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Geospatial Techniques for Urban Environment Quality Assessment

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Abstract—*Excessive urbanization, changing land use patterns and associated human activities are influencing the environmental quality in urban area of Jaipur, India. This study is an attempt to map and evaluate the urban environmental quality (UEQ) using geospatial technologies. For this study remote sensing satellite data, demographic data and environmental data has been used to analyze the processes of spatial and temporal changes in UEQ of Jaipur. Present work evaluates population density, open green space, impervious surface area, air quality change, water quality change and land surface temperature to get detailed information for environmental quality. Landsat images of year 2000, 2011 and 2016 were used to quantify the spatio-temporal changes in impervious surface area, open green space and land surface temperature in Vidhyadhar nagar zone of Jaipur. GIS technologies were adopted to analyze the changes in air quality, water quality and population density. Results infer that the quality of environment has been degraded with the rapid urban expansion in Jaipur. This study demonstrates that integration of satellite remote sensing and GIS was an effective approach for monitoring and assessment of UEQ.*

Keywords*: Geographic Information systems, Remote Sensing, Environmental monitoring, Land Surface temperature.*

1. INTRODUCTION

Urbanization has been an important social and economic phenomenon taking place all around the world [1] and its growth considerably affecting the urban environment and existing infrastructure. Urban population in the world was estimated at 2.4 billion in 1995 and a doubling is expected at about the year 2025 [2]. By 2035, the world's population living in urban areas will reach 5 billion, principally in African and Asian countries [3]. Growing population, changes in lifestyle and rapid urbanization is changing the landuse pattern significantly around the globe [4]. The main basis of urbanization is the economic change and in particular the growth of secondary and tertiary occupation in urban areas [5]. The extent of urbanization or sprawl not only transforms the land use patterns but also induce the serious environmental issues, which may threaten the urban sustainable development [6,7]. Most of the urban centers of India are also facing number of socio-economic and environmental issues with varying scale and scopes and hence affecting the urban environment quality (UEQ) of the cities.

Jaipur the capital of Rajasthan is the 10th most populous metropolitan region in India with an annual urban population growth rate of 4 %. Population of Jaipur was 0.160 million in 1901 which has grown to 3.1 million in 2011 (Figure1). Jaipur as many other metropolitan cities of India, faces expanding urbanization due to high population growth, dramatic land use/land cover (LULC) changes, and socio-economic transformations. As a result, these changes have become a topic of tremendous interest within the human dimensions of the environmental change research community [8,9,10]. Integration of remotely sensed data with geographic information system (GIS) made possible to study these environmental and socio-economic transformations in less time, at low cost and with better accuracy [11,12,13].

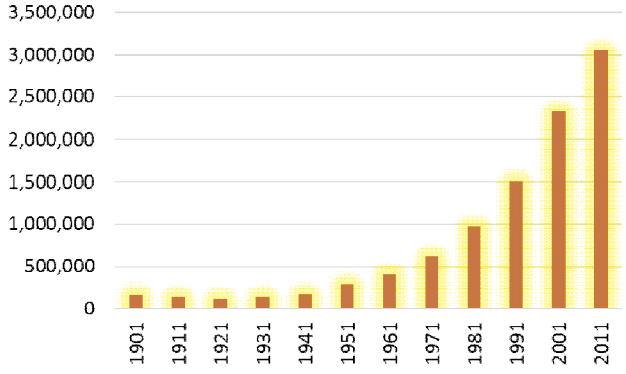

Fig. 1: Decadal Population growth of Jaipur City (1901-2011)

Remotely sensed imagery is an effective data source for urban environment analysis that is inherently suited to provide information on urban LULC characteristics and their changes over time at various spatial and temporal scales [14,15,16]. Geospatial techniques has been widely used in assessment of UEQ with the inclusion of various aspects such as Urban Heat Islands (UHIs) analysis, quantification of green space,

impervious surface area estimation and environment quality of the urban area. In this paper an attempt has been made to assess the urban environmental issues which Jaipur is currently facing due to unplanned growth of the city in all directions. Therefore, the main objective of this article is to examine the spatio-temporal pattern of urbanization in Vidhyadhar Nagar zone of Jaipur using geospatial techniques and to evaluate the urban environment quality in Vidhyadhar Nagar of Jaipur urban region during 2000 to 2016.

2. MATERIAL AND METHODS

2.1 Study area

Jaipur district, covering geographical area of 11,061.44 sq. km and extending between 26° 25'N to 27° 51'N latitudes and 74° 55'E to 76° 15'E longitudes forms east-central part of the Rajasthan State. Jaipur, the capital of Rajasthan, popularly known as Pink city is located in the Aravali hills at an altitude of 431 meters above mean sea level. Jaipur is the main political and administrative center of Rajasthan and a major tourist gateway with fascinating forts and magnificent palaces. Physiographically the city area is characterized by sandy-plains, hills, intermountain-valleys, pediments etc. Major part of the city is covered by the alluvial sandy plains. There is no major river drainage system in the Jaipur Urban Area. One streamlet originating from Nahargarh Hill namely Amanishah Nalla flows southerly up to Sanganer area where it takes easterly flow direction due to structural control. Jaipur has a semi-arid climate and annual rainfall is 650 mm. Most of the rainfall is received in the monsoon months between July and September. The mean daily maximum temperature is highest (40.6°C) in May, whereas mean daily minimum temperature is highest (27.3°C) in June. The on-set of monsoon in June end/July brings down the temperature. Jaipur urban region is

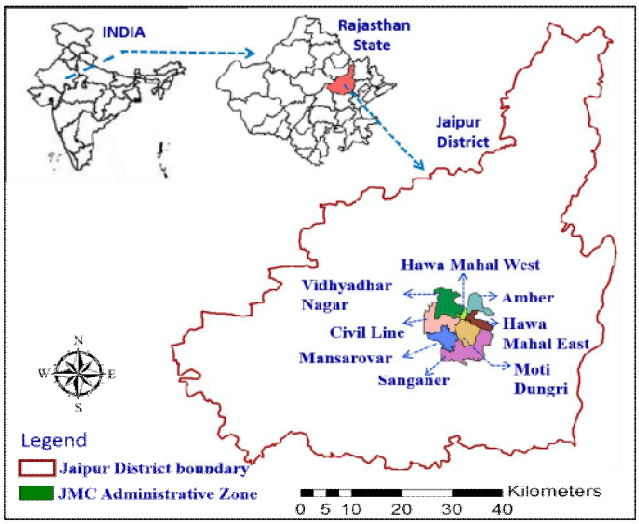

Fig. 2: Location map of Study area

divided into eight administrative zones by Jaipur Municipal Corporation (Figure 2). The municipal authorities and decision makers need to know the status of UEQ of Jaipur, for better infrastructure planning and future urban development. Therefore, UEQ of Vidhyadhar Nagar was evaluated using satellite data and geospatial tools.

2.2 Data used and UEQ parameters analyzed

The data has been collected from primary and secondary data sources. The data collected from the primary sources include Landsat and Indian Remote Sensing (IRS) LISS-III images for the years 2000, 2011 and 2016. The data collected from secondary sources include the zonal boundaries from municipal department, demographic data from the Directorate of Census Operations, Census of India [17,18], air quality data (2011 and 2016) for four monitoring stations and pre-monsoon water quality data (2012 and 2016) form Ground Water Department, Rajasthan. Since 2011 water quality data was not available, data of year 2012 has been taken as nearest representative of the same. ERDAS Imagine and ArcGIS software have been used to generate various thematic layers, like district boundary map of Jaipur, Jaipur Municipal Corporation (JMC) zones map, impervious surface, land surface temperature, green surface area, air quality and water quality.

The population density data was prepared using urban population data for the year 2001 and 2011. Compounded exponential growth model was used to estimate the average population for the period 2001 to 2011 and 2011 to 2016 for Vidhyadhar Nagar zone. These population estimates were utilized to calculated average population density for the period 2001 to 2011 as 148.1 persons/hectare and for the period 2011 to 2016 as 170.1 persons/hectare.

The expansion of impervious surface area is quantified using temporal satellite data of Landsat and Resourcesat 2 LISS III (Linear Imaging Self-Scanner) for 2000, 2011 and 2016. Impervious surface refers to the residential and commercial areas, industrial complexes, roads and paved ways etc., is captured for Vidhyadhar Nagar zone using satellite imageries and Erdas Imagine software. Supervised classification using maximum likelihood classification (MLC) algorithm has been performed for the classification of satellite

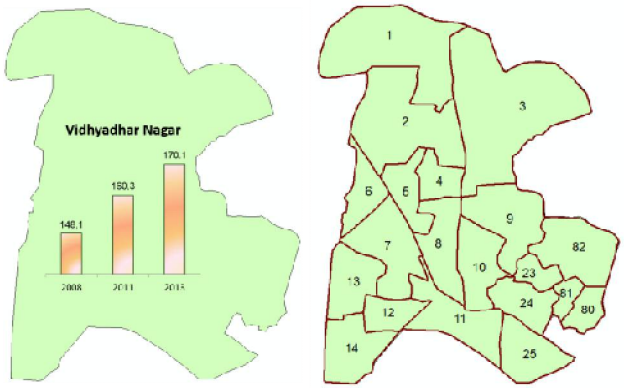

Fig. 3: Population density and ward map of Vidhyadhar Nagar images.

The algorithm was trained by supervised training process, after collection of parametric and nonparametric signatures. The classification results were re-checked with ground data and other secondary data to find out wrongly classified or missing pixel and these pixels were updated adequately.

Green surface area was estimated using Landsat images for the years 2000, 2011 and 2016. Normalized Differential Vegetative Index (NDVI) was calculated using following equations

$$NDVI = (DN_{NIR} - DN_{Red})/(DN_{NIR} + DN_{Red}) \quad (1)$$

Where, DN_{NIR}=Digital Number in Near InfraRed band, DN_{Red}=Digital Number in Red band. NDVI values range from -1 to 1. Dense and healthy vegetation show higher values, while non-vegetated areas show low NDVI values.

Land surface temperature was calculated using Spectral radiance model equation [19]:

$$L_{(\lambda)} = L_{\min(\lambda)} + \left(L_{\max(\lambda)} - L_{\min(\lambda)}\right)Q_{dn}/Q_{max} \quad (2)$$

where $L_{(\lambda)}$ is the spectral radiance received by the sensor (Wm^{-2} sr^{-1} μm^{-1}), Q_{max} is the maximum DN value with Q_{max}=255, and Q_{dn} is the grey level for the analysed pixel of Landsat image, $L_{min(\lambda)}$ and $L_{max(\lambda)}$ are the minimum and maximum detected spectral radiance for Q_{dn}=0 and Q_{dn}=255, respectively.

Spectral Radiance (L_{λ}) to Brightness Temperature (BT) in Celsius may be calculated by using inverse Planck function as expressed in equation (2)

$$BT = \frac{K2}{ln\left[\frac{K1}{L_{\lambda}}+1\right]} - 272.3 \quad (3)$$

Where; BT= at-satellite brightness temperature [Celsius degree], K1=calibration constant 1(Wm^{-2} sr^{-1} μm^{-1}), K2=calibration constant 2 (degree Kelvin), ln =natural logarithm, L_{λ} =spectral radiance from equation (1)

Land Surface Temperature can be calculated from At-Satellite Brightness Temperature (BT) as [20]:

$$LST = BT/[1 + (w * BT/C_2)\ln(e)] \quad (4)$$

Where, BT=at-sensor brightness temperature, w = wavelength of emitted radiance,

$C_2 = h \times \frac{c}{S}$ i.e. 1.4388×10^{-2}mK, h=Plank's constant i.e. 6.626×10^{-34} Js, s=Boltzmann constant (1.38×10^{-23}J/K), c = velocity of light (2.998×10^{8} m/s), e =Land Surface Emissivity (LSE). LSE was estimated using Normalized Differential Vegetative Index (NDVI).

$$P_V = (NDVI - NDVI_{min}/NDVI_{max} - NDVI_{min})^2 \quad (5)$$

$$e = 0.004P_V + 0.986 \quad (6)$$

Where, P_v=Proportion of vegetation, $NDVI_{min}$=minimum value of NDVI, $NDVI_{max}$=maximum value of NDVI, e= Land Surface Emissivity

Temporal and seasonal variations in air quality of Vidhyadhar Nagar zone was evaluated for the year 2011 and 2016. The concentration of gaseous air pollutants viz. sulfur dioxide (SO_2), nitrogen oxides (NO_X) and particulate air pollutant viz. respirable suspended particulate matter (RSPM) or PM_{10} are higher during summer and winter season [21], therefore winter (November to February) and summer (March to June) season data was analyzed. The ambient air quality data was collected from Rajasthan Pollution Control Board for different locations of Jaipur city namely, Vishwakarma Industrial Area; Regional Office Building, RPCB, Sikar Road; Ajmeri Gate and Chandpole. The location of all these four air quality monitoring stations was plotted in GIS to evaluate the ambient air quality pattern in Vidhyadhar Nagar zone of Jaipur city. Total twenty wards exist in this zone as shown in figure1. The air quality index (AQI) index has been computed by using the following equation [22]:

$$AQI = 1/3\ [{}_{actual}PM10\ /_{standard}PM10 + {}_{actual}SO2\ /_{standard}SO_2 + {}_{actual}NO_X\ /_{standard}NO_X] \times 100 \quad (7)$$

AQI values so derived was divided into five categories i.e. 0 - 25 = Clean air, 26-50 = Light air pollution, 51-75 = Moderate air pollution, 76-100 = Heavy air pollution and the value above 100 signifies severe air pollution.

In order to assess the physico-chemical parameters, the water quality data of pre-monsoon season (2012 and 2016) was collected from Ground Water Department for 8 different locations in and around the Vidhyadhar Nagar zone of Jaipur city. Different physico-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium, magnesium, fluoride, chloride, sulphate and nitrate were evaluated to determine the drinking water suitability. However sodium percentage (Na%), sodium absorption ratio (SAR) and Residual sodium carbonate (RSC) were examined to determine the suitability of groundwater for agricultural uses. The Spatial Analyst Tool in the ArcGIS software was employed for interpretation of data. Inverse distance weighted (IDW) technique was used to determine the cell values using a linearly weighted combination of a set of sample points. The weighted arithmetic water quality index (WQI) was calculated for pre-monsoon season. For computing WQI, each of the nine parameters has been assigned a weight (w_i) according to its relative importance in the overall quality of water for drinking purposes [23] and the relative weight (W_i) is computed from the following equation:

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (8)$$

Where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. Then quality rating scale (q_i) is calculated for each parameter

$$q_i = \left(\frac{C_i}{S_i}\right) * 100 \quad (9)$$

where q_i is the quality rating for i^{th} parameter, C_i is the concentration of each chemical parameter in each water sample in mg/L, and S_i is the Indian drinking water standard for each chemical parameter in mg/L according to the guidelines of the Bureau of Indian Standards. SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation

$$SI_i = W_i * q_i \quad (10)$$

$$WQI = \sum SI_i \quad (11)$$

SI_i is the sub index of ith parameter; q_i is the rating based on concentration of ith parameter and n is the number of parameters. The computed WQI values are classified into five types, i.e. excellent (WQI <50), good (WQI = 50–100), poor (WQI = 100–200), very poor (WQI = 200–300), and water unsuitable for drinking and irrigation (WQI >300).

3. RESULTS AND DISCUSSIONS

The phenomena of accelerated urbanization are the main cause for unplanned residential areas, environmental pollution, non-availability of services and amenities [24]. Figure 4 depicts the spatial and temporal changes in built-up area of Vidhyadhar Nagar Zone. Increase in built up area has been clearly seen in the last 17 years. Result implies the excessive urban growth in most of the wards of Vidhyadhar nagar except ward number 1, 80 and 82. Slower expansion in these wards is due to the presence of natural barrier i.e. hills.

Estimation of green surface area is meaningful in many applications such as urban planning, disaster assessment, flood forecasting, and wetland conservation [25]. Figure 5 depicts the decrease in vegetation cover with the expansion in urban area. Most of the wards are indicating reduction in vegetation cover in 2016 except ward number 1, 2 and 3. However these wards were also influenced by transformations in LULC during 2000 to 2016.

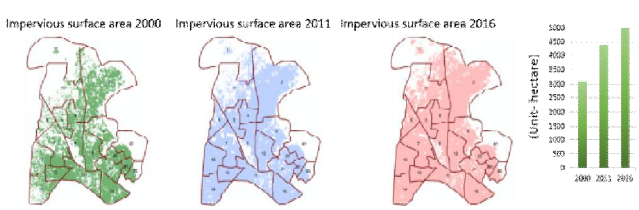

Fig. 4: Spatial and temporal changes in impervious surface

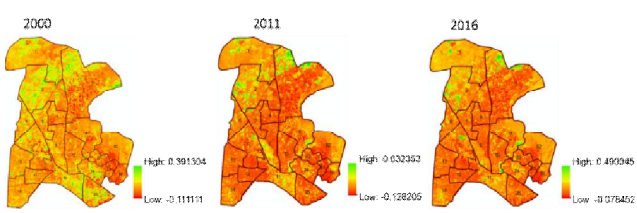

Fig. 5: Spatio-temporal changes green surface area

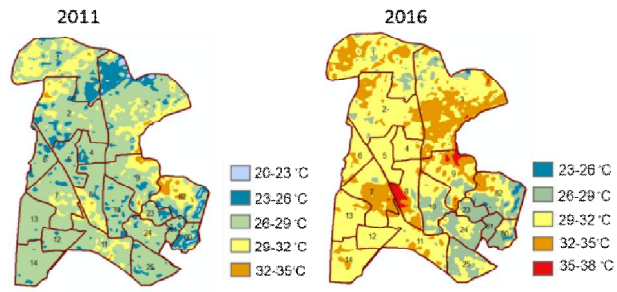

Fig. 6: Spatio-temporal changes in LST

Land Surface Temperature (LST) is an important parameter and plays a significant role in urban environment analysis, climate change, and ecology monitoring [26]. Figure 6 reveals the urban heat island analysis during 2011 to 2016. The spatial and temporal changes in LST indicates 3˚C rise in temperature of the Vidhyadhar Nagar zone with the expansion in built-up and decrease in vegetative cover.

Figure 7 a, b, c and d represents the seasonal variation of NO_X, SO_2, RSPM or PM_{10} and AQI in different wards of Vidhyadhar Nagar of Jaipur city during 2011 to 2016. The results indicate that seasonal annual average concentration of NO_X and SO_2 concentration (Figure 7ab) did not cross the reference levels of 80/120 μg/m^3 in Vidhyadhar Nagar zone. However PM_{10} concentration was higher than the prescribed limits by Central Pollution Control Board (CPCB). The high concentration of PM_{10} in all the wards of Vidhyadhar Nagar zone (Figure 7c) is due to the industrial emission and heavy transportation activities [27,28]. AQI results (Figure 7d) also indicates the presence of heavy and severe air pollution in

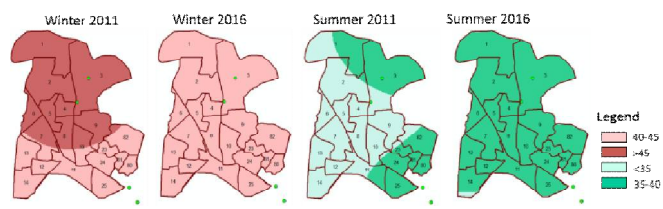

Fig. 7a: Seasonal and temporal variations in NOx

Remarks * Green points indicates the location of Air Quality monitoring station

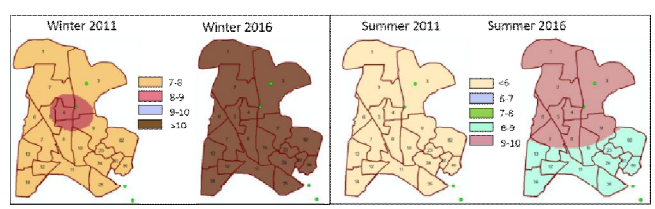

Fig. 7b: Seasonal and temporal changes in SO_2

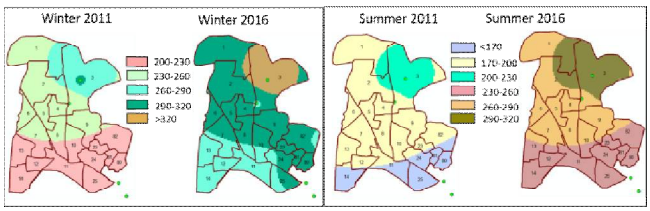

Fig. 7c: Seasonal and temporal changes in PM_{10}

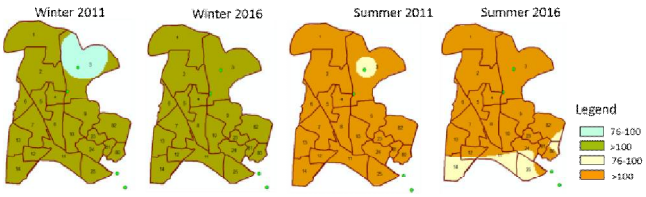

Fig. 7d: Seasonal and temporal changes in AQI

almost all the wards of Vidhyadhar Nagar during winter and summer season of 2011 and 2016.

The physico-chemical attributes of groundwater were examined for the year 2012 and 2016. Parameters such as pH, TDS, TH, calcium, magnesium, fluoride, chloride, sulphate and nitrate were evaluated to determine the drinking water suitability through WQI as shown in Figure 8a. These parameters were compared with the standard guideline values as recommended by the Bureau of Indian Standards for drinking and public health purposes [29]. WQI results implies that water quality is good (<100) however, EC value varies from medium (251–750 µS/cm), high (751–2,250 µS/cm) in all the wards. If RSC exceeds 2.5 meq/L, the water is generally unsuitable for irrigation. If the value of RSC is between 1.25 and 2.5 meq/L, the water is marginally suitable, while a value <1.25 meq/L indicates good water quality [30]. Figure 8b implies that most of the wards in 2012 were under marginally suitable category and changed to good water quality category in 2016 except ward number 3. SAR is important in classifying the water for irrigation purposes because sodium concentration can reduce the soil permeability. The waters having SAR values <10 are considered excellent, 10–18 as good, 18–26 as fair, and above 26 are unsuitable for irrigation use [30]. It is observed from figure 8b that, all the wards fall in excellent and good category, which is safe for agricultural usage. Na% is a common parameter to assess water suitability for irrigational purposes. The water having Na% values 20-40 as good, 40-60 as permissible and 60-80 as doubtful. Figure 8b shows that most of the wards are under permissible category.

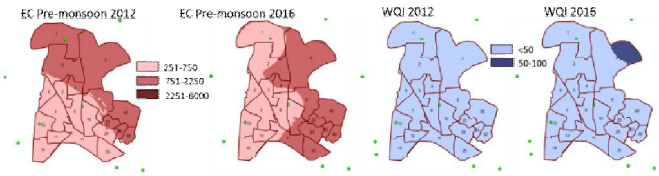

Fig. 8a: Variation of EC and WQI for pre-monsoon season

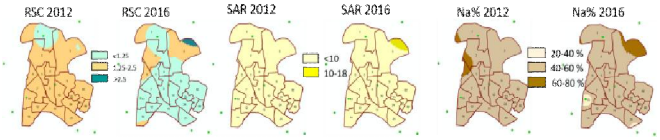

Fig. 8b: Variation in RSC, SAR, Na% for pre-monsoon season

4. CONCLUSIONS

Geospatial techniques are very useful for extraction and evaluation of information like impervious surface area, urban heat island analysis, open green space, air and water quality that are important attribute for assessing the urban environmental quality for a rapidly growing urban area. Results reveal that rapid urban growth in Vidhyadhar Nagar zone of the Jaipur city have adverse impact on air quality of the area. Though different maps depict different regions where specific parameter indicates higher environmental degradation, but in general it could be ascertained that north east region i.e. ward 2 and 3 is more impacted as compared to other regions of the Vidhyadhar Nagar zone. Further, the population growth and urban sprawl has threatened the quality of life in Vidhyadhar Nagar with rise in land surface temperature, poor ambient air quality and loss of open green space. The spatial and temporal changes in green space indicate the land transformation during last 17 years. However, water quality in the area is satisfactory and suitable for drinking and irrigation purpose. This may be attributed to the less number of tube wells in that area and piped water supply from Bisalpur pipe line. With alarming rate of urban sprawl, there will be more problems compounding urban environment quality, therefore, many measures need to be taken for proper management of land resources and to reduce the risks of further environmental degradation.

5. ACKNOWLEDGMENT

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