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Policy Brief on Enhancing Social Resilience through Geospatial Based Soil Cartography: Pathways to Sustainable Farming and Soil Fertility Optimization under Stressed Environment of Punjab, Pakistan

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Abstract

Soil cartography with next-generation Geographic Information Systems (GIS), Global Positioning Systems (GPS), and Remote Sensing (RS) can greatly contribute to social resilience by helping optimize soil fertility with precise mapping in Punjab, a fertile region of Pakistan. This article attempts to synthesize how these tools can effectively tackle soil degradation, food security, and social resilience against floods and salinity-induced environmental shocks. It attempts to draw on existing literature to outline policy implications and recommendations for incorporating these tools into Punjab's agricultural policies.

Key words: Social Resilience, Soil Cartography, Soil Fertility Optimization**,** Stressed Anxious**.**

Introduction

Punjab province generates over 70% of Pakistan's total agricultural output, but it is facing serious challenges related to soil degradation, urbanization, water scarcity, and climate change, which are adversely affecting food security and social stability (FAO, 2012; Ahmad et al., 2019). Traditional methods of soil assessment are inefficient and not spatially precise, resulting in inefficient fertilizers and an annual yield loss of 20-30%. Next-gen GIS, GPS, and RS technologies are transforming soil mapping by providing high-resolution, real-time data on soil physicochemical properties, thus enabling optimization of fertility levels according to local conditions (Onwu and Lanki, 2024). In Punjab province, digitization of soil profiling by the Soil Fertility Research Institute's (SFRI) project is an example of such a next-gen technology, which has mapped nutrient levels such as nitrogen, phosphorus, and potassium across tehsils of Punjab province for precision agriculture (SFRI, 2020). Social resilience has been defined as an ability of people to adapt to shocks by improving their management of resources, and it is enhanced by empowering farmers, comprising 80% of Punjab's agrarian population, to mitigate shocks related to floods such as 2010, 2014, and 2022 floods (Saja, et al., 2021; FAO, 2022).

Key Findings

Geospatial technology has highlighted significant spatial differences in soil fertility, with northern Punjab registering higher levels of soil organic matter (2-3%) than the saline soils of the south, which register less than 1% (FAO, 2017). Satellite imagery-based indices obtained from Landsat and Sentinel satellites, coupled with GPS-based ground truthing, have enabled the mapping of phosphorus deficiency on 60% of Punjab's cultivated area, which corresponds with wheat and rice yield gaps (Vermote et al., 2016; Khaliq et al., 2019). Soil informatics models developed using GIS technology have predicted soil fertility hotspots, which highlight 25% of the soil area of Khanewal and Multan as deficient in micronutrients such as zinc and iron, which can cause malnutrition among local communities (Hameed et al., 2021). Research has established that variable rate fertilizer applications, enabled by GIS technology, can reduce fertilizer costs by 15-20% while increasing crop yields by 10-15%, which can be used for direct poverty alleviation (Singh et al., 2023). Moreover, if soil maps are overlaid with flood vulnerability maps, it has been found that fertility-optimized areas in flood-vulnerable regions such as southern Punjab can restore 30% faster after a disaster, thus establishing a relationship between geospatial precision and social adaptive capacity (FAO, 2017; Abdelkareem and Mansour, 2023).

Policy Implications

The application of soil cartography can enhance the agricultural policy of Punjab by strengthening the policy of the Punjab Agriculture Department, which is in line with the national policy of food security in the face of a growing population that is expected to reach 30 million by 2030 (GoP, 2018). It can also address the equity dimension by providing assistance to small farmers in areas of low fertility, where the impact of climate change is felt most, potentially reducing rural poverty by 12% (World Bank, 2022). The application of GIS/RS in the development of disaster risk reduction strategies, as piloted in the DDPLA project of SFRI, can enhance the resilience of the people of Punjab by proactively addressing nutrient management, thus limiting migration from areas of degraded farmland (SFRI, 2020). However, the siloed nature of the data of the different institutions in the province, as well as the limited access of farmers to GIS/RS platforms, necessitate policy reforms in the digital space (Ahmad et al., 2024).

Policy Recommendations

- Mandate soil cartography in all provinces with the aid of GIS/GPS/RS under SFRI, with annual updates included in the digital platform of the Punjab Land Records Authority for real-time access by farmers (SFRI, 2020).
- Provide subsidies for variable rate applicators and mobile GIS apps for 500,000 small-scale farmers, especially in the southern part of Punjab, and provide training through 100 new extension centers.
- Create a Punjab Soil Resilience Fund to fund micronutrient additions, with geospatial maps and blockchain technology for transparency.
- Develop legislation for the free access and use of soil data, requiring the departments of agriculture, irrigation, and climate to make data interoperable for soil resilience planning (FAO, 2017).
- Engage international organizations like FAO in capacity-building programs in AI-based RS analysis, with a target of 50% coverage of the total 20.5 million hectares in the state by 2030 (FAO, 2012; Ahmad et al., 2019).

Conclusion

The next-gen cartography of soil using GIS, GPS, and RS can transform Punjab's agricultural sector from reactive to resilient, thereby ensuring food security and stability in society. It can help communities overcome nutrient deficiencies and climate changes using precision data, as seen in various pieces of research.

Future Recommendations

Expand to include AI-driven predictive modeling for climate scenarios, pilot drone-based hyperspectral RS for weekly monitoring, and longitudinal impact studies on resilience metrics post-implementation. Invest in farmer cooperatives for community-owned GIS hubs for inclusive scaling.

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