GEOGRAPHICAL ANALYSIS

ORIGINAL ARTICLE

Assessing the Impact of Waterlogging and Soil Salinity Problems on Land Productivity and Crops Production in Central Haryana

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Abstract

Waterlogging and soil salinity are severe challenges to agricultural productivity in Central Haryana. This study evaluates the spatial and temporal changes in waterlogging and salinity for the years 2010 and 2019-20, analyzing their impacts on land productivity and crop yields. Remote sensing data from LANDSAT 7 and 8 were employed to map affected areas using NDWI and NDSI indices. Geospatial analysis was complemented by a survey of 1,050 farmers, which provided insights into crop patterns, yield reductions, and economic losses due to these issues. The results revealed that waterlogging affected 14,091 hectares during the pre-monsoon season in 2010, increasing to 63,446 hectares post-monsoon. By 2019-20, waterlogged areas reduced to 13,480 hectares pre-monsoon and 44,159 hectares post-monsoon. Conversely, salinity levels increased significantly, particularly in moderately and strongly saline categories. The economic impact is considerable, with an annual estimated loss of ₹490 million, primarily due to reduced yields of key crops such as wheat, rice, and cotton. Factors contributing to these problems include excessive irrigation, canal seepage, poor drainage systems, and unregulated groundwater extraction. The study underscores the need for sustainable solutions such as subsurface drainage, efficient irrigation practices, and crop diversification. Policymakers and stakeholders must prioritize these interventions to mitigate waterlogging and salinity, ensuring sustainable agricultural practices and enhancing the livelihoods of farmers. By integrating advanced geospatial techniques with ground-level surveys, this research offers a comprehensive framework for addressing land degradation challenges in similar agro-climatic regions.

Keywords: Waterlogging, Salinity, Land Productivity, Crop Production, RS, GIS

1 Introduction

Soil salinity and waterlogging are coincided with land degradation problems in arid and semi-arid region on the earth surface [11]. These land degradation problems arise due to both natural processes and anthropogenic activities, and their prevalence is increasing worldwide. Both problems are highly affecting the production of crop, productivity of soil and growth of crops [12, 13, 25]. Globally, nearly 10% of area is suffering from waterlogging [18]. Waterlogged soil reduced by 80% of the crop yield production as compared to normal soil [20]. Above 800-million-hectare or 6% of land of the earth is suffered from soil [17].

Waterlogging occurs when soil becomes saturated with water to the point where air pockets are replaced by water, leading to oxygen deficiency. This condition disrupts plant respiration, impairs root function, and reduces nutrient availability [19]. Salinity, on the other hand, refers to the accumulation of soluble salts in the soil, which inhibits plant growth by causing osmotic stress and ion toxicity. Both waterlogging and salinity have compounding effects, as waterlogged soils often exhibit increased salinity due to capillary rise and salt deposition on the surface [5, 15]. Nearly 20% area of cultivated land is suffering from salinity [26]. Approximately 11 to 15 mha of wheat crop was annually affected by waterlogging problem which declined 20 to 50 % yield loss [7].

Studies have documented the impacts of these stresses on agricultural systems worldwide. Studies have documented the impacts of these stresses on agricultural systems worldwide. For instance, Mohamedin et al. (2010) [16] reported that nearly 40% of cultivated land in the Nile Delta suffers from waterlogging and salinity, leading to significant yield reductions. Similarly, Bakker et al. (2010) [2] found that salinity and waterlogging in Western Australia's Mediterranean climate resulted in lower pasture productivity. In the Indian context, Singh (2013) [22] highlighted that waterlogging in Muktsar district, Punjab, reduced cropping intensity by 50% in affected areas. These findings underscore the widespread nature of these problems and their dire consequences for food security and rural livelihoods. Saturated soil in terms of waterlogged soil is subjected to saline soil having sodicity is responsible for decreasing the infiltration [3].

Remote sensing and geographical system are developed as modern approach [21, 23] to map the waterlogged and salinity affected area. Techniques such as the Normalized Difference Water Index (NDWI) and Normalized Difference Salinity Index (NDSI) enable the accurate delineation of waterlogged and saline areas. These indices utilize spectral properties of satellite imagery to differentiate between healthy and degraded land [8, 9, 10]. In the false color composite satellite imagery, waterlogged area displayed in blackish brown color [6]. Productivity of waterlogged and saline land was analyzed in Mediterranean climate in Western Australia that pasture productivity was declined due to salinity [2]. Land degradation processes like as waterlogging and salinity were analyzed in Nagarjunsagar Left Bank Cannal command area by using LANDSAT and IRS-1B LISS-1 data. Near about 1380 ha and 6830 ha irrigated area was waterlogged and saline [4]. Impacts of waterlogging on cropping pattern and crop productivity were analyzed in Muktsar district of Punjab. Study results showed that cropping pattern shifted and productivity of land was also decreased by 50% in problematic area as compared to normal land productivity [22].

The primary causes of waterlogging and salinity are varied and include factors such as excessive irrigation, poor drainage, canal seepage, and unsuitable cropping patterns. The introduction of canal irrigation during the Green Revolution significantly increased agricultural productivity in Haryana, but it also led to unintended consequences such as rising water tables and soil salinization. According to the UNDP/FAO (1985) [24], approximately 500,000 hectares in Haryana are affected by these issues. This problem is particularly severe in Central Haryana, which includes districts such as Rohtak, Sonipat, Charkhi Dadri, and Jind. These districts are characterized by intensive agriculture, which relies heavily on canal irrigation and groundwater extraction.

Despite the significant insights provided by this study, several gaps remain in the understanding of waterlogging and soil salinity issues. Firstly, the temporal scope of this research is limited to two specific timeframes (2010 and 2019-20), which may not fully capture long-term trends and seasonal variations. Secondly, while the study integrates geospatial techniques and farmer surveys, it does not delve into the socio-economic dimensions of these issues, such as migration patterns, farmer coping mechanisms, and policy inefficiencies. Addressing these gaps in future research will provide a more holistic understanding of the problem and inform more effective interventions.

This study focuses on assessing the extent and impact of waterlogging and salinity in Central Haryana for the years 2010 and 2019-20. It employs advanced remote sensing and GIS techniques to map affected areas and analyze the implications for land productivity and crop production. By integrating satellite imagery with primary data collected through farmer surveys, the study provides a comprehensive understanding of the issue. Therefore, the main objectives of the present study are- 1) mapping of waterlogged and saline area 2) to assess the waterlogging and salinity impact on land productivity of central Haryana.

2 Study area

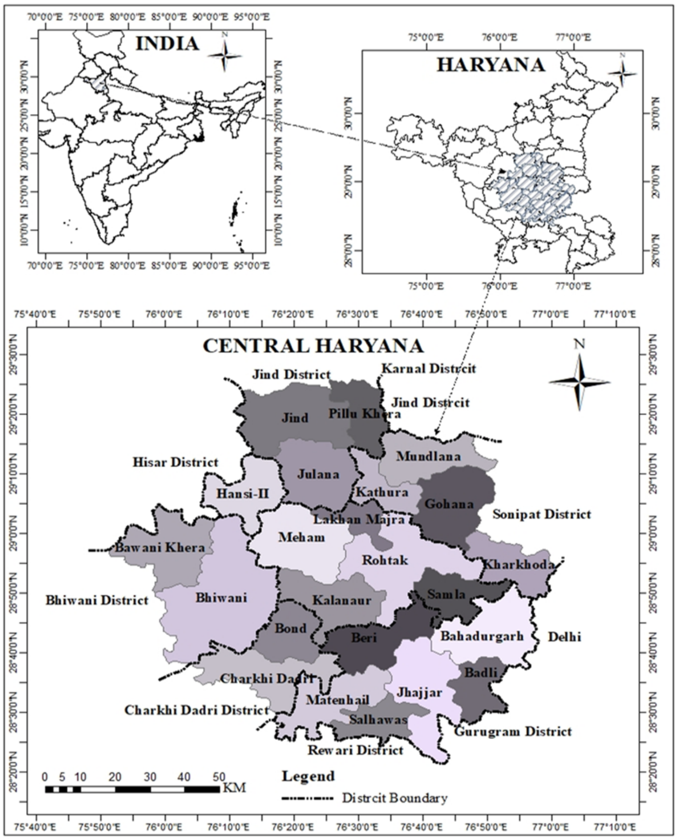


Fig. 1: Location map of study area

In Central Haryana mainly includes the area of Rohtak, Sonipat, Charkhi Dadri, Jind, Bhiwani, Hisar, and Jhajjar. The study area lies between $28^{0}21^{'}$ to $29^{0}27^{'}$ N and $75^{0}55^{'}$ to $77^{0}00^{'}$ E. The whole area is bounded by Jind, Delhi, Sonipat and Gurugram districts in the east, Karnal and Jind district in North, Hisar, Charkhi Dadri and Bhiwani district in the west and Rewari district in the south. Central Haryana covered an area of 7715.57 km^2. Geo-morphologically, most of the study area is lies in Ghaggar-Yamuna plain. The study area has an elevation of 201-250m while 251-300m elevation in southern part. Whole part of the study area has four Geomorphological units namely Older Alluvial plain, Aeolian plain, Sand Dune and Dune Complex. Average annual rainfall of the study area is 30-110 cm, and 24.60 to 25.0^{0} C mean annual temperature. Most of the agricultural area is irrigated by Western Yamuna, Jui canal and Sahibi Nadi. Solemnized and Sierozem are the major soil types of study area. Main vegetation types of the study area are Sub tropical dry deciduous. The study area has groundwater quality in safe, critical, semi critical and over exploits category (Central Groundwater Board, 2014-15; HARSAC-digital Maps). The study area is an agricultural dominated region of Haryana state. According to census 2011, study area has the population of 39, 99,019. [Fig. 1] displays the location of Central Haryana.

3 Database and Methodology

LANDSAT 7 and 8 satellite were used for waterlogging and salinity area mapping for the year of 2010 and 2020 of pre-monsoon and post-monsoon period. Satellite imageries were downloaded from USGS earth explorer. After downloading the data, radiometric correction was done for LANDSAT 7 data by using the Landsat Toolbox.tbx (Tech-Tutor with Fitsum, 2020).

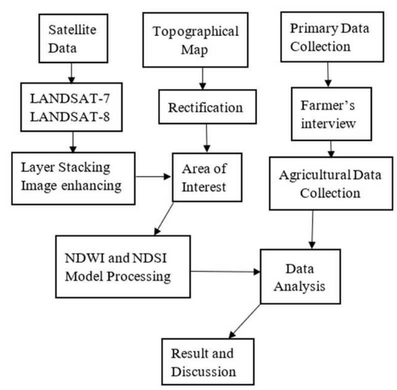


Fig. 2: Flow chart of methodology

Unsupervised image classification and Normalized Differential Water Index (NDWI) and Normalized Differential Salinity Index (NDWI) were calculated by using ERDAS IMAGINE 2015 and Arc GIS 10.2 software. Index formula for NDWI [14] and NDSI [1]-

$$NDWI = \frac{Green\ Band - NIR\ Band}{Green\ Band - NIR\ Band}$$

$$NDSI = \frac{Red\ Band - NIR\ Band}{Red\ Band + NIR\ Band}$$

Total 1050 farmers were interviewed to gather data on crop showing, yield, pattern, intensity, labour, land cost, crop disease and controlling efforts regarding waterlogging and salinity problems. [Fig. 2] showed the flow chart of methodology.

4 Result

Based on satellite data interpretation and analysis of farmer's interviewed data following results were prepared.

4.1 Waterlogging and salinity mapping

Waterlogging and salinity maps were prepared for pre monsoon and post monsoon period of 2010 and 2020. Waterlogging and salinity maps reveal significant spatial and temporal variations between 2010 and 2019-20. In 2010, waterlogged areas covered 14,091 hectares during the pre-monsoon season, increasing to 63,446 hectares post-monsoon. By 2019-20, waterlogged areas declined to 13,480 hectares pre-monsoon and 44,159 hectares post-monsoon. The reduction in waterlogged areas can be attributed to changes in rainfall patterns and localized drainage improvements. However, salinity-affected areas exhibited an upward trend.

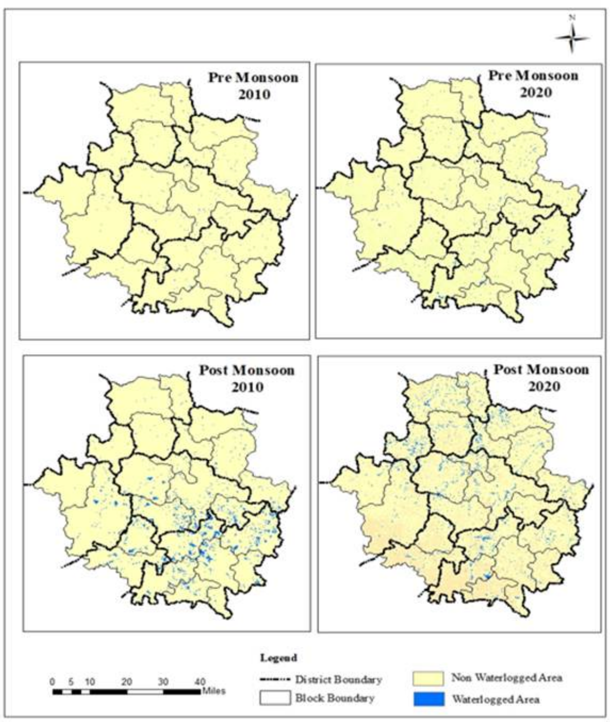


Fig. 3: NDWI pre monsoon and post monsoon

The area under moderate and strongly saline conditions increased significantly, indicating worsening soil health. [Fig. 3] showed the NDWI index for waterlogged extraction. [Fig. 3] displayed NDSI index for salinity affected area.

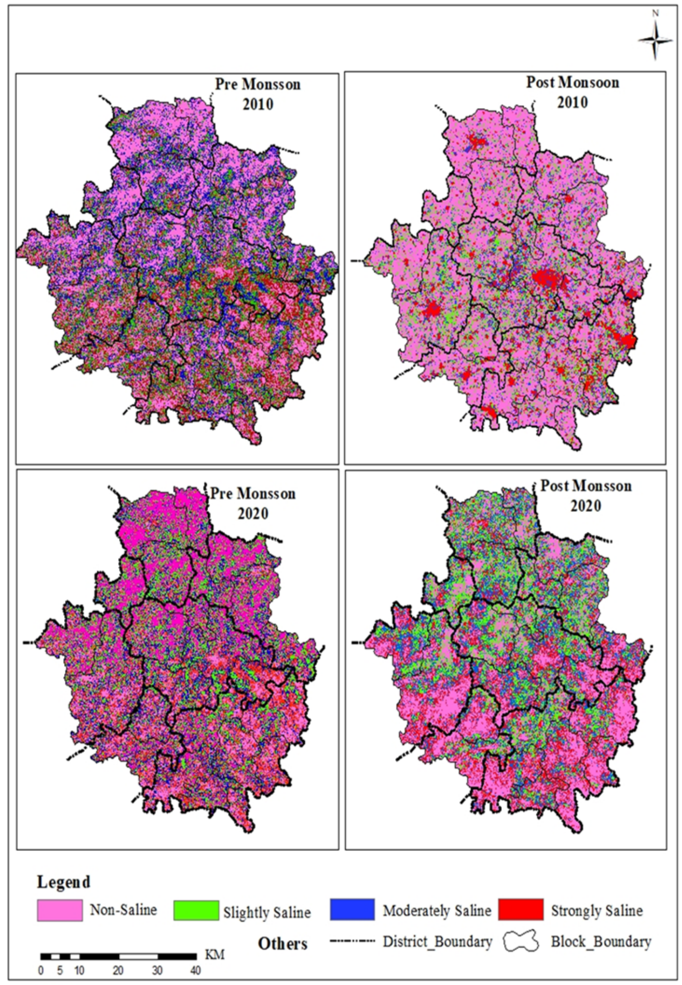


Fig. 4: NDSI pre monsoon and post monsoon

According to [Table. 1], waterlogging area in 2010 was 14091 ha pre monsoon which increased as 63446 ha in post monsoon. Heavy rainfall was the major reason for increasing waterlogging in post monsoon period. In 2019-20, waterlogged area was 13480 ha in pre monsoon which increased as 44159 ha post monsoon. Waterlogging showed declined trend from 2010 to 2019-20 in pre monsoon period and post monsoon period. In other hand, saline area was increased. Area under non saline, slightly saline, moderately saline was decreased while increased in moderately saline and strongly saline class.

Table 1: Area under waterlogging and salinity in study area

Years	Season	Area under Waterlogging (ha)			
2010	Pre-Monsoon	14091		63446	
2019-2020	Post-Monsoon	13480		44159	
		Area under Salinity (ha)			
Years	**Season**	**Non-Saline**	**Slightly Saline**	**Moderately Saline**	**Strongly Saline**
2010	Pre- Monsoon	294764	213176	123652	139908
	Post- Monsoon	298619	192174	158798	121909
2019-20	Pre- Monsoon	255441	234552	143240	138267
	Post- Monsoon	222304	177938	170027	201231

Source: Software calculation

Table 2: Cropping pattern in the study area 2010-20

Rabi Crops	% of total cultivated area	Kharif crops	%of total cultivated area
Wheat	75.7	Cotton	56.8
Mustard	3.8	Paddy	12.9
Others crops	9.3	Other crops	7.3
Cultivable waste land	2.4	Cultivable waste land	3.6
Current Fallow	2.6	Current Fallow	13.2
Permanent Fallow	6.2	Permanent Fallow	6.2
Total	100	Total	100

4.2 Cropping Pattern

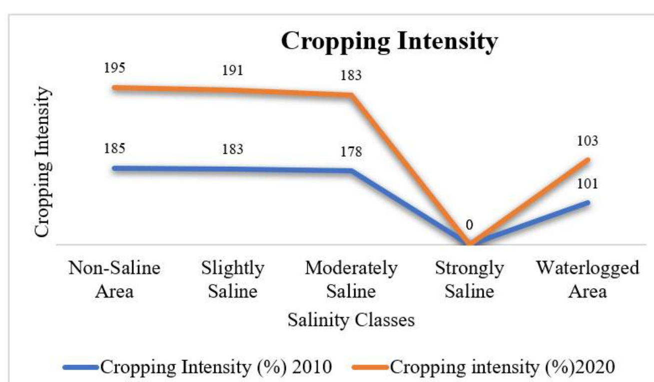
More than 75% population of Central Haryana is directly and indirectly involved in agricultural activity. Cropping pattern in the study area was mainly rabi and kharif season is given in [Table. 2]. Major crops of the study area were wheat, rice, bajra, mustard, cotton, maize, Sorghum, sugarcane and vegetables etc. Area under wheat, mustard, rice, bajra and cotton has been increased. Wheat and rice-cotton are the dominant crops of rabi and kharif season. Area under wheat crops was 70% in 2019-20 which increased as 2-3% of 2010. Other crops occupied very few increasement in area while some crops had no changes in their cultivated area.

4.3 Crop Intensity

Cropping intensity in the study area was analyzed based on NDWI and NDSI index-based result given in [Table. 3]. Cropping intensity was calculated by ratio of total cultivated area and net shown area. Intensity increased during the period of 2010 to 2020. Cropping intensity of the study area decreased as salinity and waterlogged area increased.

Table 3: Cropping Intensity based on waterlogging and salinity index

Index	Cropping Intensity 2010	Cropping intensity 2020
Non-Saline Area	185	195
Slightly Saline	183	191
Moderately Saline	178	183
Strongly Saline	0	0
Waterlogged Area	101	103



4.4 Crop Yield

Crop yield of the study area was analyzed for waterlogged and salinity affected area. Wheat and cotton-paddy are the major crop of the study area. As problems increased, crop yield decreased. Crop's yield is decreasing in each and every soil salinity class which becomes more severe with increasing soil salinity. Farmers are more concerned about these problems, and they give much attention to those crops which are grown in this environment. Average yield of crops such as wheat, rice, cotton and mustard as tons per hectare is given [Table. 4].

4.5 Production cost

When waterlogging and salinity problem increased in soil, then crop production and labour input are increased. Production cost was analyzed normal to salinity and waterlogged affected soil. Cost of all inputs increased in rabi and kharif season in waterlogged and saline soil.

4.6 Outcomes from crops production

Outcomes of each crop decreased with increasing waterlogging and salinity problem. Per hectare value of gross margin and net production were calculated. Gross margin calculated by given formula and [Table. 6].

$$Gross\ outcome = \text{Gross production value} - \text{production cost}$$

Table. 4: Ave yield of crops (t/h) in waterlogged and salinity area

Crops	Cropping Intensity (%)2010					Cropping intensity (%)2020				
	1*	2*	3*	4*	5*	1*	2*	3*	4*	5*
Wheat	15.5	15.1	14.7	00	15.6	16.3	16.2	16	00	16.4
Rice	1.4	1.36	1.3	0.0	1.5	1.42	1.37	1.3	0.0	1.52
Cotton	3.3	3.2	3.0	0.0	3.34	3.9	3.7	3.5	00	3.34
Mustard	1.3	1.27	1.25	0.0	1.3	1.4	1.34	1.3	0.0	1.3

(1* non-Saline Area,2* Slightly Saline,3* Moderately Saline,4* Strongly Saline,5* Waterlogged Area)

Table 5

Crops	Production Cost (Rs/ha)2010					Production Cost (Rs/ha)2020				
	1*	2*	3*	4*	5*	1*	2*	3*	4*	5*
Wheat	9575	10200	6500	0	7589	9890	10900	6700	0	7000
Rice	10800	11500	6800	0	10000	11900	12500	7000	0	11300

(1* non-Saline Area,2* Slightly Saline,3* Moderately Saline,4* Strongly Saline,5* Waterlogged Area)

Table 6: Margin and average production value (Rs/h)

Crops	Production Value (Rs/h)2010					Production Value (Rs/h)2020				
	1*	2*	3*	4*	5*	1*	2*	3*	4*	5*
Rabi	22500	21200	15000	0	20500	23000	12000	9700	0	22700
Kharif	23600	22670	13500	0	21600	22800	12100	9100	0	22300
	Margin (Rs/h)2010					Margin (Rs/h)2020				
Rabi	10500	9800	7600	0	10600	11300	9500	6800	0	10600
Kharif	11200	10600	8700	0	11100	11000	10100	7580	0	11000

(1* non-Saline Area,2* Slightly Saline,3* Moderately Saline,4* Strongly Saline,5* Waterlogged Area)

4.7 Overall assessment of waterlogging and salinity damage

Land production of kharif and rabi season were used to calculate land productivity. In this table, assessment of damage was analyzed which was caused by waterlogging and salinity. Near about 490 million rupees (calculation on current price) is the annual loss caused by waterlogging and salinity in the study area. Total damage in 2020 was lower than 2010. In non -affected area, production was increasing while in affected area production was reached at very low value. Sometimes severity of problem is so high that farmer left their field unsowed. They purchased food grains for their family from market. Nearly 2.03% farmers migrate from their village for livelihood. They are helpless to leave their land as a waste property because no buyer is available for waterlogged and saline area. Paddy crop is the main reason for waterlogging in study area. Very less tube well is available in whole area. Increasing irrigation practices raised the water depth table. No drain system is available. Satellite data interpretation also showed the increasement in salinity while waterlogging is decreased.

5 Discussion

The findings of this study highlight the critical impact of waterlogging and salinity on agriculture in Central Haryana. These issues not only reduce crop yields but also increase production costs, thereby threatening the livelihoods of farmers. The results align with global studies that emphasize the detrimental effects of abiotic stresses on agricultural systems [13, 25]. Remote sensing and GIS have proven effective in mapping and monitoring these issues, providing valuable insights for policymakers and stakeholders. The study also identifies key drivers of waterlogging and salinity in the region, including excessive irrigation, poor drainage, and canal seepage. These factors are exacerbated by socio-economic constraints such as limited access to advanced farming technologies and inadequate policy support. Addressing these challenges requires a multi-faceted approach that integrates technological, institutional, and community-based solutions.

6 Conclusion

Overall result concludes that soil salinity and waterlogging decreased the production of crops, income of people which affects the livelihood of the farmers. The present research paper showed that crop intensity and crops yield per hectare decreased when waterlogging and salinity was increased. Cropping pattern is changing according waterlogging and soil salinity range. These problems also declined resource efficiency. Waterlogging and salinity problems in the study area are not in continuous tract. These problems currently affect the small patches in study area. Subsurface drainage can be used to minimize these problems.

While this study provides a comprehensive assessment, it is limited by its reliance on satellite data and farmer surveys. Long-term monitoring and field-based experiments are needed to validate the findings and develop more robust solutions. Additionally, future research should explore the socio-economic dimensions of waterlogging and salinity, including their impact on migration, food security, and rural development. Advanced technologies such as machine learning and predictive modelling can also be employed to enhance the accuracy of mapping and impact assessments.

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