**Land and Water Resource Degradation in Agricultural Zones of Haryana: Drivers, Consequences, and Remedial Measures**

**Abstract:**

The study uses empirical field data to explore land and water resource degradation in Haryana, focusing on three agro-ecological zones: Zone-I (dry sub-humid), Zone-II (semi-arid), and Zone-III (arid). Primary data were collected from 360 farmers across six districts (Karnal, Panipat, Sirsa, Fatehabad, Jhajjar, and Mahendragarh), with 15 normal and 15 problematic farms selected from each of the 12 villages. A pretested structured schedule was used for personal interviews, and the data were analyzed using logistic regression (logit model) to identify key factors influencing degradation. The findings revealed that abiotic stress, saline irrigation water, and excessive fertilizer use were major contributors to land degradation, while erratic rainfall and poor drainage exacerbated water resource issues. Majority of farmers reported declining crop yields and rising cultivation costs as primary consequences. Mitigation strategies such as conservatory tillage, crop rotation, and proper drainage systems were widely recommended. The study underscored the need for policy interventions promoting sustainable practices, efficient irrigation, and extension services to ensure long-term agricultural productivity and ecological balance in the state.

*Keywords: Land degradation, water degradation, logit model, factors responsible.*

1. **Introduction**

**The scarcity of water and land resources increased considerably over recent decades due to population growth, urbanization, pollution, and climate change (Aalirezaei *et. al*., 2021; Li *et. al.*, 2021; Elleuch *et. al.*, 2019). With the global population projected to reach ten billion by 2050, food production needed to increase by over 60 per cent, requiring optimal use of finite resources (United Nations, 2020). Agriculture, which depended heavily on soil and water, faced severe stress from biotic and abiotic pressures, including erratic monsoons, floods, and droughts, salinity, sodicity leading to declining productivity (Gawande, 2000).**

**Water, a critical yet diminishing resource, was under strain from rising demand and inefficient management, particularly in agriculture, where irrigation consumed significant shares (Bithas *et. al*., 2014; Yelling *et. al*., 2007). Sustainable practices like rainwater harvesting and efficient irrigation became essential to mitigate scarcity (Elleuch *et. al*., 2019). Land degradation, exacerbated by salinization, waterlogging, and erosion, threatened food security, with global yield losses exceeding 60 per cent in affected regions (Qureshi *et. al.*, 2003; Haque, 2018; Khanam *et. al.*, 2020).**

**In India, states like Rajasthan and Haryana experienced acute degradation due to arid conditions and over-exploitation of groundwater (Planning Commission, 2009). Haryana's agricultural sustainability was further compromised by water-intensive cropping and declining water tables, with some regions recording annual declines of one meter (Sunita, 2023). Additionally, fertilizer runoff contaminated water sources, worsening ecological and socioeconomic challenges (USGS, 2001).**

**Addressing these issues required integrated management of land and water resources to balance agricultural demands with environmental preservation. This study examine the drivers of degradation in Haryana and propose actionable solutions for sustainable resource use.**

1. **Methodology**

Considering the significance of land and water resource degradation, the present study was carried out in Haryana state. An attempt has been made to describe briefly the basic approach of the selection of study area, sampling framework, sources of data, analytical techniques and models adopted in the present study.

**2.1 Different Agro-ecological Zones of Haryana**

Haryana state is divided into three agro-ecological zones on the basis of climate(rainfall), soil type, and cropping pattern :-

**Zone-I:** This zone comprises of 8 districts having dry sub-humid climate, viz. Panchkula, Ambala, Kurukshetra, Yamunanagar, Karnal, Kaithal, Panipat and Sonipat.

**Zone-II:** This zone includes 7 districts having semi-arid climate, viz. Sirsa, Fatehabad, Hisar, Jind, Rohtak, Faridabad and Palwal.

**Zone-III:** This zone includes 7 districts having arid climate, viz. Bhiwani, Mahendragarh, Charkhi Dadri, Rewari, Jhajjar, Gurugram and Mewat.

**2.2 Selection of study area**

The primary data in order to address the objectives of the study was obtained from the selected farmers using a pretested well-structured schedule developed for the study through personal interviews. However, two districts were selected based on problem of degradation from each zone of Haryana. Therefore, a total of six districts viz. Karnal, Panipat, Sirsa, Fatehabad, Jhajjar and Mahendragarh were selected from Zone-I, Zone-II and Zone-III, respectively for the study. Further, two villages were selected from each of the selected districtsbased on normal and problematic land due to soil alkalinity, salinity, water depletion or waterlogging. Hence, total of twelve villages were selected for the present study. In the final stage, 15 farmers (Normal farms) and 15 farmers (Problematic farms such as farms facing salinity, waterlogging & alkalinity problems) from each identified village were selected randomly to constitute a total sample of 360 farmers.

**2.3 Analytical tool**

For the purpose of analysis to meet the objectives of study, appropriate analytical techniques were employed to draw valid inferences from the study.

Dichotomous phenomena (binary responses) cannot be analyzed using ordinary regression techniques as this breaches various statistical assumptions (Hair *et. al.* 1998). Typically, the behavior of binary responses is described through three models: the linear probability model (LPM), logit, and probit models (Sheikh *et. al.* 2003). Discriminant analysis can also be used for such studies but requires more restrictive assumptions than logistic regression (Grimm and Yarnold 1995). Nonetheless, the logit and probit models are preferred choices for binary responses, as the probabilities predicted by both models consistently fall within the range of 0 to 1 (Sheikh *et. al.* 2003; Asrat *et. al.* 2004).

In this instance, we opted for a logistic regression model due to its advantages over probit models and its mathematical simplicity that yields interpretable results (Asrat et al. 2004). It effectively assesses the impact of continuous, categorical, and dummy independent variables on a dichotomous dependent variable (Tiwari et al. 2008). It is favored for ease of calculation, straightforward interpretation in terms of the logarithm of odds, and is founded on the cumulative logistic probability function. The logit model is applicable for converting dependent variables to predict probabilities within the range of 0 and 1 (Sheikh et al. 2003).

Hence, logistic regression or LOGIT analysis was used to examine the factors responsible for the degradation of land and water resources as the model is used to predict the value of response variable ‘Y’ using the values of a number of explanatory variables. It is assumed that the binary response, ‘Y’, takes on the value of 0 and 1, representing normal farm and degraded farm, respectively.

Y = *β0+ β1X1+ β2X2+............. + βnXn + Ui*

Where,

Y is the level of degradation (1, if farm is degraded (salinity/waterlogging/alkalinity); 0, otherwise),

β0 is the intercept, β1,β2,...........…, βn are the regression coefficient associated with each explanatory variable X1, X2,...........Xn such as

X1 = age (no.),

X2 = education (no.)

X3 = family size (no.),

X4 = mono-cropping system (1 if yes, otherwise 0),

X5 = poor irrigation water (1 if yes, otherwise 0),

X6 = over-use of fertilizers (1 if yes, otherwise 0) and

Ui is the error term.

1. **Results and Discussion**

Land and water degradation pose significant threats to agricultural productivity, food security, and rural livelihoods, as evidenced by the unanimous concern among farmers in Haryana regarding declining crop yields and land values. Identifying key factors such as abiotic stress, poor irrigation practices, excessive fertilizer use, and mono-cropping systems provided critical insights into the root causes of degradation. By understanding these factors, targeted interventions can be designed to mitigate their impact, such as promoting conservatory tillage, crop rotation, and proper drainage systems. Additionally, raising awareness through extension services and adopting climate-resilient practices can empower farmers to sustainably manage their resources. Addressing these issues not only enhances agricultural efficiency but also ensures long-term ecological balance, economic stability, and the well-being of farming communities.

* 1. **Results**

The data in table 1 outlined the perceptions of farmers regarding the factor responsible for the degradation of land among farmers, as reported by farmers across three zones in Haryana. The data were categorized by specific factors, with the number of respondents and corresponding percentages (in parentheses) provided for each zone and the total sample. A total of 180 respondents participated in the study, with 60 respondents from each zone of the state.

The most widely perceived factor contributing to land degradation as presented in table 1 was abiotic stress (erratic rainfall or over-extracted groundwater), with 162 respondents (90.0%) acknowledging its role. This factor received unanimous recognition in zone-III (100.0%) and near-unanimous recognition in Zones I and II (78.33% and 91.67%, respectively). Similarly, the use of saline and sodic underground water for irrigation was identified as a significant factor by 160 respondents (88.88%), with 100.0 per cent of respondents in zone-III and high percentages in Zones I and II (80.00% and 86.67%, respectively) endorsing this view. This aligned with studies by Mandal *et. al.* (2009), who found that poor-quality irrigation water exacerbates soil salinity and reduces crop yield. Another critical factor was the less application of organic manure, which was cited by 150 respondents (83.33%), with 100.0% of respondents in zone-III and a majority in Zones I and II (58.33% and 91.67%, respectively) highlighting the importance of organic inputs in maintaining soil fertility and structure (Bhattacharyya *et. al*., 2015).

**Table 1: Perception of farmers on factors responsible for degradation of land**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Particulars** | **Zone-I** | **Zone-II** | **Zone-III** | **Total** |
|  | Abiotic stress | 47(78.33) | 55(91.67) | 60(100.0) | 162 (90.0) |
|  | Use of saline and sodic underground water for irrigation | 48(80.00) | 52(86.67) | 60(100.0) | 160 (88.88) |
|  | Less application of organic manure | 35(58.33) | 55(91.67) | 60(100.0) | 150(83.33) |
|  | Non-cultivation of recommended/tolerant varieties for degraded soil | 42(70.00) | 38(63.33) | 35(58.33) | 115 (63.89) |
|  | Mono-cropping system | 43(71.67) | 31(51.67) | 38(63.33) | 112 (62.22) |
|  | Lack of knowledge/technical know-how | 36(60.00) | 37(61.67) | 35(58.33) | 108 (60.00) |
|  | Non-application of gypsum in alkaline soil | 34(56.67) | 33(55.00) | 34(56.67) | 101 (56.11) |
|  | Excessive use of chemical fertilizers  | 32(53.33) | 30(50.00) | 27(45.00) | 89 (49.44) |
|  | **Total Respondents** | **60****(100.0)** | **60****(100.0)** | **60****(100.0)** | **180 (100.0)** |

**Note: Figures in parenthesis indicate percentage to total**

Other factors, though perceived as less dominant, still garnered considerable attention as noted from the table 1. For instance, the non-usage of recommended or tolerant varieties for degraded soil was identified by 115 respondents (63.89%), with varying levels of recognition across zones (70.00% in Zone-I, 63.33% in Zone-II, and 58.33% in Zone-III). The mono-cropping system was cited by 112 respondents (62.22%), with Zone-I showing the highest concern (71.67%) compared to Zones 2 and 3 (51.67% and 63.33%, respectively). Additionally, lack of knowledge or technical know-how was perceived as a contributing factor by 108 respondents (60.0%), with relatively consistent responses across all zones (60.00% in Zone-I, 61.67% in Zone-II, and 58.33% in Zone-III). Lesser-cited factors included the non-application of gypsum in alkaline soil, which was noted by 101 respondents (56.11%), and the excessive use of chemical fertilizers, which was identified by 89 respondents (49.44%). These factors received moderate recognition across all zones, with percentages ranging from 45.00 per cent to 56.67 per cent. These findings were supported by research indicating that the absence of crop diversification and the use of non-tolerant varieties can lead to nutrient depletion and soil degradation (Jat *et. al*., 2020).

The findings of table 2 highlighted farmers perceptions regarding the effect of land degradation across three zones, revealing a uniform concern about its adverse impact on agriculture and livelihoods. A significant finding was that all **180 respondents (100%)**, equally distributed across **Zone-I, Zone-II, and Zone-III**, unanimously agreed that **land degradation leads to a decline in crop yield**. Similarly, the decline in land value was also unanimously recognized as a significant impact, with 100.0 per cent of respondents in all zones agreeing on its occurrence. These two effects highlighted the direct and immediate consequences of land degradation on agricultural productivity and economic value (Datta *et. al.*, 2002 and Lal, 2015).

**Table 2: Farmers perception on effect of degradation of land**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Particulars** | **Zone-I** | **Zone-II** | **Zone-III** | **Total** |
| 1 | Decrease in crop yield | 60(100.0) | 60(100.0) | 60(100.0) | 180 (100.0) |
| 2 | Decline in land value | 60(100.0) | 60(100.0) | 60(100.0) | 180 (100.0) |
| 3 | Increase in cost of cultivation | 34(56.67) | 33(55.00) | 34(56.67) | 101 (56.11) |
| 4 | Shifting to other occupation like business or job | 21(17.50) | 28(23.33) | 21(17.50) | 70 (19.44) |
| **5** | **Total Respondents** | **60****(100.0)** | **60****(100.0)** | **60****(100.0)** | **180****(100.0)** |

**Note: Figures in parenthesis indicate percentage to total**

Another notable effect as noted from the table 2 was the increase in the cost of cultivation, which was reported by 101 respondents (56.11%). This perception was consistent across all zones, with 56.67 per cent of respondents in Zone-I, 55.00 per cent in Zone-II, and 56.67 per cent in Zone-III identifying this issue. This suggested that land degradation not only reduced yield but also escalates farming expenses, further exacerbating the challenges faced by farmers.

In contrast, the shifting to other occupations like business or job was reported by a smaller proportion of respondents, with only 70 respondents (19.44%) acknowledging this effect. The percentages were relatively low across all zones, with 17.50 per cent in Zone-I, 23.33 per cent in Zone-II, and 17.50 per cent in Zone-III. This indicated that while some farmers considered diversifying their livelihoods due to land degradation, it is not yet a widespread response.

Land degradation mitigation practices suggested by farmers across Zone-I, Zone-II, and Zone-III, highlighting various techniques aimed at improving soil health and sustainability is highlighted in table 3.

As depicted from the table 3, among the 180 surveyed farmers, the most widely recommended practice was conservatory tillage, with 84.44 per cent (152 farmers) suggesting its use. This practice was particularly favored in Zone-I (100%) and Zone-II (93.33%), indicating a strong belief in its ability to break compacted soil layers and improve aeration and water infiltration (Bhattacharyya *et. al.*, 2015; Jat *et. al*., 2020). However, in Zone-III, only 60 per cent of farmers adopted conservatory tillage, possibly due to variations in soil type and cropping patterns.

**Table 3: Farmers perception regarding mitigation practices for degraded land**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Particulars** | **Zone-I** | **Zone-II** | **Zone-III** | **Total** |
|  | Conservatory tillage | 60(100.0) | 56(93.33) | 36(60.00) | 152(84.44) |
|  | Application of gypsum for alkaline soil | 60(100.0) | 55(91.67) | 35(58.33) | 150(83.33) |
|  | Crop rotation/Inclusion of legumes in cropping system | 55(91.67) | 48(80.0) | 42(70.0) | 145(80.56) |
|  | Controlled irrigation | 50(83.33) | 41(68.33) | 43(71.67) | 134(74.44) |
|  | Usage of organic manures/FYM | 37(61.67) | 38(63.33) | 42(70.00) | 117 (65.00) |
|  | Recommended use of chemicals and fertilizers | 32(53.33) | 37(61.67) | 26(43.33) | 95 (52.78) |
|  | Extension services to create awareness | 26(43.33) | 23(38.33) | 25(41.67) | 74(41.11) |
|  | **Total Respondents** | **60****(100.0)** | **60****(100.0)** | **60****(100.0)** | **180****(100.0)** |

**Note: Figures in parenthesis indicate percentage to total**

Similarly, the table 3 highlighted the application of gypsum for alkaline soil was highly endorsed, particularly in Zone-I (100%) and Zone-II (91.67%), though slightly lower in Zone-III (58.33%), with a total approval of  83.33 per cent (150 farmers). Again, crop rotation/inclusion of legumes in cropping system also received significant support, especially in Zone-I (91.67%), while controlled irrigation was more prevalent in Zone-I (83.33%) and Zone-III (71.67%) compared to Zone-II (68.33%). The usage of organic manures/FYM was also a prevalent suggestion, with 65 per cent of total respondents supporting it. Notably, Zone-III (70%) had the highest preference for this approach, followed by Zone-II (63.33%) and Zone-I (61.67%).

Another crucial aspect highlighted was the recommended use of chemicals and fertilizers, with 52.78 per cent (95 farmers) reflecting a reliance on external inputs to sustain soil productivity (Sharma *et. al*., 2010). Zone-II suggested the highest (61.67%), followed by Zone-I (53.33%), whereas Zone-III (43.33%) showed relatively lower interest, possibly due to limited accessibility or higher prices. Additionally, role of extension services in creating awareness was suggested by 41.11 per cent (74 farmers). While, Zone-I (43.33%) and Zone-III (41.67%) showed moderate preference, Zone-II (38.33%) had slightly lower preference for this method.

The data presented in table 4 outlined the perceived causes of water resource degradation as reported by farmers across three zones in Haryana. The data was categorized by specific factors, with the number of respondents and corresponding percentages (in parentheses) provided for each zone and the total sample. A total of 180 respondents participated in the study, with 60 respondents from each zone.

**Table 4: Farmers perception on factors responsible for degradation of water resources**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Particulars** | **Zone-I** | **Zone-II** | **Zone-III** | Total |
|  | Excess or inadequate rainfall | 43(71.67) | 49(81.67) | 46(76.67) | 138(76.67) |
|  | Lack of proper drainage | 32(53.33) | 40(66.67) | 34(56.67) | 106 (58.88) |
|  | Excess use of chemical fertilizers and pesticides | 31(51.67) | 38(63.33) | 34(56.67) | 103 (57.22) |
|  | Over-use of canal water | 30(50.00) | 36(60.00) | 33(55.00) | 99(55.00) |
|  | **Total Respondents** | **60****(100.0)** | **60****(100.0)** | **60****(100.0)** | **180****(100.0)** |

**Note: Figures in parenthesis indicate percentage to total**

The most widely perceived factor contributing to water resource degradation was excess or inadequate rainfall, which was identified by 138 respondents (76.67%). This factor received significant recognition across all zones, with 71.67 per cent of respondents in Zone-I, 81.67 per cent in Zone-II, and 76.67 per cent in Zone-III acknowledging its impact. This highlighted the increasing unpredictability of rainfall patterns due to climate change, exacerbating water scarcity and flooding, thereby affecting water availability and quality (Mishra & Singh, 2010).

The second most cited factor as noted in the table 4 was the lack of proper drainage, which was reported by 106 respondents (58.88%). This issue was more pronounced in Zone-II (66.67%) compared to Zones 1 and 3 (53.33% and 56.67%, respectively). Another significant factor was the excessive use of chemical fertilizers and pesticides, which was identified by 103 respondents (57.22%). This factor was recognized by a majority of respondents in Zones 2 (63.33%) and 3 (56.67%) respectively, while slightly fewer respondents in Zone-I (51.67%) acknowledged its role. The excessive application of agrochemicals can contaminate water bodies, affecting both surface and groundwater quality. The over-use of canal water was also identified as a contributing factor by 99 respondents (55.0%). This issue was reported by 50.00 per cent of respondents in Zone-I, 60.00 per cent in Zone-II, and 55.00 per cent in Zone-III.

The effect of water resource degradation as reported by farmers across three zones in Haryana in highlighted in table 5. The most universally acknowledged effect of water resource degradation was the decrease in yield, which was reported by all 180 respondents (100.0%) across all three zones. This unanimous recognition underscored the direct and severe impact of water resource degradation on agricultural productivity (Lal, 2015).

**Table 5: Farmers perception on effect of degradation of water resources**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Particulars** | **Zone-I** | **Zone-II** | **Zone-III** | **Total** |
| 1 | Decrease in yield | 60(100.0) | 60(100.0) | 60(100.0) | 180(100.0) |
| 2 | Increase in cost of cultivation  | 54(90.00) | 47(78.33) | 49(81.67) | 150 (83.33) |
| 3 | Installment of deeper tubewell | 42(70.00) | 48(80.00) | 38(63.33) | 128 (71.11) |
| 4 | Incidence of human disease | 22(36.67) | 35(58.33) | 20(33.33) | 77 (42.78) |
| **5** | **Total Respondents** | **60****(100.0)** | **60****(100.0)** | **60****(100.0)** | **180****(100.0)** |

**Note: Figures in parenthesis indicate percentage to total**

Another significant effect as revealed in the table 5 was the increase in the cost of cultivation, which was reported by 150 respondents (83.33%). This perception was highest in Zone-I (90.00%), followed by Zone-III (81.67%) and Zone-II (78.33%). The rising costs were likely due to the need for additional inputs, such as deeper tubewells or more fertilizers, to compensate for water scarcity or poor water quality.

The installation of deeper tubewells was identified as a response to water resource degradation by 128 respondents (71.11%). This practice was most common in Zone-II (80.00%), followed by Zone-I (70.00%) and Zone-III (63.33%). The need for deeper tubewells reflected the declining availability of groundwater and the efforts by farmers to access deeper aquifers (Mukherjee *et. al.*, 2018). Also, a less frequently reported effect was the incidence of human diseases (likely include waterborne, vector-borne, and chemical exposure-related illnesses), which was noted by 77 respondents (42.78%). This issue was most prominent in Zone-II (58.33%), with lower percentages in Zone-I (36.67%) and Zone-III (33.33%).

The mitigation strategies suggested by farmers across different zones in Haryana to address water resource degradation is presented in table 6. The data highlighted the key approaches identified by farmers to ensure sustainable water management in agriculture. The proper drainage system was the most widely suggested strategy, with 90.56 per cent of total respondents emphasizing its importance. It received unanimous support from farmers in Zone-II (100%), followed by Zone-I (90%) and Zone-III (81.67%). This indicated that inadequate drainage is a critical issue, leading to water stagnation, soil salinity, and declining land productivity (Raju et. al., 2015).

Another highly suggested strategy was installation of greater number of tubewells, endorsed by 90 per cent of total respondents. The highest preference for this measure was again seen in Zone-II (100%), followed by Zone-III (86.67%) and Zone-I (83.33%). This reflected the need for increased access to groundwater for irrigation, although it also raised concerns regarding over-extraction and declining groundwater levels.

**Table 6: Farmers perception regarding mitigation strategies for degraded water resource**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **S.No.** | **Particulars** | **Zone-I** | **Zone-II** | **Zone-III** | **Total** |
|  | Proper drainage system  | 54(90.00) | 60(100.0) | 49(81.67) | 163 (90.56) |
|  | Installation of greater number of tubewells  | 50(83.33) | 60(100.0) | 52(86.67) | 162(90.00) |
|  | Cultivation of recommended crop varieties or less water-intensive crops | 49(81.67) | 50(83.33) | 40(66.67) | 139 (77.22) |
|  | Use of groundwater mixed with canal water for irrigating crops | 42(70.00) | 32(53.33) | 36(60.00) | 110 (61.11) |
|  | Extension services to create awareness | 26(43.33) | 36(60.00) | 32(53.33) | 94 (52.22) |
|  | **Total Respondents** | **60****(100.0)** | **60****(100.0)** | **60****(100.0)** | **180****(100.0)** |

**Note: Figures in parenthesis indicates percentage to total**

It is evident from table 6 that the cultivation of recommended crop varieties or less water-intensive crops was also suggested as a key strategy, with 77.22 per cent of farmers across all zones recommending it. Zone-II (83.33%) and Zone-I (81.67%) had a higher proportion of farmers favoring this solution compared to Zone-III (66.67%). This indicated a growing awareness among farmers regarding climate-resilient and water-efficient cropping patterns.

The use of groundwater mixed with canal water for irrigating crops was another significant suggestion, with 61.11 per cent of farmers advocating for its adoption. This approach was more widely recommended in Zone-I (70%), followed by Zone-III (60%) and Zone-II (53.33%), indicating a effort was made to optimize irrigation practices and reduce dependency on a single water source (Mandal et. al., 2009). Another mitigation measure suggested was extension services to create awareness, with 52.22 per cent of total respondents supporting this approach. The highest endorsement came from Zone-II (60%), followed by Zone-III (53.33%) and Zone-I (43.33%). This highlighted that farmers recognize the role of agricultural advisory services, training programs, and information dissemination in improving water resource management and mitigating degradation (Jat *et. al*., 2020).

The logit model has its ability to isolate and quantify the marginal effects of specific agricultural practices and socio-economic factors on land degradation while controlling for confounding variables. By analyzing zonal variations (Zone-I, II, III, and overall Haryana), the model identified region-specific drivers of degradation, which was critical for formulating targeted policy interventions. For example, the finding that "poor irrigation water" significantly increased degradation likelihood (p < 0.05 across all zones) underscored the need for improved water management strategies. Furthermore, the model’s robustness was evident in its capacity to handle heteroskedasticity and provide reliable standard errors for significance testing, ensuring that the conclusions drawn were statistically valid.

However, the logit model was employed for this study primarily because the dependent variable (land degradation status) was binary, categorizing farms as either degraded or normal. Unlike linear regression models that assume a continuous outcome, the logit model is specifically designed for binary response variables by estimating the probability of an event occurring (in this case, land degradation) through a logistic function. This ensured that predicted probabilities remained bounded between 0 and 1, aligning with the nature of dichotomous outcomes. The variables were derived from farm-level characteristics affecting soil health, with regression analysis quantifying their impact.

The data highlighted in table 7 presented the estimates of a logit regression analysis identifying factors contributing to land degradation across different zones in Haryana. Age and education showed minimal influence, with coefficients mostly insignificant. Whereas, family size was positively correlated with land degradation in all zones, with significant effects in Zone-II (6.91, significant at 1%) and Haryana overall (0.37, significant at 1%). Larger families may contribute to the overuse of land resources, maybe due to greater subsistence needs.

The mono-cropping system was a strong predictor of degradation across zones, with significant positive effects (e.g., 2.79 in Zone-I, 2.02 in Zone-III, and 1.86 statewide, all significant at 1%). This result aligned with on-farm evidence indicating that mono-cropping depletes soil nutrients, increases susceptibility to pests, and reduces long-term productivity. This result was consistent with on-farm evidence from Haryana, where the widespread adoption of rice-wheat monoculture has been linked to declining soil health and productivity (Jat *et. al*., 2020).  Studies by Mandal *et. al.* (2009) further emphasized the need for crop diversification and conservation agriculture practices to mitigate the adverse effects of mono-cropping on soil fertility and sustainability.

**Table 7: Estimates of the factors responsible for degradation on sampled farm**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1. **No.**
 | **Particulars** | **Zone-I** | **Zone-II** | **Zone-III** | **Haryana** |
|  | **Constant** | -3.20(2.80) | **-9.97\*****(2.69)** | **-4.98\*\*\*****(2.83)** | **-5.91\*****(1.37)** |
|  | **Age** | -0.07(0.04) | 0.06(0.03) | 0.01(0.04) | -0.07(0.09) |
|  | **Education** | -0.60(3.91) | -0.03(0.26) | -0.01(0.30) | -0.05(0.69) |
|  | **Family size** | **0.49\*\*\*****(0.27)** | **6.91\*****(0.22)** | **0.29\*\*\*****(0.16)** | **0.37\*****(0.10)** |
|  | **Mono-cropping system** | **2.79\*\*****(0.56)** | **1.52\*\*\*****(0.58)** | **2.02\*****(0.55)** | **1.86\*****(0.33)** |
|  | **Poor irrigation water** | **1.33\*\*****(0.56)** | **1.61\*\*****(0.56)** | **1.65\*\*****(0.49)** | **1.32\*****(0.28)** |
|  | **Over-use of fertilizers** | **2.03\*****(0.60)** | **1.75\*****(0.49)** | **0.95\*\*\*****(0.44)** | **1.18\*****(0.25)** |

**Note: Figures within parentheses represent Standard Error**

**\* indicates significance at 1 per cent level, \*\* indicates significance at 5 per cent level, \*\*\* indicates significance at 10 per cent level**

Poor irrigation water also significantly contributed to land degradation, with consistent effects across zones (e.g., 1.33 in Zone-I, 1.65 in Zone-III, significant at 5% and 1.32 statewide, significant at 1%, respectively). This reflected the detrimental impact of saline or sodic water, which leads to soil salinity and reduced crop yield. The over-use of fertilizers was another key factor, with significant positive effects across zones (e.g., 2.03 in Zone-I and 1.75 in Zone-II, and 1.18 statewide significant at 1%, 0.95 in Zone-III, significant at 10%). While, fertilizers initially boost productivity, excessive application can harm soil structure, reduce organic matter, and contaminate water resources, exacerbating degradation (Sharma *et. al.*, 2010).

1. **Conclusion:**

The study highlighted the critical factors contributing to land and water degradation in Haryana, as perceived by farmers, and proposed actionable strategies to mitigate these issues. Key factors such as abiotic stress (erratic rainfall and over-extracted groundwater), poor irrigation practices, excessive fertilizer use, and mono-cropping systems were identified as major drivers of land degradation, leading to declining crop yields, reduced land values, and increased cultivation costs. Similarly, water resource degradation was attributed to erratic rainfall, improper drainage, overuse of chemical inputs, and excessive canal water usage, resulting in decreased agricultural productivity and higher costs for farmers.

To address these challenges, the study emphasized the adoption of sustainable practices like conservatory tillage, crop rotation, controlled irrigation, and the use of organic manures to improve soil health. For water resource management, strategies such as proper drainage systems, cultivation of less water-intensive crops, and mixed irrigation methods were recommended. Additionally, the importance of extension services to raise awareness and disseminate knowledge about sustainable practices was underscored.

The findings call for targeted policy interventions, including promoting climate-resilient farming techniques, improving irrigation efficiency, and regulating fertilizer use. By implementing these measures, the state can enhance agricultural productivity, ensure long-term ecological balance, and improve the livelihoods of its farming communities.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Details of the AI usage are given below:

1.

2.

3.

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