6. Conclusions and Recommendations

6.1 General

This chapter shows the conclusions obtained for the individual objective. Based on the conclusions, recommendations and suggestions have been given.

6.2 Conclusions

1. All the DEMs used in the study have imperfections for the delineation of the small river like Vishwamitri. Moreover, a comparison shows that SRTM 30 m and ASTER 30 m failed to delineate main drainage for the Vishwamitri river. However, Cartosat 30 m DEM exhibited better results. The Cartosat-generated drainage network is much closer to the actual river network followed by the SRTM-derived drainage network. A large number of sinks in ASTER DEM and SRTM DEM around the actual river have considerably contributed to the deviation in ASTER DEM- and SRTM DEM-derived streams from the actual stream. Such error indicates that there are probably residual and artifactual anomalies that most certainly degraded the overall accuracies of ASTER and SRTM DEMs. Moreover, watersheds delineated by ASTER DEM and SRTM DEM could not follow the ridgeline and hence they have encompassed the Dhadhar river in them. It can be concluded that for hydrological studies, the Cartosat DEM should be given first preference followed by the SRTM DEM for the area under study, where the relief class belongs to a flat relief.
2. Principal Component Analysis (PCA) based approach is far superior to the traditional approach for clssification. PCA extract the useful spectral information by compressing redundant data embedded in each spectral channel. The overall classification accuracy of MLE classifier was increased from 22% to 41% (19% increase) in the PCA based approach. The overall accuracy RF classifier was increased by 10% reaching 70%, whereas SVM classifier outperformed both the classifiers with 76% overall accuracy (increased by 12%). PCA with Support Vector Machine is able to produce highly accurate land use and land cover classified maps. Support Vector Machine outperformed the Maximum Likelihood Estimation and Random Forest Tree classifiers in both traditional as well as PCA based approach even with a small training dataset. The uncorrelated principal component bands enhanced the classification accuracy as compared to the use of Sentinel–2 original bands. This confirms the feasibility of PCA in remote sensing to extract land use and land cover information and enhance the classification accuracy.
3. The morphometric parameters derived from the Cartosat-1 digital elevation model (30 meters) helped to understand the hydrological behaviour of various sub-watersheds of Vishwamitri watershed. Based on the integration of flood influencing parameters and calculated compound

value, the Sub-watershed I and IV (C_v= 3.64) of Vishwamitri watershed have been categorized into high priority, Sub-watershed II (C_v= 2.91) and V (C_v= 2.64) into moderate priority, and Sub-watershed III (C_v= 2.18) into low priority. Morphometric parameters are ideal for providing fundamental data for drawing conclusions that concern the effect of river morphology on the flood situation. In countries like India, high maintenance costs and the requirement for skilled operators make providing gauge stations to each watershed probably expensive. As remote sensing data are widely used in mathematical watershed models to simulate and evaluate the existing and proposed management scenarios, the runoff curve numbers estimated from remotely sensed parameters, such as land use and land cover and soil data, in combination with observed rainfall, predicted runoff and peak flow, may result in high accuracy of hydrological modeling.

4. Suitability map of potential runoff storage zones by integrating the thematic layers of slope derived by topographic position index, LULC, curve number, height above nearest drainage, stream order and topography wetness index using analytic hierarchy process and weighted overlay process within GIS is reliable and accurate. Result shows that 17 % of the study area is optimally suitable, 33.2% of the area is moderately suitable, 33.1 % of the area is marginally suitable and 18.7% of the area is not suitable for water storage zones/structures. Proposed suitability map for potential water storage zones developed by the GIS technique for the study area may be implemented in the future to overcome growing water scarcity due to global/regional climate change. Since the approach and the analysis showed in this research have non-exclusive relevance, they are exceptionally valuable for other parts of the world, especially for developing countries, despite hydrological and agro-climatic variations. This approach is less time-consuming, more precise and can be utilized for identifying potential locations for different interventions for large watersheds. Results will help concerned authorities in the proficient arranging and execution of water-related plans and schemes, improve water shortage, reduce dependability on ground water and ensure sustainable water availability for local and agricultural purposes.
5. Effective and quick response is required during disasters like flooding. Rapid mapping of such events will be beneficial to urban and infrastructure planners, risk managers and disaster responses during extreme and intense rainfall events. The research carried out shows a simple and efficient method for mapping inundation extent with only the C-band of S1A, with coarser geometric resolution and fixed polarizations (VV-VH) by considering the case of Kerala and Assam. Based on the analysis of the obtained results it can be concluded that the the side-looking geometry inherent to conventional SAR sensors leads to the production of radar

shadowing and layover. The backscattering coefficient values become high as the water roughness causes high signal return, decreasing the contrast and making the separation of the land-water covers difficult. Despeckle filters with good noise removal capabilities often tend to degrade the spatial and radiometric resolution of an original data and cause the loss of image details. This may be acceptable for applications involving large scale image interpretation or mapping. However, the retention of the subtle structures of an image is important and, therefore, the performance of speckle noise suppression technique must be balanced with the filter's effectiveness to preserve the fine details. The performance evaluation of de-noising methods in the study showed that Lee filter with 3×3 kernel size provided a good balance in feature preservation as well in despeckling compared to the other filters used in the study. The accuracy assessment of machine learning algorithms for flood classification over Kerala shows that random forest classifier has higher overall classification accuracy (88.80%) than the support vector machine (about 5% higher in VV polarization). However, both the classifiers performed slightly better in VV polarization than VH polarization for Kerala region. For study area Assam, SVM in VH polarization achieved higher overall accuracy (92%) and least performance was observed by RF in VV polarization. It is also concluded that, a single threshold should not be used as large swath of a SAR image suffers from environment heterogeneity caused by wind-roughening and satellite framework parameters.

6. The proposed approach shows the potential for monitoring damages caused by floods, providing basic information that can help local communities manage water-related risk, planning land and water management as well as other flood control programs.

   The hydrodynamic-based surface runoff computations in rainfall-runoff simulation at the catchment scale shows the application of the hydrodynamic model HEC-RAS for identifying the inundation areas, in regions with very limited or no ground-based observational data. Ward numbers 2, 5, 6, 8 of Vadodara city were severely affected by the flood and percentage of area inundated in these wards varies form 35.69% to 39.86%. Ward numbers 4, 7, 10, 12 were moderately affected by the flood and percentage of area inundated in these wards varies from 16.34% to 21.92%. Ward numbers 1, 3, 9, 11 were marginally affected by the flood and percentage of area inundated in these wards varies form 0.56% to 3.54%. Moreover, 55.65% of total flood extent are located in the very low hazard class (H1) followed by H4—high hazard class (17.73% of total flood extent), H3—medium hazard class (14.69% of total flood extent), H2—low hazard class (7.26% of total flood extent), H5—extreme hazard class (4.67% of total flood extent). A significant advantage of the given framework is considered to be its ability to produce results using only good quality topographical, rainfall, land use and soil data. In this way, the technique will yield results for ungauged catchments. The integrated analysis of morphometric, land cover, and topographic analysis for characterising the hydrological behaviour of the Vishwamitri watershed, as shown in this study, may be the sensible alternative until the automated observation network is built in such areas. For validating and calibrating the hydrological simulation models, the availability of the discharge data is crucial. Therefore, the establishment of a network of hydrometeorological and river discharge stations in the basin to facilitate better prediction of the flooding process is of the utmost importance.

7. Spatial distribution of land surface temperature provides critical information for the understanding of local climatic conditions in the cities and can be used as a potential measure to introduce necessary steps to minimize the adverse effects of high land surface temperature. The results indicated the highest land surface temperature was recorded for baresoil while the lowest was recorded for water bodies. Based on research results, the study suggests that a new urban heat mitigation strategy is an important element in the spatial arrangement of impermeable surfaces and green areas as well as water bodies that manage urban heating and cooling. The evaluation of the prediction models shows that the K-NN, NN and SVM models, are the optimum models for predicting the land surface temperature in Vadodara city using neighboring biophysical independent variables relationship with land surface temperature. In addition, it is shown that the K-NN (5×5 observation grid) model exhibits good performance with RMSE of 0.549 ◦C. The model can help to predict land surface temperature under temporary cloud cover spots, which are present in the data at the time of the acquisition using neighboring biophysical (cloud free) independent variables relationship with land surface temperature.

6.3 Recommendations

1. DEM data with a high spatial resolution must be used. Accurate terrain or morphologically accurate data have a significant effect on geoscientific and hydrological studies such as flood risk prediction, morphometry, 2D hydraulic modelling and so on. Some of these applications include quantitative terrain descriptors derived from DEMs such as slope, aspect, curvature, drainage networks, or watershed delineation to describe shape and topology. Despite the real importance of the applications of DEMs in numerous fields and the technological advances for its creation and availability, aerial photographs or globally available DEMs such as ASTER and SRTM are commonly used, which leads to low accuracy due to the significant effect of inherited anomalies in the DEMs. According to the results analysed in this study, the Cartosat DEM should be given first preference followed by the SRTM DEM for the study area where the relief class belongs to a flat relief. It is also recommended to use DEMs produced by advancement of

current technologies such as light detection and ranging (LiDAR) systems. LIDAR data are much denser sample models of Earth's continuous and irregular surface, should be preferred, if a more detailed and robust analysis is being pursued. It is an efficient technique to provide terrain data with high resolution as compared to other DEM sources. The use of a LiDAR system to generate DEM data has many advantages over other methods. LiDAR data can be collected during the day, night, and even in cloudy conditions. Moreover, it has the ability to penetrate the ground surface in vegetated and urban areas more reliably than either photogrammetry or Interferometric Synthetic Aperture Radar (IfSAR).

2. It is recommended to use principal component analysis for image compression and eliminating noise, redundancy, and irrelevant information which ultimately leads to reduction in the computation costs without compromising the desired variability in the data. Principal component analysis coupled with Support Vector Machine will be appropriate for multispectral as well as for hyperspectral images with small structures or artifacts to detect, or where spectral groups or spectrally related classes predominate, as it minimizes classification errors and make them superior to the parametric classifiers for obtaining effective LULC classification.
3. The cost of implementing a GIS is significant, particularly when the cost of data collection and manipulation is incorporated. The map data and tabular data documenting tracts of land use and cover have been time-consuming and costly to update. When the application area is greater than a few square kilometers, the use of satellite images is justified since defining curve numbers using conventional methods is time-consuming. The determination of the curve number is dependent on the resolution of the satellite, and higher spectral and spatial resolution may provide more accurate estimates. To achieve satisfactory results, further research is needed to be carried out with finer resolution.
4. In the sense of near real-time mapping, it is important to collect data as soon as a flood event occurs. The temporal fusion of SAR and optical data will reduce the time between the flood and data acquisition. Furthermore, the spatial fusion of SAR and optical data may aid in the detection of inundated areas in steep slope terrains that are difficult to detect using SAR data due to radar shadowing and foreshortening. It is recommended to use VH and VV polarization for flood area mapping application due to the reduced nature of scattering and speckles in absence of HH polarization. SAR data has a number of drawbacks that must be considered during the data collection process, such as the inability to record flooding in urban areas due to the corner reflection concept, double-bounce effect, noise, and increased measurement uncertainty due to speckle. Such a radar response is insufficient for mapping the real flooded areas of urban areas. As a result, in the context of a real-time disaster situation, flood area

mapping of urban areas is a difficult job and should be typically handled by domain experts using a LiDAR height map of the urban area aided with hydraulic modelling. A comprehensive evaluation of further Sentinel-1 scenes is expected in the future, including a thorough study of the performance of VV and VH polarization in various environments and wind conditions. Since Sentinel-1 imagery is collected in a systematic manner, time-series analysis may help us enhance the robustness of the flood mapping workflow provided.

5. Mitigation steps should be implemented in upper tributary streams, such as an early flood warning system, introduction of water storage areas (check dams), levees/embankments, flood walls, flood gates, strategic agriculture, the creation of flood risk maps, the prevention of further growth in flood-prone areas, and the adaptation of advanced flood forecasting techniques.
6. In order to mitigate floods, it is proposed that there is a significant need to create a flood spill channel that can take up one-third of the total flow of the Vishwamitri River. Moreover, to prevent floods in the downstream agricultural areas and settlements, additional reservoir must be created in Sub-watershed I. Along with this, mitigation measures such as check dams, nala bunds, gully plug, bundhis (local name in India), percolation tanks etc. can be constructed in a planned and systematic manner in Sub-watershed I, II and IV to create water buffer within the catchment, which will help reducing vulnerability to seasonal variations in rainfall.
7. Vishwamitri River discharges have to be measured accurately with uniformity in time of observations. For this purpose automated observation network of gauging stations would need to be established in each sub-watershed with current meter observations, where the river section is relatively straight and uniform, free of obstructions and vegetation, with no progressive tendency to scour or accrete, and free of the backwater effect of tributaries, downstream structures (dams, bridges). The flow should be contained within defined boundaries. Gauge site should be sensitive to the extent that a significant change in discharge, even for the lowest discharges, should be accompanied by a significant change in stage. Gauges will have to be established with gauge levels conforming to G.T.S. (Great Trigonometrical Survey) benchmark so that they are connected to common datum.
8. To overcome growing water scarcity due to global/regional climate change, water storage structures must be made on potential water storage zones as shown in the study. More investments in infrastructure development (i.e., dams and water supply pipe networks) would help future population cope with the growing water demand as an uneven distribution of precipitation in time is expected due to climate change. Ponds are suitable for small flat areas with slopes 5%, 0.15 % of study area belongs to middle slope, nala bunds are suitable on

moderate slopes of 5–10%, 12.49 % study area belongs to upper slope, terracing is suitable for steeper slopes of 5–30%. Ridges and upper slope together forms 30.79 % of the study area, they indicate least potential for rainwater harvesting because higher sloping land is inappropriate for constructing water storage structures. Valley and lower slope together constitutes for 33.58 % of the study area, small dams or check dams like structures are preferable on such sites.

9. Rising global temperatures pose a growing challenge to safe and healthy living conditions. Because of the materials used to construct houses, streets, and infrastructure, these environmental changes have had a particularly negative impact on cities. Increasing the albedo of roofs appears to be an effective approach to reduce the temperature rises caused by urban heat island and also the least-cost alternative compared with green roofs and urban forestry. It is therefore recommended that the Vadodara city employ heat mitigation strategies such as the use of high albedo urban materials, reflective pavements, increasing the area of vegetated land in the city, green roofs, addition of large urban bodies of water, etc.