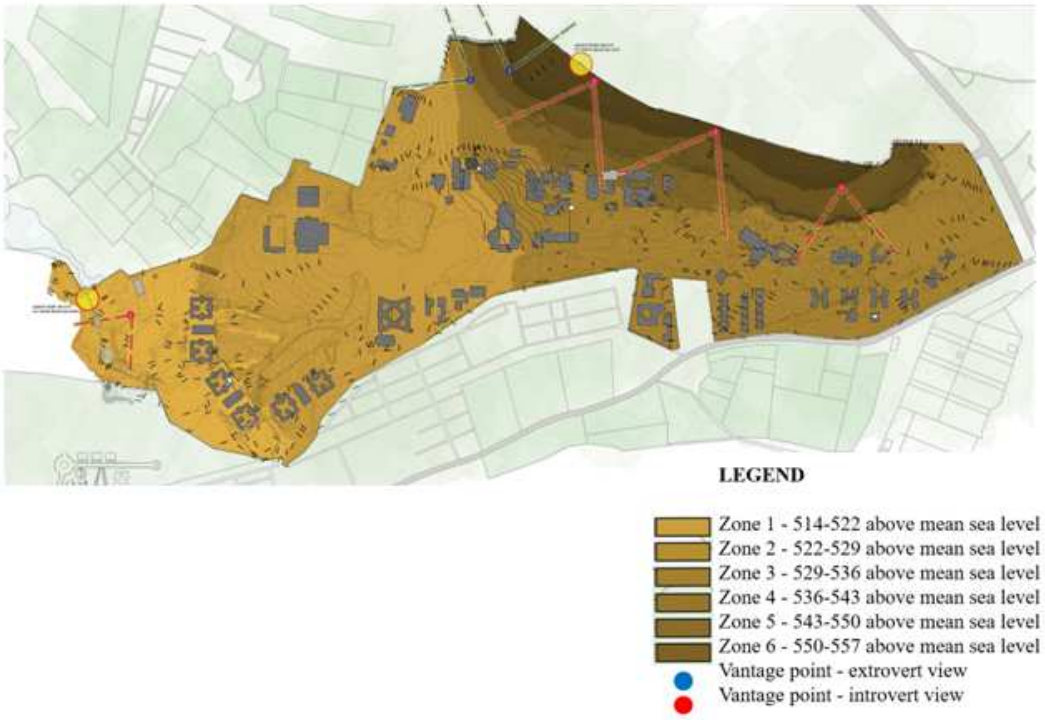

Figure 8: Relief Map showing highest and lowest elevations on site
Source - Author

The contours were divided into 6 zones based on elevation differences. Zone-1 covers contours between the range of 514m to 522m, zone-2 covers the range between 522m to 529m ,zone -3 covers the range between 529m to 536m , zone-4 covers the range between 536m to 543m , zone-5 covers the range between 543m to 550m and zone-6

covers the range between 550m to 557m . All the zones are color coded according to their range from darkest shade to the lightest. The Highest point on site is 557 m above mean sea level whereas the lowest point is 514m. The elevation difference between highest and lowest point on site is 43m. The highest point acts as a vantage point on the site, it shows the view of countryside as well as surrounding agricultural landscape. These variations in elevations create different types of slopes.

9. Slope Analysis:

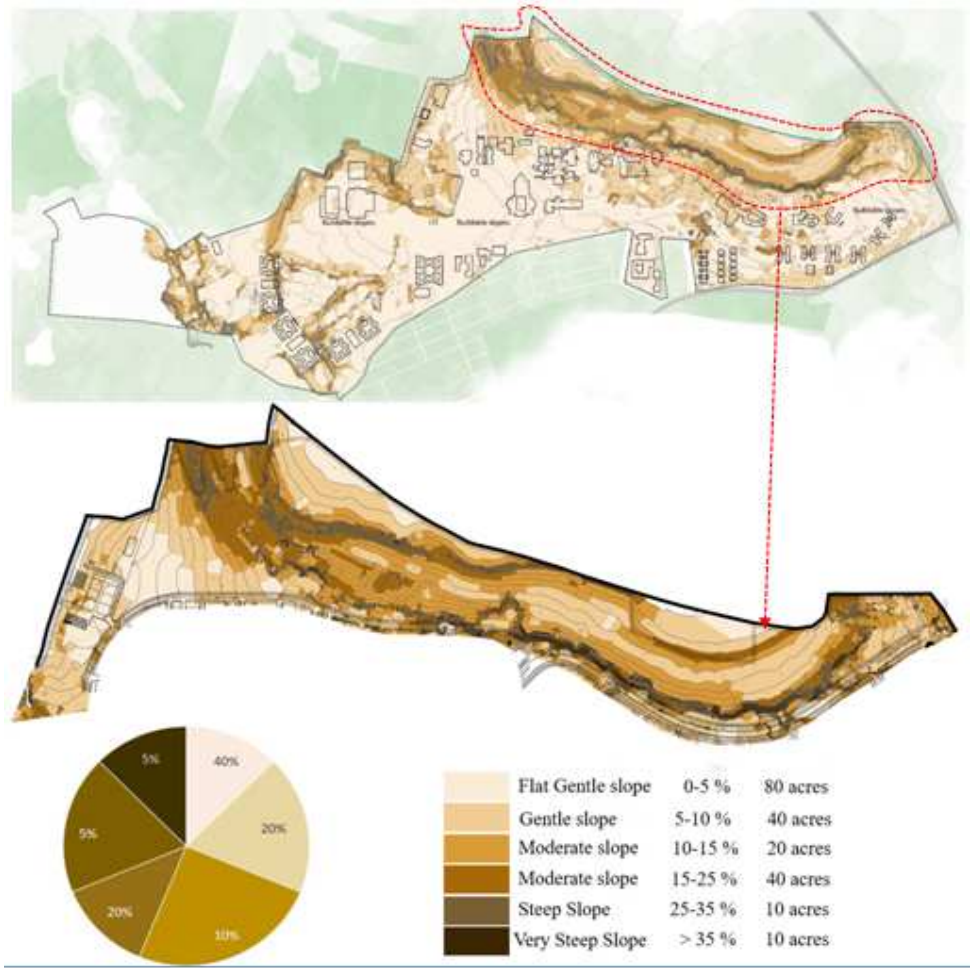

Figure 9: shows percentage of different slopes Source - Author

80 acres of the site constitutes flat gentle slope and 40 acres of the site comprises gentle slope where buildings can be constructed without any cut and fill. 20 acres of site has moderate slope in the range of 10-15% and 40 acres of site has moderate slope in the range of 15-25% where ramps, roads and steps can be constructed with some cut and fill . 10 acres of site is steep with 25- 35% slope and very steep with greater than 35% which is non buildable and susceptible to erosion. All the existing and proposed buildings lies on flat gentle and gentle slopes respecting topography. The very steep and steep slopes exists at south eastern edge of site hence rill erosion is significant here. Therefore,slope stabilization measures are required.

10. Aspect Analysis:

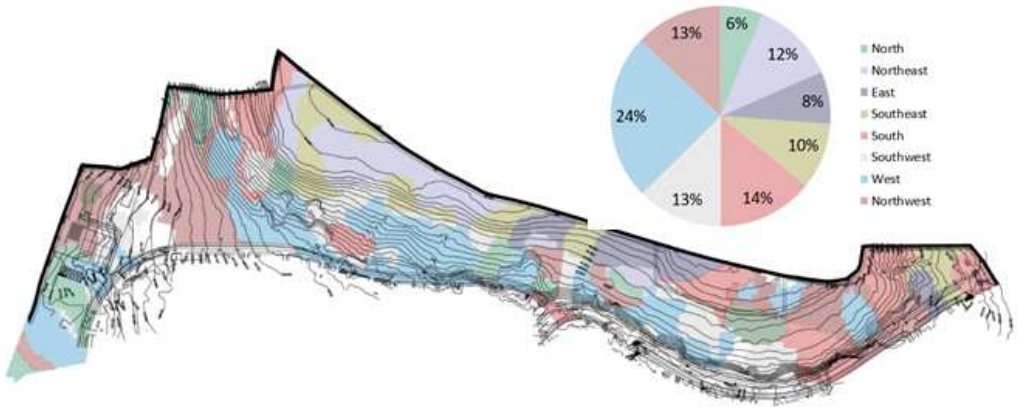

Figure 10: shows percentage of different slope aspects Source - Author

In hills and mountains, there are slopes in all directions. The hillock in IISER campus also has slopes in all directions and the compass direction that the slope faces is aspect. The aspect is measured clockwise starting north at 0°. The range varies from 0° to 22.5° for north , 22.5° to 67.5° for northeast , 67.5° to 112.5° for east, 112.5° to 157.5° for southeast, 157.5° to 202.5° for south , 202.5° to 247.5° for southwest, 247.5°to 292.5° for west and 292.5° to 337.5° for northwest. In IISER hillock, 6% are north, 12% are northeast, 8% are east ,10% are southeast east ,14% are south ,13% are southwest, 24% west and 13% are northwest aspects. The aspects are studied in microclimate studies for biodiversity conservation, slope stability and for plantation of specific species. The effect of aspect increases with latitude. The latitude of IISER site is 23° which is less. Therefore , it has little impact on microclimate.

11. Landform Analysis: Landforms are relief features that are result of complex geological process (Hargitai, 2015).Ridges and valleys often change soil moisture movement during rainfall. It can alter the infiltration and runoff(Wang and Chen, 2021). As a result of which concave and convex slopes are formed. Concave slopes are the result of erosional activity as shown in figure 10.a. and convex slopes are the result of depositional activity as shown in figure 10b.These slopes need to be stabilized by planting material and slope stabilization techniques.

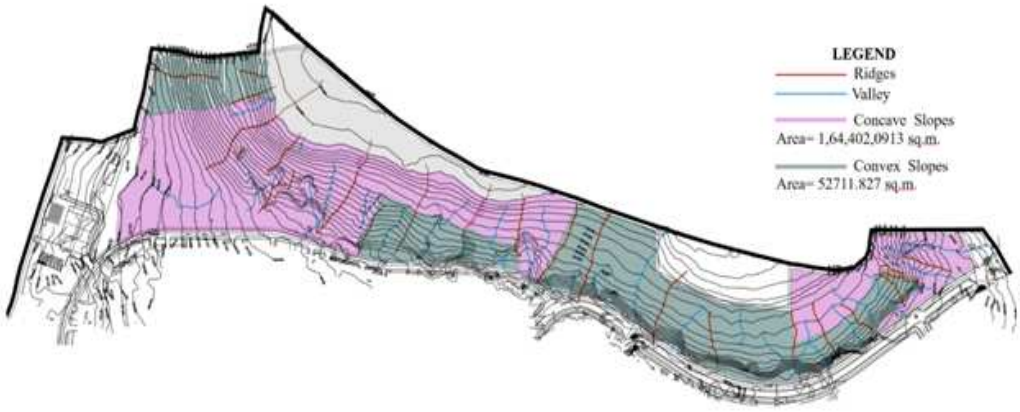

Figure 10: shows percentage of different landforms- ridges, valleys , concave and convex slopes . Source – Author

Figure 10: a. Concave Slopes Source- Author

Figure 10: b Convex Slopes Source- Author

IV. CONCLUSION

Results from this study shows that climate responsive design approach should be adopted at microclimate level which in turn influences meso-climate and macro-climate. If climate balance is achieved at site planning and building level , it can alleviate the adverse

impacts on climate at regional level . It will create an overall balance in the ecosystem. Some of the climate sensitive approaches includes identification of thermal discomfort zones in different seasons by shadow analysis of the proposed buildings on their surrounding environment.These areas need landscape design interventions in terms of passive cooling techniques such as introducing trees with large canopy cover , fountains , water bodies etc. during summers. During winters , deciduous planting can be provided which will allow sunlight to pass through. Design of shading devices and opening sizes in terms of adequate penetration of sunlight in buildings to reduce heating and cooling loads(Freewan, 2014) .This would also reduce the energy demand of the building.The spacing between buildings should be large enough that the wind drops between buildings for better ventilation which creates isolated roughness wind flow regime. Steep slopes which are highly susceptible to erosion requires slope stability measures to prevent flooding on site. These measures should be incorporated in early design phase of architectural design process . All the climatic considerations including identification of high flood level, rainfall patterns , wind flow , sun path etc needs to be incorporated as part of architectural design.

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