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1. INTRODUCTION: Civil Engineering is one of the oldest and important branches of engineering, comprises of many sub-divisions such as surveying (topographic/cadastral/natural resources etc.), construction (urban/rural/municipal infra-structure/materials etc.), transportation (roads/bridges/traffic etc.), water resources (water supply/treatment/ canals/dams/ storm/sewers etc.), environmental (chemical and biological waste/public-health/pollution-impact/remedy/resource management etc.), geological (rock, soil mechanics/ earthquake engineering etc.) and coastal (erosion/flood defense/hydro-dynamics etc.). In simple terms the civil engineering applications can be divided into two groups: a) human related b) environment related, and remote sensing plays a vital role in providing required near-real-time images/data about the ground/topography/weather/ landcover which will potentially help the civil engineers for effective planning and decision making (Fig. 1).

One of the basic requirements in civil engineering is ground investigation (i.e., survey). Classical land surveying in civil engineering refers to the process of determining position, distance, angle and height of buildings and terrestrial features. Surveying is an integral part of any developmental activity however technological advancements have brought key changes in the *survey process* and *quality of data*. Key benefits of remote sensing in surveying applications comes from three important developments: a) *advancements* in spatial, spectral and temporal resolutions (which helps in accurate detection, demarcation of objects/boundary and status/changes), b) *capability* to produce 3D stereo viewing (which helps in measuring heights of objects and terrain) and c) *availability* of advanced Geo-spatial algorithms and tools.

Surveying in a remote inaccessible areas and mountainous regions have posed great difficulty in the past and one has to invest lot of time for travel, man power and money. Fortunately, remote sensing technology has provided a possibility to see and survey those remote locations from the lab and to quantify all needed parameters of the terrain (such as height, slope, aspect, contours, watershed delineation, surface area, volume etc.) without actually going to field (See Tables 1 & 2 for details). Moreover, data are acquired today at various scales starting from sub-meter level (car, building, individual tree) to broader level (river/forest/geomorphological pattern) and hence providing a gold mine of data and information for surveyors. Apart from geometrical facts about ground features it is also important to have multi-scale database about land condition, its usage and geo-environmental interaction (i.e., drivers) so as to equip urban/environmental administrators for a better future planning and develop strategy for unforeseen calamity (such as fire, earthquake, flood, landslide etc.).

Aerial photo dependent Photogrammetric techniques were used in the past for extracting elevation of objects/ground, digital surface model (DSM), 3D city modelling, and close range photogrammetry techniques are being used recently for measuring 3D properties of buildings, monuments and quantify surface deformations [1][2]. Today, data from High spatial resolution satellites, LIDAR (Light Detection and Ranging device mounted on small aircraft) and UAV are more preferred for building inventory and city surveying [3][4][5] as it provides highly accurate elevation data (micro-contours), quickly reveals city geometry and helps to model climate change impact (e.g., flood scenario in a city) as well as contributes in establishing baseline maps for future studies. For example, Netherlands lies below mean sea level and hence they are prone to sea water intrusion and flooding. To ensure the safety of their citizen Dutch Government (Ministry of transport, public works and water management - Rijkswaterstaat) carry out regular LIDAR survey along their dikes to monitor water levels, health of groynes (structures of sand and stone), soil volume, deformations, wave characteristics etc.

[6][7]. Planning, development of infrastructure and urban facilities requires cost-effective analysis in identifying proper sites for different categories of human activities (such as residential, commercial, park etc.) and optimal transportation. Here, remote sensing, GIS and GPS proves to be a powerful combination to solve spatial urban problems faced by civil engineers and for various applications at macro, meso and micro-levels (Figure. 1, Table 1 & 2).

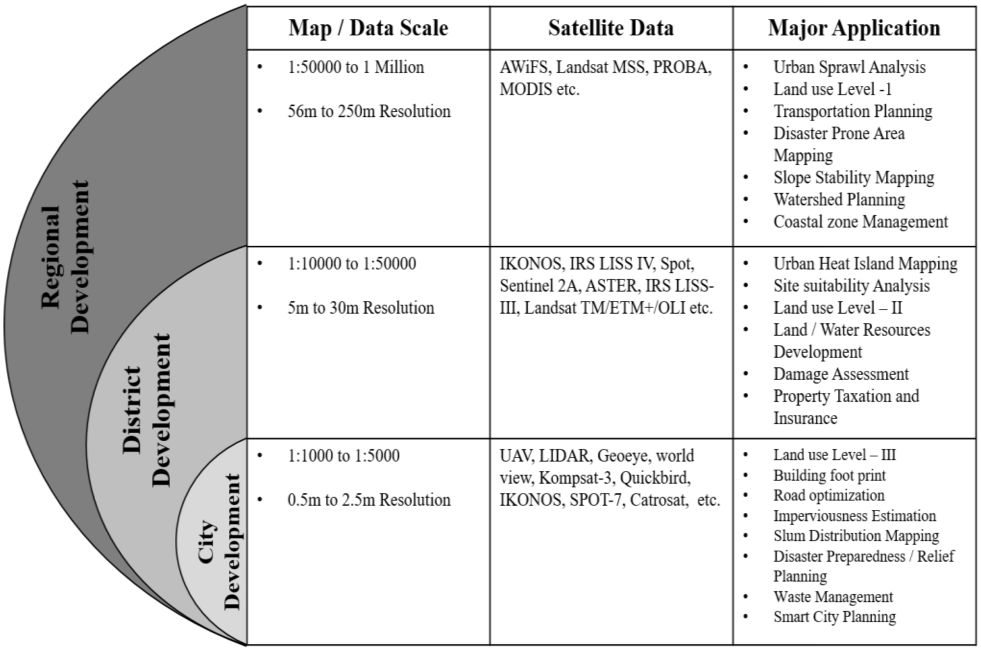

Figure I: Remote sensing based Civil Engineering Survey & Mapping Applications at Various Levels.

Satellite/Sensor	Data Available	Usability
Cartosat-1	Elevation data (30m) i.e., Digital Elevation Model (DEM)	Watershed Characterisation and Hydrological Modelling (e.g., basin area, flowline length, flowline slope, flow direction, flow accumulation, runoff coefficient, flood inundation etc.) Dam Site Selection Route Alignment in Hilly region Sun light availability and Shadow simulation
Oceansat-2 (OCM2)	Surface Water Layer (360m)	Regular Monitoring of Water Resources (like Water availability/extent in Lake/River/Dams etc.).
Oceansat-2 (OCM2)	Surface Albedo (1km)	Evapotranspiration and Energy-Balance Studies.
Oceansat-2 (OCM2-GAC)	NDVI (8km & 1km) Vegetation Fraction (1km)	Drought Monitoring Urban Greenness Quantification Impervious Surface Extraction
Multi-Sensors data based	**Hydrological Products (16.5km):** Surface Runoff Surface Soil Moisture Evapotranspiration	Drought Monitoring Watershed Characterisation Hydrological Modelling Energy/Water Balance
IRS (LISS II)	**National Soil Data (5km):** Soil Depth Soil Texture Mean Soil Carbon Density	Carbon Balance studies Regional CO_2 emission Hydrological/Climate Modelling

Resourcesat-2 (LISS III)	**National Land Degradation Data (5km):** Salt Affected Area Wind Erosion Water Erosion Water Logging	Hydrological/Climate Modelling Energy Budget Carbon Cycle

Table I: List of Free Spatial Data from Bhuvan (bhuvan.nrsc.gov.in)

Website	Data Available	Usability
https://earthdata.nasa.gov/	**NASA Earth Data Repository**	For all applications. (Satellite data, theme based data, field campaign data etc.). For civil Engineerings - see under Human Dimensions and Land.
http://opentopo.sdsc.edu/lidar	**OPENTOPOGRAPHY data** LIDAR Data (sub meter resolution)	3D City Modelling Building Foot Print extraction Oil & Gas Pipeline Planning Electricity Routing Earthquake Damage/Risk Assessment
http://vterrain.org/Locations/eu/	**Europe LIDAR data**	City Level Applications 3D Applications
ftp://ftp.dnr.state.mn.us/pub/gisftp/lidar	**Minnesota Free LIDAR Data and Training Materials**	LIDAR Learning City Level Applications 3D Applications
https://modis.gsfc.nasa.gov/data/dataprod/	**MODIS data*** Land Products Atmospheric Products Ocean Products Cryosphere Products *(250m, 1km and 5km resolutions)*	Land Degradation studies Vegetation Monitoring Climate Change Studies (District Level, Regional Level and Country Level Studies)
https://trmm.gsfc.nasa.gov/data_dir/data.html	**TRMM Data** Rainfall Products *(0.25degree Resolution)*	Drought Monitoring Runoff Modelling Evapotranspiration studies
https://lta.cr.usgs.gov/SRTM1Arc http://gdex.cr.usgs.gov/gdex/	**SRTM DEM** Elevation data *(30m & 90m Resolution)* **ASTER DEM** Elevation data *(15m & 30m Resolution)*	Large Area Topographic Modelling Earthquake Engineering Hydrological Modelling DEM/DSM Gravity Modelling (see also Table 1)
http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings/parameters	**GES-DISC Modelled Data** Rainfall rate Snowfall rate Surface runoff Snowmelt Incident Solar Radiation Surface Temperature Ground heat flux Near surface wind Near surface humidity	Earth System Modelling Hydrological Modelling Drought Monitoring Runoff Modelling

	Soil Moisture *(1km to 2.5degree resolutions)*	
http://earthexplorer.usgs.gov/	**LANDSAT & AVHRR** data Multispectral and Thermal data (30m resolution)	EIA Land cover Mapping Urban heat Island studies Route Alignment Site Suitability Studies Land Degradation studies
http://openstreetmapdata.com/data http://download.geofabrik.de/asia.html	**OPENSTREET Vector DATA** Land polygons Coastlines data Water Polygons **OPENSTREET Asia Data** Road Network Rail Network Building Foot Prints Land use polygons Places	Planning and Decision Making Emergency Management Utility/Facility Management Optimal Path Analysis
http://worldclim.org/version2	**WORLDCLIM data** **Monthly mean Climate Data** (Temperature, rainfall, wind speed, solar radiation) (1970 to 2000 average) (1km to 18km resolution)	Earth System Modelling Hydrological Modelling Drought Monitoring Wind Energy Site Selection Solar Energy Site Selection
http://bhuvan-poi.nrsc.gov.in:8080/geonetwork/srv/eng/main.home	**BHUVAN Data Discovery** Diverse Data over India	For Diverse Applications

Table 2: Other Free Sources of Spatial Data available in Web

* MODIS – Moderate Resolution Imaging Spectroradiometer; TRMM – Tropical Rainfall Mapping Mission; SRTM – Shuttle Radar Topography Mission; GES-DISC – Goddard Earth Sciences Data and Information Services Centre;

2. LIDAR IN CIVIL ENGINEERING: LiDAR stands for Light Detection and Ranging (LiDAR), is an active optical remote sensing system which can be airborne systems (Airborne Laser Scanning) mounted on aircraft, or ground based (Terrestrial and Mobile Laser Scanning) mounted on tripod or a vehicle. It does not require Sun to illuminate the target, rather it emits its own laser pulses which strikes the object and reflected back by the object. It measures distance from the sensor to the object by calculating the time taken by the laser pulse (i.e., from the release of laser pulse to receiving back the laser pulse). Each laser pulse can produce more than one return due to partial reflection from different objects. For example, portion of a laser pulse hitting a top of the tree is reflected first (called 1st return), then remaining part of the pulse travels further down and may be reflected back by branches (2nd return) and the final part of the pulse may hit the trunk/ground and return back (3rd return). Normally the strength of the return pulse helps to decide whether a particular return pulse is useful or not. LiDAR operates in optical region (Blue-Green/Near Infrared) of Electro-Magnetic Spectrum (EMS), whereas RADAR works in microwave region. The topographic LiDAR works in NIR region (900–1064 nanometers) of EMS for precise measurement of land surfaces. Bathymetric LiDAR in Blue-Green region of EMS, due to its water penetration capabilities, is used for obtaining topography above and below the water surface.

The typical LiDAR data consists of huge collection of points (called point-cloud) with precise measurements in xyz, together with their information on the ground reflected laser signals. It being an active remote sensing technology, can be operated during night time also. LiDAR is an upcoming technology which has enormous applications in civil and construction engineering. It has an accuracy of cm level in vertical as well as horizontal, and hence its application ranges from precise topographic survey to wide range of geotechnical, coastal, transportation, structural engineering, 3D modeling and planning applications. LiDAR surveys produce accurate elevation information with high precision and hence it can be used in water resource monitoring, computation of cut and fill quantities, detailed surveys of road and other construction projects. Few of the broad applications of LiDAR in civil engineering field is discussed in subsequent sections.

2.1 3D OBJECT MODELLING: Three dimensional modeling of built structures has gained momentum over the last decade and have been applied for various applications like urban planning, visualization and navigation of built objects, computer gaming, virtual tourism, real time emergency response and many more[8]. There are many open source and commercial software are available for creating 3D models such as google sketch-up etc. However, it needed high level of human effort to build even a model of single building. Airborne LiDAR data in combination with aerial images overcome this limitation and is considered as the best technology for rapid creation of accurate 3D urban surface models [9] [10] extracted building polygons from Airborne LiDAR data and when checked against photogrammetric height, the extracted building heights found to be more accurate. This makes LiDAR data best suitable data for variety of 3D modeling applications.

2.2 TOPOGRAPHIC SURVEYS: LiDAR data provides Digital Elevation Model (DEM) and micro- topography with high level of precision. The data can even penetrate below the tree canopy, hence provides the surface value and even the tree structure. Also, it can be processed to obtain the Bare Earth Model (terrain model) efficiently. The high resolution surface model obtained from LiDAR have been used in flood modeling [11][12], watershed and stream delineation, landslides and slope stability analysis [13], cut and fill analysis [14], tsunami inundation modeling and shoreline mapping [15], infrastructure planning and monitoring, integrated storm water management plan, geomorphological studies, road and rail route alignment, site planning and many more. The high quality DEM in conjunction with Geographic Information System (GIS) enable planners and engineers to create alternate scenarios at the planning and design stage itself.

2.3 TRANSPORTATION: Recently Mobile LiDAR integrated with multi-purpose survey equipment have been used extensively for transportation applications such as survey of road geometry, pavement defects and condition and pavement distress survey [16] . The dense 3D LiDAR point cloud is being employed to detect potholes and their volumes for assessing the amount of fill material [17][18] , to identify uneven or low surface susceptible to flood and drainage problems [19], for evaluation of pavement surface conditions [20], to create 3D models of a road surface and identify cm level cracks [21]. However, presently the high cost of the equipment, hardware and recurring expenditures prohibits its widespread use.

2.4 STRUCTURAL HEALTH MONITORING: Terrestrial LiDAR or Terrestrial Laser Scanner (TLS) helps in Structural Health Monitoring (SHM) and is being used for identification of structure displacement, strain, distress, surface crack, corrosion and collision damage, and critical structural factors, such as bridge clearance, degree of curve and skew distance [22][23]. The bridges with lower clearance are vulnerable to vehicle collision and damage. Change in clearance height over a period of time can reflect vertical structural movement, pavement overlays or ground subsidence [24]. The continuous bridge inspection is vital for avoiding the incidents of bridge collapse and structural failures, the frequency of which is increasing. [25] found that vehicle-mounted laser scanning systems can significantly reduce the time for bridge inspection. It helps to visualizing and analyze bridge, dam or any other massive structures in a 3D environment and can work as a standard technique for structural health monitoring. TLS is used to acquire 3D data of an excavated tunnel at different point of time and found that it is a promising technology for tunnel applications [26][27]. Digital documentation of cultural heritage and monument structures can also be carried out using TLS [28].

3. MAPPING URBAN IMPERVIOUSNESS: Urban landscape is becoming more and more of roads and concrete structures, and the amount of naturally exposed ground area has been reducing with time, and even pavements are not spared. The potential impact of this type of un-natural surface is that it does not allow rain water to penetrate into the ground (i.e., impervious) and hence affecting the soil moisture and ground water level and potentially accelerating an urban heat island scenario. In addition, urbanisation process replaces near-by agriculture areas, marshlands and wetlands with impervious surfaces, and hence affecting hydrological processes [29] and effect of these conversions can be seen from recent flooding events in the metros. From the environmental point of view civil engineers need to address this problem of imperviousness in a city, as it is a pseudo indicator of environmental quality, so as to provide sustainable living condition. Imperviousness is considered as a soil sealing and a major cause for land degradation in Europe. Considering its negative effect on soil European Commission published a report and guidelines about soil sealing based on remote sensing derived CORINE land cover data [30] Imperviousness can be assessed using remote sensing in many ways. [31] provides a detailed review about usability of remote sensing for studying impervious surfaces, its types, extraction process, and linkages with water quality and hydrological modelling. One direct way to extract impervious surface from remote sensing data is to classify the multi-spectral remote sensing data using supervised classification (refer classification section in chapter 10). Also, various indices are developed over time to extract built-up areas from remote sensing data - for example, Urban Index (UI)[32], Bare soil index (BI) [33] , Normalised Difference Built-Up Index (NDBI) [34], Normalised Difference Bareness Index (NDBaI)[35], Index-based Built-Up Index (IBI) [36], and Enhanced Built-up and Bareness Index (EBBI) [37]. In the early satellite era, spatial data was coarse (spatially) and hence there was a high level of land cover mixing within a pixel. In such cases one has to estimate some spectral vegetation/building index as greenness/built-up indicator first (such as NDVI) at each pixel and then establish the relationship with ground impervious condition measured using aerial photos/ground sample locations. Based on the established regression equation whole image can be converted into grades of imperviousness [38]. Also, researchers have used Linear Spectral Mixer Analysis for extracting impervious surfaces [39]. Availability of high spatial resolution multi-spectral remote sensing data (such as IKONOS, Quickbird, Resourcesat-LISS-IV, Orbview, KOMPSAT, GeoEYE, etc.) is a boon for mapping the spatial distribution and amount of impervious surface area in a city/town. In the high resolution data object-oriented classification and decision tree algorithms proved to be a very useful tool for extracting impervious surfaces [40] as it incorporates spatial arrangement and context apart from spectral characteristics. **Figure 2** reveals different ways (i.e., approaches) of deriving impervious surfaces from remote sensing data. Analysing the evolution of impervious surface over time have helped civil engineers in understanding the impact of city development on the stream network, and to identify hydrologically active areas for urban planning and storm water management [29]. Also, information about spatial distribution of impervious surface would help in urban ecosystem studies such as urban hydrology, urban climate, land use planning and resource management [41]. One may consider imperviousness information as one of the parameter in the urban land use suitability modelling.

4. EXTRACTING BUILDINGS IN URBAN ENVIRONMENT: City planning needs diverse demand and supply data such as number of buildings, persons living in a locality, quality of living conditions, traffic pattern, electricity and water usage, road conditions etc. Information about spatial distribution of buildings is one of the vital indicators which can provide clue about many of the above said parameters, and also help in property tax assessment, income disparities, detecting planned/unplanned developments, illegal constructions and growth of slum areas [42][43][44. In this regard, remote sensing provides first hand information about buildings location, shape, size, distribution and temporal changing pattern.

Property tax is calculated differently in different countries/cities, and the factors generally considered are: number of rooms, rental value, area, age and property usage. In India, Unit Area Method (UAM) is emerging as a new taxation method which is currently being used in Delhi, Chennai, Bangalore, Hyderabad and many more cities [44][45]. In this UAM approach the tax is calculated based on easily measurable quantities such as area, age and use of building. Recent Remote sensing approaches especially 3D-Stereo images acquired using satellite and LIDAR point clouds (dense 3D point representation) can help to estimate the area easily, and number of floors can also be estimated indirectly based on height of the building. Shape, size, roof top and surroundings would also help in understanding usage of the property such as commercial activity, school, park, mall etc. Integrating these information along with ward boundaries would help metropolitan development authorities to assess required information (such as geometrical homogeneity, condition of road and its network, greenness indicators) to assess socio-economic status. Generally used methods/techniques for extracting building foot prints are: a) object oriented and decision tree classification (for object detection), b) edge detection filters (for boundary detection), c) Building Index based (for detecting constructed area), d) Spectral Indices (for clustering roof tops), e) spatial metrics (for understanding spatial arrangement), f)Thinning and automated vectorisation (for fine tuning extracted feature boundaries) and g) Manual digitisation (for accurate building foot print delineation) [46] [5].

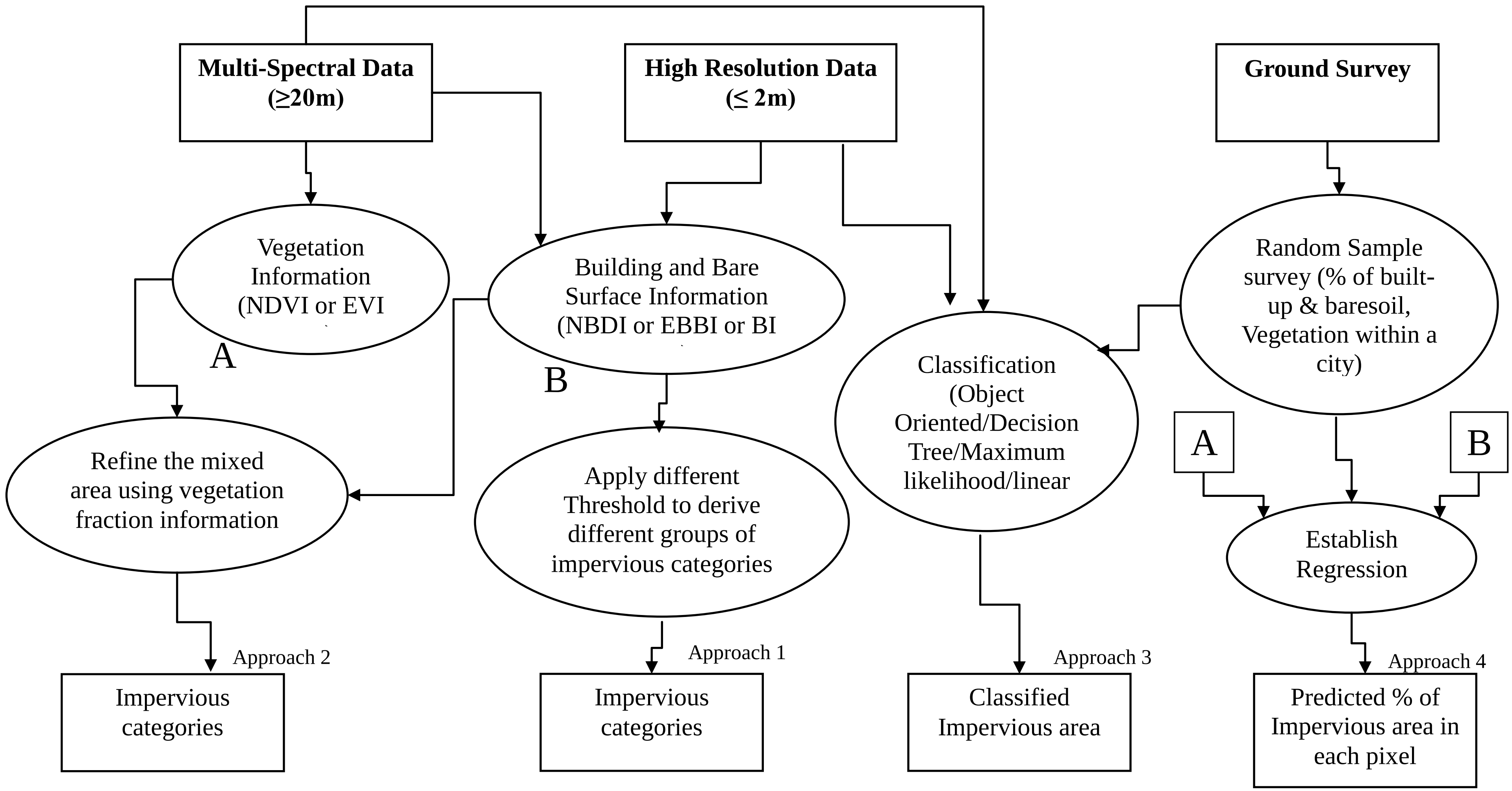

Figure 2: Remote Sensing based approach for extracting Impervious Surfaces

Figure 3: Remote Sensing data and Building Foot Print over some portion of Kolkata. (Source: Google Earth & Open Street Map)

Figure 3 provides an example of having building foot print (digitized manually) over a remote sensing high resolution image. **Figure 4** illustrates different ways of extracting buildings and its height information from remote sensing data. Point Clouds from LIDAR data provides height details, and user can differentiate different features easily based on elevation information at these points. These points can be converted into continuous surface (called Digital Surface Model -DSM) using interpolation technique. If the points from bare ground (i.e., terrain) alone are used to derive continuous surface then it will be called Digital Terrain Model (DTM). By subtracting DTM from DSM one can see all the above ground features (i.e., nDSM), and by eliminating unwanted features, like vegetation using multi-spectral data. from nDSM one can derive only buildings related information. Stereo images can also help to extract the height of various features which can be associated with classification process to extract buildings with height information.

Slum is a group of informal settlements in the urban area (Fig. 5b) with dense population having substandard facilities and poor hygiene. Rate of increase in slum areas are alarming especially in the developing countries for example 30% of urban population in Asia lives in slums [47]. It was observed in a survey conducted during 2012 in Delhi that there were 6343 slums having 1million dwellers [48]. Improving the lives of 100 million slum dwellers by 2020 is one of the global agenda under Millenium Development Goals [49], and controlling the growth of slum area is one of the tough tasks for city planners. But lack of accurate, relevant and temporal data is a big hurdle in achieving the said target.

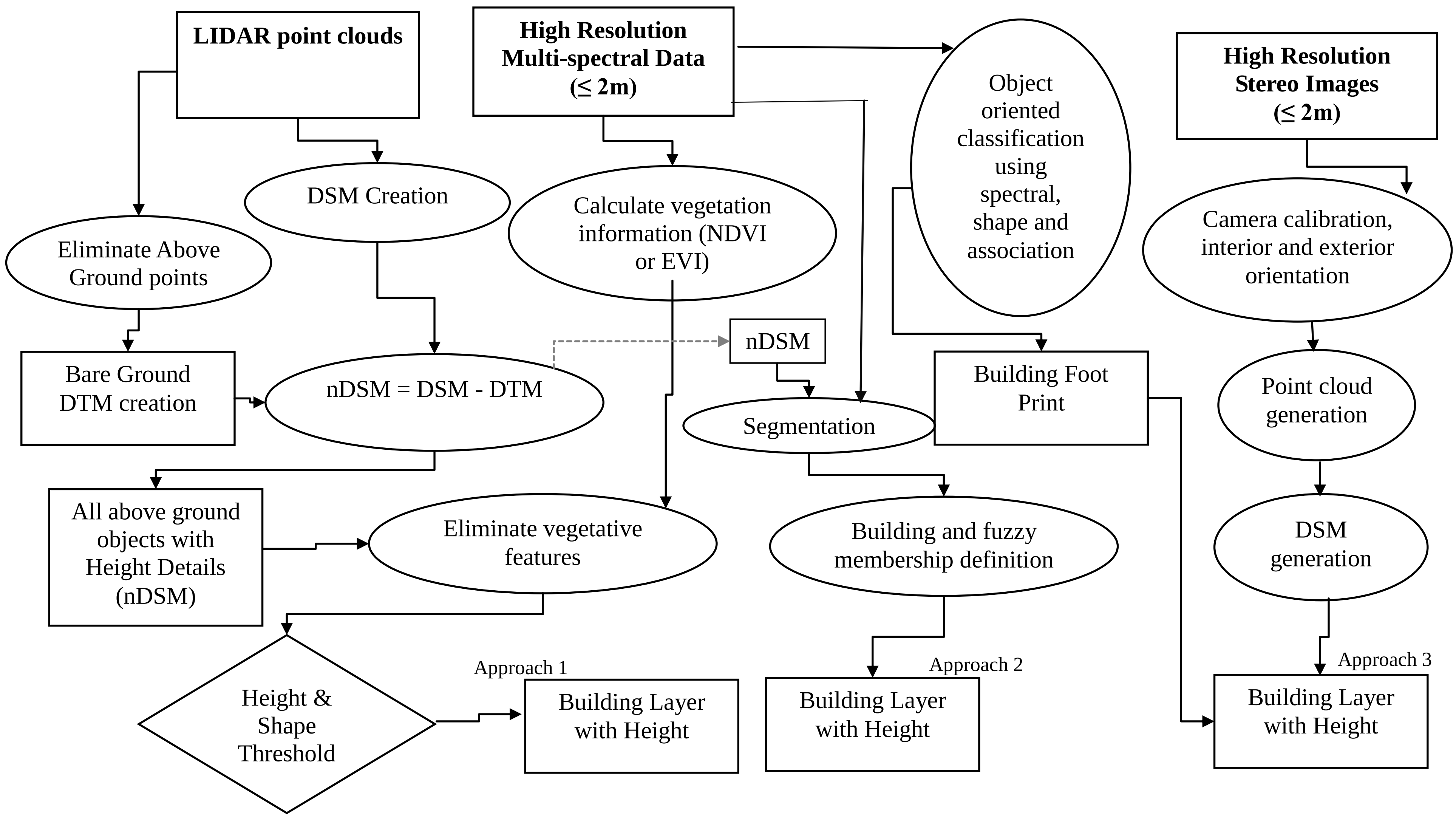

Figure 4: Building Extraction Process from Remote Sensing Data

However, advancements in remote sensing and GIS technology have contributed significantly in mapping and monitoring slum [50] [51]. The morphology of slum areas is totally different than the normal residential area as one do not find organised buildings in slums, and there is not much gap between individual settlements and hence slum area looks texturally different than other areas (see **Figure 5 a & b**) and [51] have provided a detailed review about progress made towards mapping slum area with the help of remote sensing, and they have revealed that object based classification methods, machine-learning algorithms (like ANN, Random Forest etc.) and texture based methods showed efficient results in extracting slum areas. Physical characteristics (such as size, pattern, texture etc) alone are not enough for understanding a city, and the contextual characteristics (neighbourhood fabric, road density, micro-climate, topography etc.) are also very important, and same is applicable for mapping slum area as well. Many studies have used diverse remote sensing data and methods for slum mapping in different Indian cities [52][53][54][55][56][57] and civil engineers/city planners can benefit from such studies.

(a)

(b)

Figure 5: Planned built-up (a) and unplanned slum areas (Dharavi in Mumbai, India) (b) as seen in remote sensing data. (Source: Google Earth)

5. SOLID WASTE MANAGEMENT: Uncontrolled Population growth has negatively impacted urban area with pollution (air and water), waste (solid and liquid), ground water quality, chaotic traffic and urban heat island. With population, demand for resource consumption has increased many folds and, as well as, resulted in generation of enormous amount of waste [58][59][60]. Managing solid waste from urban environment is a major challenge for city planners [61][62][63][64][65]especially when there are unplanned growth, population influx and fund crunch. Amount of waste generated per person is expected to reach 700gm/day in metros[65] and hence one can imagine the enormous pressure on civil engineers/planners. Although, waste can be managed through various techniques such as incineration, biological treatment, and recycling but landfilling is the largest adopted technique [66].

With urbanization and development there is a continuous need for new landfill sites and it has to be selected with suitable socio-economic-environmental considerations as gaseous emissions and leachate discharge occur at the sites that has harmful effects on society and environment [67][68][69]. Landfill site selection process using remote sensing and GIS have often been used globally by various scientists [70][71][72]. Different approaches such as Multi Criteria Decision Analysis (MCDA), Pairwise comparison Technique, Weighted Overlay Analysis (WOA) are used for managing solid wastes. In the site suitability modelling (Figure 6) one can use best case, worst case and optimum case scenario. In the best case scenario all the conditions (as per policy or local need) have to be fulfilled and in the worst case any one condition is fulfilled, and in the optimal case the criteria are weighted as per environmental situation and administrative requirements. Best case scenario would result in minimum suitable area (least risk) and may not fulfill the needed land requirement. Worst case scenario would result in maximum area but it has associated high risk on health and environment (as all the conditions were not equally met). So, optimum case scenario is generally recommended where weights can be associated with various conditions, and final weighted sum would reveal locations which has acceptable levels of fulfillment of all the input conditions.

6. ENVIRONMENTAL IMPACT ASSESSMENT: Environmental impact assessment is an important requirement to understand the consequences of a proposed development oriented civil engineering project (e.g., mining, thermal power plants, fly over, bridge, high way, dam etc.) on society and environment [73]. EIA enforces the civil engineers to operate within the sustainability mandate to ensure social, economic and ecological balance, and globally it was felt that EIA has positively contributed in building environmental friendly designs. Impact assessment can be carried out at pre-proposal stage (called Strategic Environment Assessment SEA) or in post proposal stage (called EIA) as per the requirements/recommendation by the inspection committee [74]. In India, EIA activity started in 1976-77 with progressive changes over time and Ministry of Environment and Forestry made it mandatory to get Environment Clearance (EC), since 2006, for all major projects as per Environmental Protection Act (1986)[75][76].

It is mandatory for civil engineers to ensure that they have EIA legal clearance before beginning the actual development, and hence it is important to understand the basic checklists for impact reporting under EIA (see http://envfor.nic.in/divisions/iass/eia/Checklist4.htm for details). Remote sensing has established its significant role in EIA process by providing continuous snap shots about ground condition (i.e., images of past and present at different scales) in various domains such as mining, thermal power plant, nuclear plant, dam and highway construction etc. GPS helps to obtain accurate locational information. GIS helps to model various spatial layers derived from remote sensing data (such as land cover, vegetation status, road, topography, drainage, lineament, geomorphology, wasteland etc.) to quantify the nature and magnitude of impact from various scenarios of proposed activities using the *multi-criteria decision framework*. Analytical Hierarchical Network (AHP) based decision making method has been used extensively for EIA as well as for environmental related decision making [77]. Buffer (inner and outer) around the proposed infrastructure is analysed from the point of view of ecology, economy and social perspectives. Criteria (i.e., ground/spatial parameter having a role in impact assessment) selection is important in EIA and civil engineers should appropriately incorporate the norms set by government in each case. Each of the Criteria need to be weighed as per their importance in relation to its impact, and classes within criteria must also be rated (i.e., statistically assign a score or expert assign a score ranging between 0 to 100 relatively) (similar to solid waste management example, see fig.6). Finally, all the layers can be integrated (i.e., weighted sum) to derive a final Impact Score which can be grouped into various categories, and then quantify the percentage of different ground features vulnerable under each impact category within each buffer zone. The advantage of this process in planning stage is that civil engineers can analyse the role of various parameters as well as different scenario/alternatives (e.g., in case of construction of new road, engineer can try impact from 3 or 4 different route alignments). In case of point source data where continuous information is not available (unlike remote sensing data) civil engineers can use *interpolation techniques* to map the status and zones of pollution in the region, and pollutant dispersion can be predicted using wind data, and finally vulnerability of the society and natural assets can be estimated.

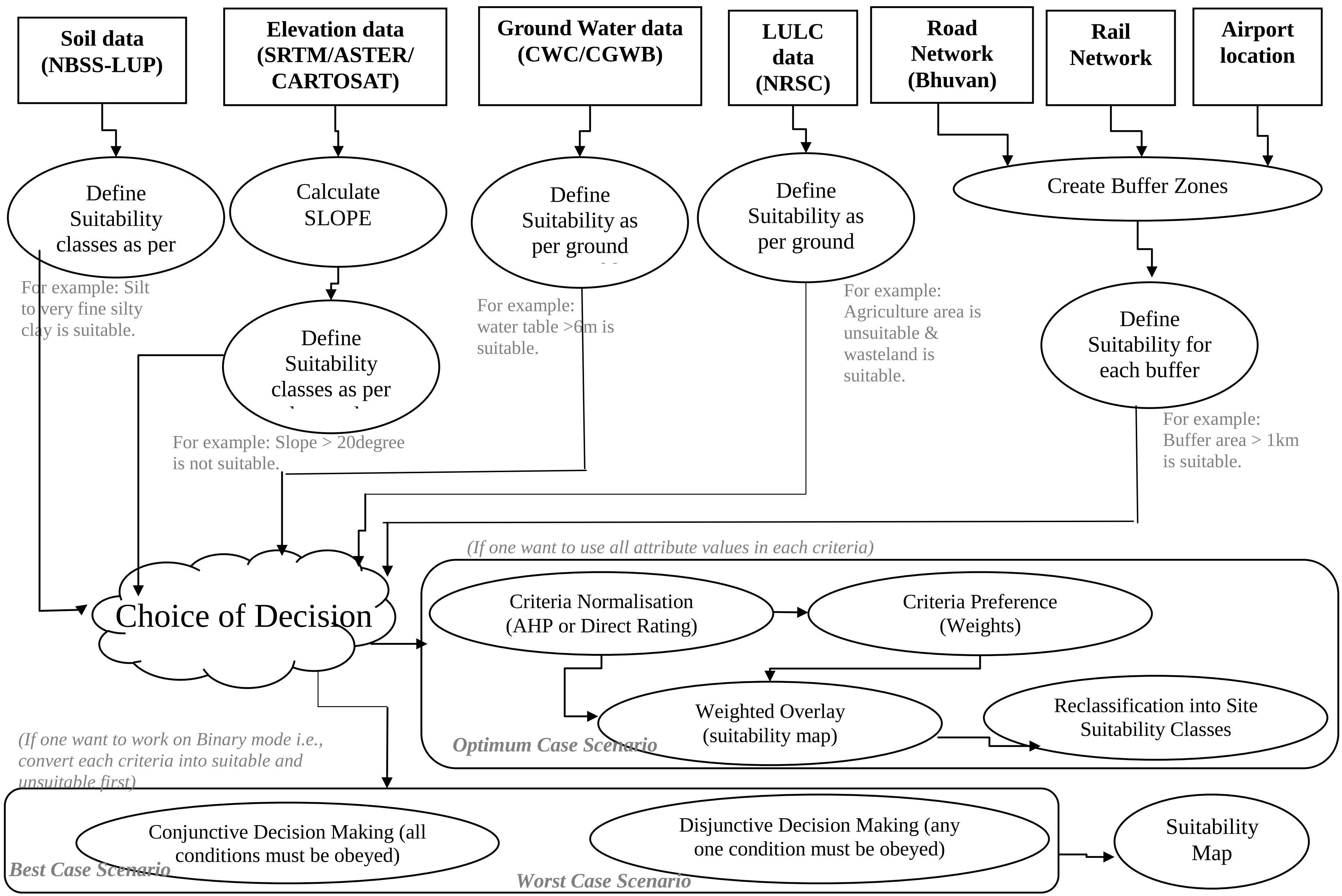

Figure 6: Solid Waste Disposal Site Suitability Modelling using RS & GIS. (NBSSLUP – National Bureau of Soil Survey and Land Use Planning; CWC – Central Water Commission: CGWB – Central Ground Water Board: NRSC – National Remote Sensing Centre).

7. REMOTE SENSING IN HYDRO-POWER GENERATION: Among the renewable energy sources, the hydropower systems produce electrical energy from potential and kinetic energy of water in rivers and streams. This renewable source is one of the clean energy options without causing the air contamination and exhaustion of fossil fuels. Though initially capital intensive, the day-to-day operational cost of hydroelectric power system (HEP) is relatively cheaper. Perennial inflow of water and suitable location providing sufficient head are the primary factors to site a HEP scheme. These must be complemented with favourable geological, environmental and socio-economic parameters. There are three types of HEP schemes: 'run-of-the-river', where electricity is generated through flow of a river'; 'reservoir', where power is generated through release of stored water; and 'pumped storage', where stored water is recycled by pumping it back up to a higher reservoir in order to be released again. HEP projects are generally classified as large (100 MW+), medium (10 - 100 MW), small (1 - 10 MW), mini (100 kW - 1 MW), micro (5 - 100 kW) and pico (< 5 kW) based on power potential (http://www.renewablesfirst.co.uk/hydropower/hydropower-learning-centre/what-is-the-difference-between-micro-mini-and-small-hydro/). The gross theoretical hydropower potential is approximately 52 PWh/year divided over 11.8 million locations. It is equal to 33% of annually required energy, while the present energy production by hydropower plants is just 3% of it. Among all the continents, the greatest contributor is Asia, which represents 48% of global hydropower potential [78]. Hydropower plays different roles in each country owing to regional variation in potential relative to electricity demand. In some countries such as the Congo, there is sufficient hydropower potential (>10 times) to meet all electricity demands, while in other countries such as United Kingdom, hydropower potential can only accommodate a small portion (<3%) of total demand [79]. India's hydropower potential ranks 5th in the world. The estimated economically exploitable hydro potential in India is assessed at 84,000 MW (@ 60% load factor) with a suggested installed capacity of 1,48,700 MW [80]. Almost 45% of the potential is concentrated in Brahmaputra-Barak basin, out of which very little has been so far developed. Indus Basin has next highest probable installed capacity of about 23% of total potential. The Indian power system requirement has been assessed to need a hydro power and thermal/ nuclear power mix in the ratio of 40:60 for flexibility in system operation depending on typical load pattern. The present ratio is 25:75 which needs to be corrected immediately to meet peak load requirements as well as system and frequency stability.

7.1 GEOSPATIAL TECHNIQUES FOR HYDROPOWER SITES SUITABILITY ANALYSIS: The basic requirement in HEP schemes is sufficient 'head', which is the difference in topographical elevations between diversion and powerhouse site. The available head can be determined using high accuracy Digital Elevation Models (DEMs) and also through virtual 3D visualization of HEP sites. The measured discharge at gauge and discharge (G&D) sites can be spatially modeled in GIS environment to determine discharge at potential HEP sites. The upstream catchment characteristics in terms of land use/land cover (LULC), topographic and morphometric parameters are useful for this modeling and these can be derived from multispectral satellite data and DEM. The DEMs are also useful for delineating the catchment areas, deriving the alignment of Head Race Channel/ Pipe/ Tunnel (HRC/ HRP/ HRT) and for estimating the area which may submerge in case of storage schemes. The geological conditions like lithological and structural information can be assessed with the help of remote sensing data. The geomorphological evaluation in terms of nature and type of valley sections and type of landforms to understand the slope stability and availability of construction material can be done with the help of remote sensing data. The existing landslides can also be mapped using the satellite data. Thus, the Remote Sensing, GIS and GPS technologies have very high potential in determining these parameters directly or indirectly. Table 1 lists various parameters to be studied for HEP sites suitability analysis, Environmental Impact Assessment (EIA), economic feasibility and their amenability with geospatial data and techniques. Fig. 7 shows the flow chart of methodology for identifying HEP sites, characteristics and potential.

Broad parameter	Decision Criteria	Geospatial data & technique
HEP sites suitability analysis	Presence of constricted valleys with stable, steep rocky slope	Stereoscopic visualization and multispectral data
	Availability of sufficient topographic head	DEM and stereoscopic visualization
	Perennial inflow to ensure continuous power generation matching with installed capacity	Hydrological modeling using Remote Sensing data and GIS
	Favourable geological conditions: structural/ lithological properties and should not coincide with landslide zone	Multispectral data interpretation
	LULC characteristics surrounding hydropower site	Multispectral data interpretation/ classification

	Site falls downstream of confluence of major tributaries and is away from meandering sections	Drainage characteristics studied using multispectral data
	Tail Water Level (TWL) of upstream site is kept above Full Reservoir Level (FRL) of downstream site	Topographic profiles drawn from DEM
Environmental Impact Assessment	Hydrology	Multispectral and DEM data
	Climate Change	
	Seismicity	
	Flora and fauna analysis	

Table 4. Parameters for assessing HEP sites suitability analysis and utility of geospatial techniques

7.2 GEOLOGICAL CHARACTERISTICS: The geological characteristics of potential HEP sites and their surroundings have high importance in suitability analysis. These characteristics may be studied using multispectral data and field evidences to ensure that geologically, the sites fall in stable zone. Geologically, the following parameters influence the HEP sites suitability- a) Presence of bedding tend to decrease shearing strength, reduces water-tightness, b) Beds striking parallel to dam axis and steeply upstream dipping are best, with respect to stability, c) Beds striking parallel to dam axis and gently downstream dipping are most unfavourable in terms of stability, d) Beds striking perpendicular to dam axis increases the chances of seepage from reservoir, laterally, e) Faults striking along valley, perpendicular to dam axis cause water seepage down-dam, f) If dam axis is perpendicular to anticlinal axis (valley along anticlinal axis) then there are chances of water leakage from the reservoir, g) If dam axis is perpendicular to synclinal axis, with beds dipping with same amount as valley side slopes, having impermeable layer at valley face offer a water-tight reservoir, h) Better to avoid dams on prominent faults/thrusts, i) Minor structures like joints/fractures have to be treated with grouting, j) Drilling to be carried out to determine spacing, opening of discontinuities, etc.

7.3 WATER AVAILABILITY AT IDENTIFIED HEP SITES: The hydrological modeling coupled with geospatial data and techniques are useful to assess dependable discharge at identified HEP sites. These hydrological models fall into following groups: a) Physically Based: derived from equations representing actual physics of process, e.g., i.e. energy balance snowmelt models, b) Conceptual: involves physics option to capture essential processes e.g., Linear reservoir model, c) Empirical/Regression e.g., temperature index snowmelt model, d) Stochastic models evaluates historical time series, based on probability. The models are also described based on spatial representation i.e., lumped or distributed.

7.4 SNOWMELT RUNOFF MODELING: Snowmelt runoff model (SRM) is a temperature index model which was originally developed by [81] to simulate and forecast daily stream flow in mountain basins where snowmelt is a major runoff factor. The model has been applied and performed very well in over 100 basins in 29 different countries. The water produced from snowmelt and rainfall is computed as given in Eq. (1):

$$Q_{n+1} = \left[C_{sn} a_n (T_n + \Delta T_n) S_n + C_{Rn} P_n \right] \frac{A.10000}{86400} (1 - K_{n+1}) + Q_n K_{n+1}$$

where Q = average daily discharge (m^3/s), C = runoff coefficient expressing losses as a ratio (runoff/ precipitation) with CS referring to snowmelt and CR to rain, a = degree-day factor (cm/^{o}C/d) indicating snowmelt depth resulting from 1 degree-day, T = number of degree-days (^{o}C d), ΔT = adjustment by temperature lapse rate when extrapolating temperature from the station to average hypsometric elevation of the basin or zone (^{o}C d), S = ratio of snow covered area to total area, P = precipitation contributing to runoff (cm), T_{CRIT} determines whether this contribution is rainfall or snow, A = area of the basin or zone (km^2), k = recession coefficient indicating decline of discharge without snowmelt or rainfall where k = $\frac{Qm+1}{Qm}$ (m, m + 1 are the sequence of days during a true recession flow period) and n = sequence of days during the discharge computation period.

7.5 REGIONAL FLOOD FREQUENCY ANALYSIS: Regional flood frequency analysis is used for the estimation of discharge at sites where little or no data are available. It involves the identification of groups (or regions) of hydrologically homogeneous catchments and application of a regional estimation method.[82] developed regional flood frequency relationships by using the level one LH-moment based on generalized extreme value (GEV) distribution for the estimation of floods of various return periods as follows-

$$Q = 4.420(A)^{0.72} \quad \text{..... (2)}$$

Where, A= catchment area, sq. km, and Q = mean annual peak flood, cumec. The model was drawn based on probability distribution analysis of 13 south flowing tributaries of Brahmaputra based on least-square approach.

7.6 EMPIRICAL RELATIONSHIP: Proportionate discharge at prospective valley segments are computed by developing a linear model using various catchment properties:

$$Q = f\,(CA, SA, FA, SL)$$

Where, Q = dependable inflow from G&D site, CA = catchment area in sq. km, SA = snow covered area in sq. km, FA = forest area in sq. km, SL = average slope of in sq. km.

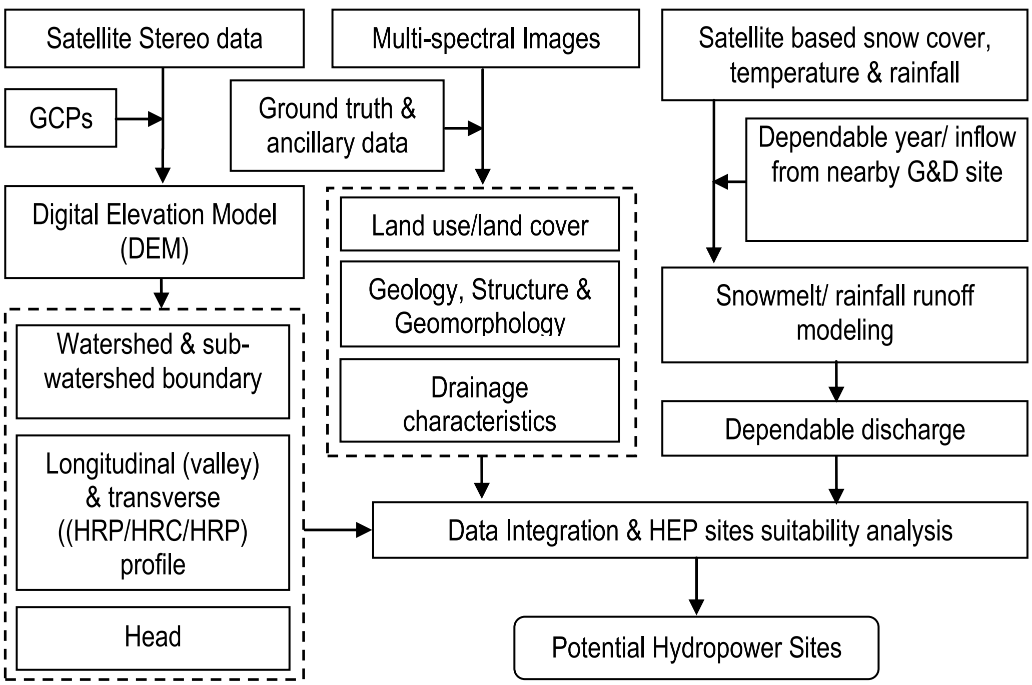

Figure 7. Methodology for identifying potential hydropower sites

8. CONCLUSION: This paper is made with an idea of providing comprehensive appraisal about potential of advanced RS &GIS technology for civil engineering applications. A birds-eye view about various applications of the Geo-Spatial Technology and associated methodologies are discussed in this paper. Though remote sensing has vast applications, there are certain limitations like cost involved in data acquisition, complex analysis of satellite data, stereo-pair availability, voluminous 3D point clouds and lack of free availability of software and domain-specific algorithms. Readers are encouraged to go through various research papers, reports and websites provided in the references for further clarification and in-depth knowledge. Authors acknowledge various authors and internet sources for sharing their study which immensely helped in shaping up this work.

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