Food and Agriculture Organization of the United Nations

Marginal lands:

potential for agricultural development, food security and poverty reduction

SOLAW21 Technical background report

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Content:

Abstract

Globally, marginal lands make up about 21 percent (2.74 billion ha) of the total land (13.5 billion ha) area. However, about 1 558 million ha of these lands are used for agriculture, out of which about 224 to 300 million ha is classified as agriculturally marginal areas. From a demographic perspective, nearly 1.75 billion people (38 percent of global rural populations) live on remote less favoured and marginal agricultural areas and nearly 1.6 (out of 1.75) billion live in developing countries. From a socioeconomic perspective food insecurity, and poverty remain predominately rural, with nearly 10 percent of the world's population or 734 million people living on less than USD 1.90 a day (2015 est.) and more than 820 million people (11 percent of the global population) remain undernourished, the majority of whom live in marginal areas of the low-income countries. A vast majority of the population depending on agriculture in marginal environments is continued to be highly vulnerable to multiple stresses and off track to achieve the Sustainable Development Goal (SDG) of achieving ending poverty in all its forms (SDG 1) and zero hunger (SDG 2) by 2030. The COVID-19 pandemic has already exacerbated the vulnerabilities and inadequacies of agrifood systems including all the activities and processes affecting the production, processing, distribution and consumption of food and pushed an additional 83 to 132 million people into food insecurity. The setback throws into further doubt the achievement of SDG 2 (*Zero Hunger*) especially in marginal environments. In post COVID-19 era, there is, a strong need to boost agricultural production by improving productivity of agriculture and food production for achieving food security and ending poverty especially in the marginal areas. This paper presents the potential of marginal lands for food security and poverty reduction through sustainable and regenerative agriculture. It presents the outcome of a systematic review on the multidimensional and complex nature of marginality and the factors that drive or characterize marginality in the broader context. The aim of the paper is to draw a working definition for agricultural environments that are considered as marginal in the context of a given agricultural economy and use it to identify the extent of global and regional marginal areas and its hotspots. Moreover, the paper attempts to explore the combinations of underlying causes of agricultural marginality and proximate factors that correlate with marginality as well as opportunities and barriers faced by the rural poor living on marginal lands.

Keywords: Marginal areas, sustainable development, regenerative agriculture, global food security, research engagement, policy outlook

JEL Classification: Q01, Q10, O13, Q56, Q57

1. Introduction

The world's population is expected to grow to almost 10 billion by 2050, and to satisfy the global demand of food and agricultural products, agriculture will need to produce almost 50 percent more food, feed and biofuel, compared to a 2012 baseline (FAO, 2018a). Simultaneously, urbanization and rising incomes in low- and middle-income countries are increasing the demand for meat, fruits, and vegetables, requiring proportionate shifts in output and adding pressure on natural resources.

Can we achieve the required production increase using the same unsustainable production approaches, even as the pressures on already scarce land and water resources and the negative impacts of climate change intensify? This raises further questions. Can agriculture meet unprecedented demand for food in ways that ensure the use of the natural resource base is sustainable, while containing greenhouse gas emissions and mitigating the impacts of climate change? Can the world secure access to adequate food for all, especially in the low-income regions where population growth is the most rapid? Can agricultural sectors and rural economies be transformed in ways that provide more and better employment and income earning opportunities, especially for youth and women, and help stem mass migration to cities with limited labour-absorptive capacity? These questions urge us to see all possible ways to act towards availing opportunities to providing employment opportunities particularly for population in the rural areas and leave no one behind.

Expected future gains in food productivity in marginal areas are important because it is unlikely that increased productivity in favourable environments will be adequate to meet projected growth in food demand for a global population likely to reach 10 billion by 2050 (Alexandratos and Bruinsma, 2012; Springmann *et al.*, 2018; Willett *et al.*, 2019), particularly with prevailing climate change and biodiversity loss. The major marginality hotspots are in South Asia (27 percent of total land area) and Sub-Saharan Africa (11 percent of total land area). A growing body of research on climate change and extreme poverty has increasingly recognized the importance of understanding the link between marginality, poverty, and rural livelihoods in formulating effective policy responses. Marginal environments are generally fragile and at high environmental risk, agricultural lands characterized by low productivity, resource degradation and reduced economic return. Empirical evidence suggests that populations, living on less favoured agricultural lands in developing countries are caught in a vicious downward spiral as they are caught in major poverty-environment traps, where they overuse environmental resources to survive, deepening the impoverishment of their environmental resources which further deprive them and make their survival more uncertain and difficult (Gray and Moseley, 2005). This is the case in remote and less favoured lands with limited access to infrastructure and markets (Barbier and Hochard, 2018) exacerbating deprivation, hunger and malnutrition is rural areas where agriculture is the main source for subsistence and livelihood.

Despite the challenges faced by marginalized poor, marginality is a temporary and dynamic concept. Each region has the potential to overcome the perceived marginality and the negative consequences of marginality can serve as the starting point of innovations (Gurung and Kollmair, 2005). Innovative approaches such as agroecology have shown that the negative consequences of marginality can be managed and can improve productivity of agricultural systems over time (Altieri, Funes-Monzote and Petersen, 2012; Cerdá and Sarandón, 2015). Recently, there has been rising interest in introducing bioenergy production in marginal lands (Nalepa and Bauer, 2012; Richards *et al.*, 2014), and food crops such as quinoa and halophytes that exhibit high tolerance to abiotic stresses typical of harsh climates (López-Arredondo *et al.*, 2015; Choukr-Allah *et al.*, 2016).

The objective of this review is to: (i) establish a common basis for understanding the characteristics of marginal environments and identify the extent and hotspots of agricultural marginality; (ii) understand the combinations of underlying causes of marginality and proximate factors that correlate with marginality and characteristics of marginal environments, and (iii) explore opportunities and barriers faced by the rural poor living on marginal lands. In support of the objectives, the paper will focus explicitly on agriculture marginality with the aim to arrive to a working definition for agricultural lands that are considered marginal in the context of a given agricultural economy. To do that, the paper first examines the evolution of the concept of marginality itself and the factors driving it. A detailed understanding of the underlying causes of marginality, characteristics of marginal environments, opportunities and barriers faced by the population depending on these marginal environments will provide an evidence base to design and devise policies and programmes that will effectively respond to the needs of the extreme poor who are trapped in such fragile and complex environments (Gatzweiler *et al.*, 2011).

2. The concept of marginality

The term "marginal" was originally used under the umbrella of economic theorizing to describe an area under given conditions where cost-effective production is not remunerated (Peterson and Galbraith, 1932). Since then, different definitions describing the concept of marginality and marginal environments emerged highlighting the complex nature of marginality and how different unfavourable conditions disadvantage individuals and communities living in those areas (Mehretu, Pigozzi and Sommers, 2000; Pulighe *et al.*, 2019). OECD defines marginal land as an area with poor agronomic characteristics and unsuitable for housing and other uses (OECD, 2001). CGIAR emphasized the concept of limitations of land for sustained application of a given use (CGIAR/TAC, 2000), while USDA-NRCS in 2010 stressed poor combination of physical and chemical characteristics of the soils for the productivity potential (USDA-NRCS, 2010). Conversely, the World Bank pointed out the untapped potential of areas (less favoured) that are farther from markets (e.g. lack of transport infrastructure), although with crop production potential (World Bank, 2003).

To conceptualize and understand the concept of marginality, Gurung and Kollmair, (2005) present a set of indicators describing marginality and marginal areas (Table 1) that alone or together may lead to the condition of marginality. According to them, the most severe case of marginality happens when spatial and societal marginality overlap. Gurung and Kollmair,

(2005) further argue that the causes and factors underlying marginality and poverty are often visible or relatively easy to understand and respond to; however single proximate causal factors alone (e.g. being from an ethnic minority, having low or no cash income and access to markets, etc.) are not sufficient to explain marginality because marginality is the outcome of a network of causal factors.

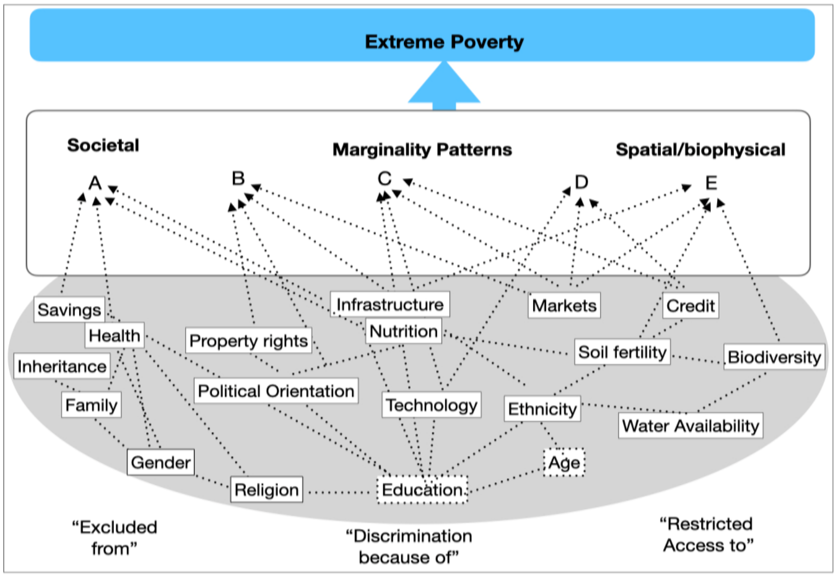
Table 1: Indicators to define marginality

Aspects/dimensions	Indicators
Societal	Child labour; gender inequalities; social exclusion; human rights violations
Infrastructure	Access to clean water; distance to transportation, bank, and communication facilities; energy supply
Health	Life expectancy; infant mortality; under- and malnutrition
Education	Literacy rate, gross enrolment ratio
Political	Participation in elections; corruption index; security status (violence, crime)
Economic	GDP per capita; unemployment rate
Environmental	Environmental pollution; conditions of natural resources
Development Index	Human development index (HDI); gender related development index (GDI); human poverty index (HPI)

Source: Gurung, G.S. & Kollmair, M. 2005. *Marginality: Concepts and their Limitations*, IP6 Working Paper No. 4. University of Zurich, Winterthurerstr. *https://www.worldcat.org/title/-/oclc/729254326*

The view that marginality is a cumulative phenomenon derived from the combination of several interlinked factors that can be related to verifiable and observable disadvantages (sometimes transient) or use restrictions (Pulighe *et al.*, 2019) visually portrayed in Figure 1 adopted from Gatzweiler *et al*. (2011). Based on the conceptual approach developed by Gatzweiler *et al*. (2011), marginality is positioned as a leading cause of extreme poverty emerging from causal combination of proximate (e.g. living in remote areas or belonging to an ethnic minority) and underlying causes (e.g. socially excluded, or having no access to water, transportation etc.). Figure 1 conceptually illustrates the network of interlinked causal factors related to economy, demography, spatial factors, behavioural and quality of life, ecosystems, infrastructure development and public or institutional domain that ultimately shape different life systems (from *A* to *E* as depicted in Figure 1) under marginal conditions. Hence, marginality as a root cause of poverty and food insecurity is manifested in causal complexities that have societal and spatial dimensions. The specific combinations of factors, number of actors and type of relationships between them are not entirely clear, however, the type of relationships can be positive and direct (↑A→↑**,** ↓A→↓B**)**, negative and direct (↑A→↓B, ↓A→↑B), positive feedback loop (↑A→ ↑B → ↑A, ↓A→ ↓B →↓A) and negative feedback loop (↑A→↓B→↑A, ↓A→↑B → ↓A), such that ↑ represents "increasing", → represents "leads to" and ↓ represents "decreasing".

Figure 1: Examples of casual factors underlying different marginality patterns as a root cause of extreme poverty



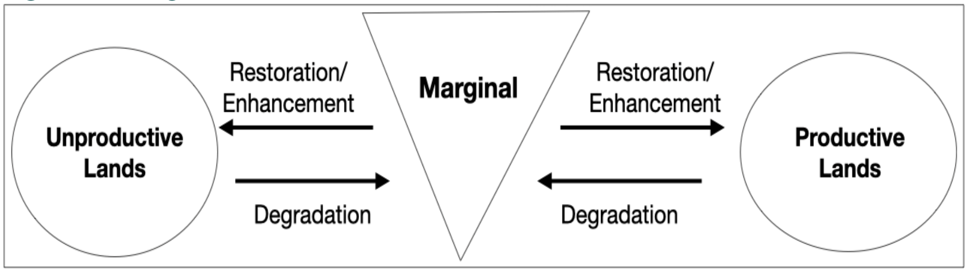
Source: Gatzweiler, F.W., Baumüller, H., Husmann, C. & von Braun, J. 2011. *Marginality: Addressing the Root Causes of Extreme Poverty*. ZEF Working Paper Series 77, Center for Development Research, University of Bonn. https://doi.org/10.2139/ssrn.2235654

Graw and Husmann (2014) argue that marginality is not only multidimensional with regard to causing poverty, but also multirelational with regard to the character of the network of causal relations. The poorest in marginal areas have described their situation as being trapped in a "complex knot which can lead to further knots if the wrong threads are pulled" (von Braun and Gatzweiler, 2013). In their book *Marginality: addressing the nexus of poverty, exclusion and ecology*, von Braun and Gatzweiler, (2013) provide a comprehensive definition for marginality that covers several dimensions;

> an involuntary position and condition of an individual or group at the margins of social, political, economic, ecological and biophysical systems, that prevent them from access to resources, assets, services, restraining freedom of choice, preventing the development of capabilities and eventually causing extreme poverty (von Braun and Gatzweiler, 2013, P. 3).

Marginality, as discussed above, is a broad concept and multifaceted issue. The coexistence and combination of different factors creates different types of marginality. Gurung and Kollmair, (2005) and Kang *et al*. (2013) argue that marginality is dynamic and impermanent, influenced by land use changes and socioeconomic (i.e. market accessibility, management practices, prices and producers' market power etc.) and other circumstances. Several interrelated facets could drive productive agricultural lands to marginal or even unproductive lands (Figure 2), but investments in technologies and application of proper management practices and tools, could reverse this direction and unproductive and marginal lands could be transformed to productive or favoured agricultural lands (Lewis and Kelly, 2014; Soldatos, 2015; Sallustio *et al.*, 2018).

Figure 2: Marginal lands – a transitional state of land uses



Source: Kang, S., Post, W.M., Nichols, J.A., Wang, D., West, T.O., Bandaru, V. & Izaurralde, R.C. 2013. *Marginal Lands: Concept, Assessment and Management. Journal of Agricultural Science*, 5(5): p129. https://doi.org/10.5539/jas.v5n5p129

An area might be marginal or less favoured for use as crop production under a specific production system due to water scarcity or lack of market access, but by introducing new water-saving technologies or new marketing routes, this same area could become more favourable (Lipper, Pingali and Zurek, 2007), or transformed from unproductive (unused) to productive (used) land, or from sub-marginal to supra-marginal land along spatially-varying background conditions (Sallustio *et al.*, 2018). Jiang and Jacobson, (2014) reinforce the impermanent marginality argument pointing out that any change in force governing peoples' willingness to use land will lead to a transition between "marginal lands" to "normal lands".

3. Marginality in the context of agriculture

In the context of agriculture, marginal lands are sometimes intended as a synonym for unused, degraded, abandoned, under-used, fallow, and free land, often stimulating an animated linguistic debate and possible misunderstanding. In fact, the definition of marginal land varies according to the aim for which the term is used, and to the given contextual background to which it is operationally applied (Sallustio *et al.*, 2018). Understanding the combination of agroclimatic potential and socioeconomic settings provides a working definition of areas that are favoured or less favoured for agricultural purpose, at least for market-oriented production (World Bank, 2008).

Less favoured agricultural lands refer to lands susceptible to low productivity and resource degradation because their agricultural potential is constrained biophysically by terrain, poor soil quality, salinity, or limited rainfall. The socioeconomic dimension of marginality involves several aspects including lack of access to market and infrastructure that cause the expected economic and social wellbeing to lag behind. Less favoured agricultural areas (LFAAs) include all less favoured agricultural lands plus any favourable agricultural land (e.g. not constrained by biophysical factors) that is remote with limited access to infrastructure and markets (Barbier and Hochard, 2016).

Albeit the multiple interlinked factors driving marginality as highlighted previously, the biophysical and socioeconomic aspects are the two central dimensions of agricultural marginality driving agricultural policy and economic welfare. Accordingly, in this paper, we argue that LFAAs indicated by the shaded boxes (*A, B, C*) in Figure 3 are in some degrees equated to agriculturally marginal lands. Given the discussion around the underlying factors and dimensions of marginality, the definition of agricultural marginality is summarized in Box 1. Although the lack of access to markets and services is a significant element in driving the overall marginality condition, biophysical constraints are a major and leading driver, particularly from a crop production and agricultural marginality point of view.

Figure 3: Classification of agricultural areas based on biophysical and socioeconomic dimensions of marginality

Sources/factors contributing to marginality		Socioeconomic dimension (i.e. access to infrastructure & markets, agrifinance, public service, etc.)	
		No/limited access	Improved access
Agricultural potential based on biophysical and environmental factors	Low	**A.** Less favoured fragile and remote areas: water scarce, steep slope, poor & degraded soils	**B**. Less favoured agricultural area: areas in arid and semi-arid regions
	High	**C.** Less favoured agricultural areas: remote areas with high degree of plant biodiversity, rich biotic environment	**D.** Favourable agricultural area

Source: adopted and modified from: Pender, John L., ed. & Hazell, P. B. R., ed., 2000. *Promoting sustainable development in less-favored areas, 2020 vision focus 4*. International Food Policy Research Institute (IFPRI). https://ideas.repec.org/p/fpr/2020fo/4.html

Box 1: Agriculturally marginal areas refer to *less favourable agricultural areas* (LFAAs) characterized by resource degradation, constrained agriculture potential and low productivity of agricultural resources attributable to *biophysical constraints* such as rugged terrain, extreme weather conditions, poor soil quality, salinization, drought and erratic rainfall and other factors that present significant constraints for intensive agriculture. For intensive agriculture, marginal areas also encompass all LFAAs and any favourable agricultural areas (e.g. areas not constrained by biophysical factors) with *limited access to rural infrastructure and agricultural markets* where *cost-effective* production is likely unfeasible (without additional support) under given conditions,

3.1. Geographical and regional identification of marginal areas

The literature offers different figures on the extent and prevalence of marginal areas, as different studies employ different methods, assumptions and criteria to estimate the extent of global marginal lands. Among the first studies to determine the extent of marginal lands and distribution of the rural poor on less favoured marginal lands globally, was the study carried by the Technical Advisory Committee (TAC) of the Consultative Group on International Agricultural Research, covering 105 developing countries across four regions. According to the CGIAR/TAC (2000) report, "favoured" agricultural lands accounted for only 10.7 percent of the agricultural area in the developing world compared with 24 percent of marginal agricultural lands.

The Food and Agriculture Organization of the United Nations (FAO) with the collaboration of the International Institute for Applied Systems Analysis (IIASA), developed a system that enables rational land-use planning on the basis of an inventory of land resources and evaluation of biophysical limitations and production potentials of land. This is referred to as the agroecological zones (AEZ) methodology (FAO, 2011; Fischer *et al.*, 2010). The in the Global

Agroecological Zones (GAEZ) Study modelling uses detailed agronomic-based information to simulate land resources availability, assess farm level management options and estimate crop production potentials. It employs detailed spatial biophysical and socioeconomic datasets to distribute its computations at fine gridded intervals over the entire globe (Fischer *et al.*, 2012; Alexandratos and Bruinsma, 2012). The GAEZ methodology combines soil, terrain and climate characteristics with crop production requirements and estimates the suitability in terms of land extents and attainable yield levels; for crop production of each land grid cell at the 5-arc-minute-level, at four technology and management levels (low, intermediate, high and mixed).

The GAEZ suitability assessments provide extents for a range of land suitability classes as follows: Very suitable, suitable, moderately suitable, marginally suitable, very marginally suitable and not suitable. Fischer *et al*. (2010) condensed these six classes into three classes, (i) prime land, (ii) good land and (iii) marginal and not suitable land. *Prime land* is characterized as very suitable land with attainable yields of over 80 percent of maximum constraint-free yields. *Good land* represents suitable and moderately suitable land with attainable yield levels of 40 to 80 percent of maximum constraint-free yields and *marginal land* includes all land with estimated attainable yields that are less than 40 percent of maximum constraint-free yields (Alexandratos and Bruinsma, 2012; Fischer *et al.*, 2012). Crops considered in the suitability assessment include cereals, roots and tubers, sugar crops, pulses and oil-bearing crops. The global land resources, excluding Antarctica, comprises 13.15 billion ha (Table 2), of which 46 percent is classified as not suitable for production (i.e. characterized by less than 5 percent attainable yield potential) and about a fifth of the total land or 21 percent (2.7 billion ha) is classified as marginal land with various degrees of suitability including marginally suitable and very marginally suitable based on attainable yield potential.

Table 2: Availability and classification of global land resources

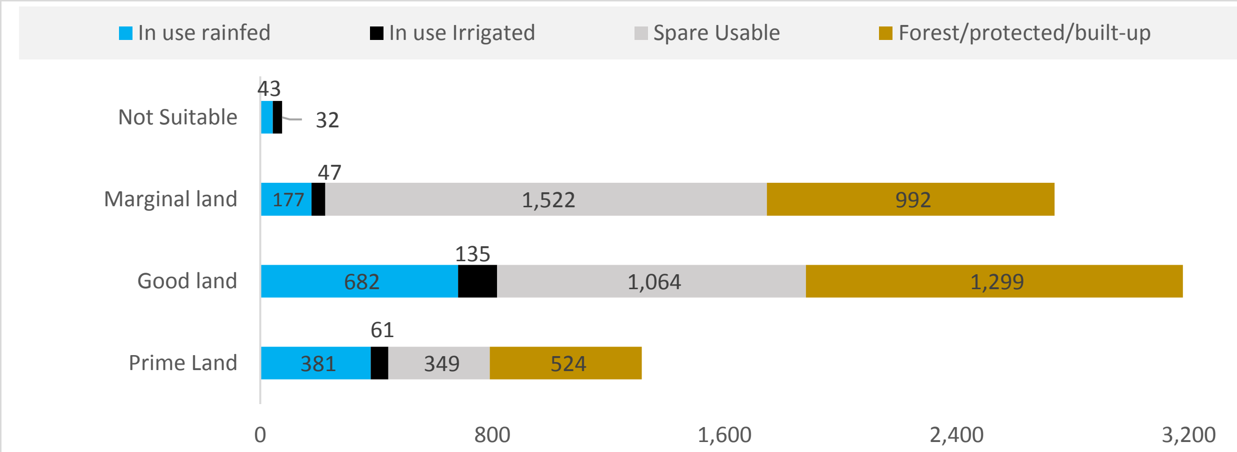
	VS	S	MS	mS	vmS	NS	Total	Potential (VS+S+MS)	Potential (mS+vmS)
Total land (in million ha)	**1 315**	**2 187**	**993**	**1 111**	**1 627**	**6 061**	**13 294**	**4 495**	**2 738**
in %	**10%**	**16%**	**7%**	**8%**	**12%**	**46%**		**34%**	**21%**
In agricultural use (1999/2001)	442	616	201	120	104	75	**1 558**	1,260	224
of which rain-fed	381	516	166	93	84	43	**1 283**	1,063	177
of which irrigated	61	100	35	27	20	32	**275**	197	47
Gross balance	*873*	*1 571*	*792*	*991*	*1 523*			*3 235*	*2 514*
Under forest	453	854	293	342	530	1,263	**3 735**	1 601	872
Strictly protected	30	50	27	39	59	432	**637**	107	98
Built-up land	41	61	14	12	10	15	**153**	116	22
Net balance	*349*	*606*	*458*	*598*	*924*			*1 412*	*1 522*

Notes: Suitability classes are defined according to attainable yields as a percentage of the maximum constraint-free yield as follows: *VS*=Very Suitable (80–100 percent potential), *S*=Suitable, 60–80 percent (yield potential), *MS*= Moderately Suitable 40–60 percent (yield potential), *mS*=marginally Suitable 20–40 percent (yield potential), *vmS*=very marginally Suitable 5–20 percent (yield potential), *NS*=Not Suitable <5 percent (yield potential). **Prime land** = VS; and Good Land = S + MS; and **Marginal land**=mS+vmS. Crops considered in the suitability analysis: cereals, roots and tubers, sugar crops, pulses and oil-bearing crops.

Source: Alexandratos, N. & Bruinsma, J. 2012. World Agriculture Towards 2030/2050, The 2012 Revision. ESA Working Paper No. 12-03. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/ap106e/ap106e.pdf

Notably, studies by Alexandratos and Bruinsma, (2012) using 2001 data and CGIAR/TAC estimated that marginal lands make up about 21 percent of the total land resources. The land suitability assessment for crop production, undertaken by IIASA and FAO in the GAEZ study (GAEZ, 2012) which updated an earlier version (Fischer *et al*., 2002, 2011) indicates that at the global level there is a significant amount of land with rainfed production potential of various degrees of suitability: 7.2 billion ha of total land resources, of which 1.6 billion is currently in use for crop production, including irrigated lands. Land-in-use includes some 75 million ha, which in the GAEZ evaluation are classified as non-suitable. This leaves a balance of 5.7 billion ha. However, not all of it should be classed as crop-ready for two reasons (Alexandratos and Bruinsma, 2012). First, 2.8 billion ha are covered by forest, protected areas, or non-agricultural uses that will expand in the future, such as human settlements, infrastructure and so on; and second, 1.5 billion ha of the remaining 2.9 billion are of poor quality for rainfed crops, classified as marginally suitable and very marginally suitable. There are currently 220 million ha of such land in use, with 47 million ha being irrigated. This leaves some 1.4 billion ha of prime land (class very suitable in the GAEZ classifications) and good land (classes suitable and moderately suitable) that could be brought into cultivation if needed, albeit at the expense of pastures and requiring significant development investments, such as infrastructure, disease control and so on (see Figure 4).

Figure 4: Spare usable land available for cultivation by suitability time



Source: Alexandratos, N. & Bruinsma, J. 2012. World Agriculture Towards 2030/2050, The 2012 Revision. ESA Working Paper No. 12-03. Food and Agriculture Organization of the United Nations https://www.fao.org/3/ap106e/ap106e.pdf

Other notable studies assessing marginal lands include Wood *et al.* (2000) and Kang *et al*. (2013) who reported that marginal lands account for about 36 percent of global agricultural land (1.3 billion ha), and support roughly one-third of the world's population. A study by the Worldwatch Institute, (2007) estimated the extent of marginal lands anywhere between 100 million and 1 billion ha, whereas Campbell *et al.* (2008) reported that he estimated global area of abandoned agriculture is 385-472 million ha.

Table 3 illustrates the geographical distribution of the 1.558 billion ha currently cultivated land. Of the 1.6 billion ha under cultivation, 0.3 billion ha or 19 percent are marginal lands, 0.44 billion ha (28 percent) are prime lands and 0.82 billion ha (52 percent) are good lands. The highest regional proportion of high potential prime and good lands currently under cultivation is found in Central America and the Caribbean (42 percent), followed by Western and Central Europe (38 percent) and Northern America (37 percent). For high-income countries, the share of prime land in currently cultivated land is 32 percent. In low-income countries, soils are often poorer (i.e. low in quality and/or low in nutrients) and only 28 percent of total cultivated land is classed as prime (Fischer *et al.*, 2010). At the regional level, marginal lands make up significantly larger proportion of currently cultivated lands in Asia and Africa.

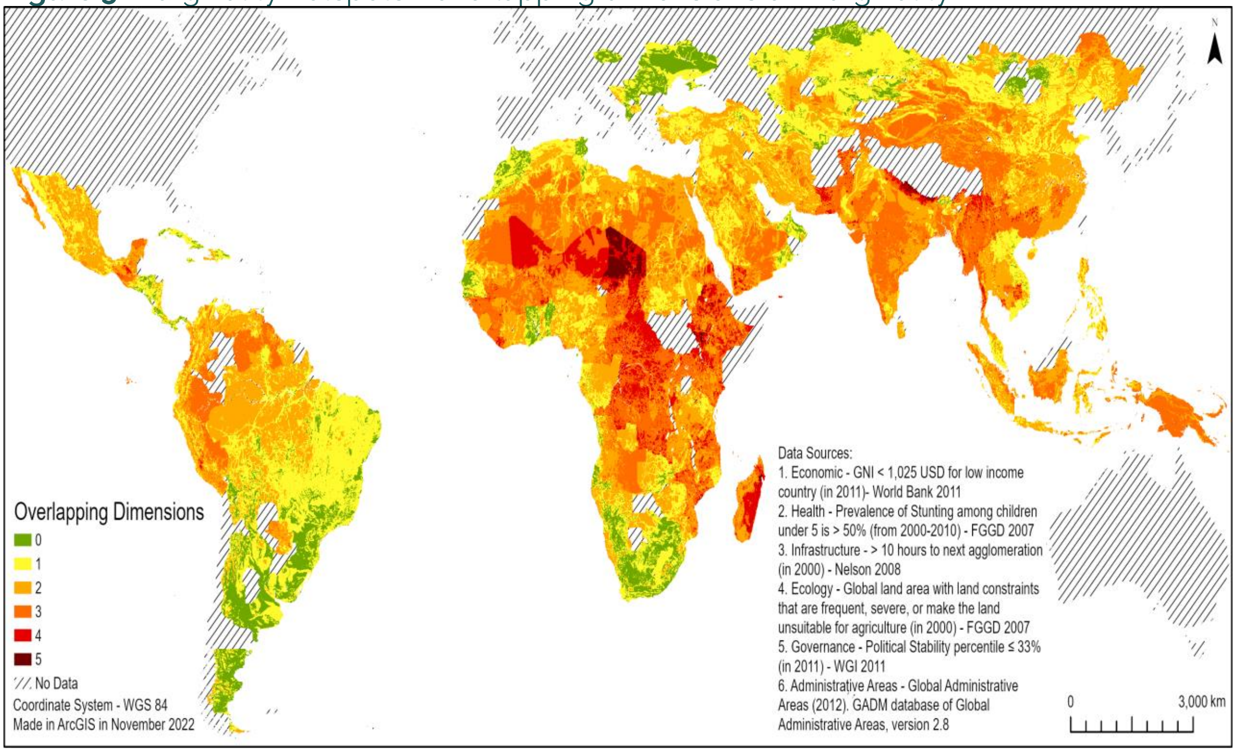
Table 3: Shares of currently cultivated land (million ha) by suitability category and geographic region

10.5	Prime Land	Good Land	Marginal Land	Total
Northern Africa	3	9	7	19
Sub-Saharan Africa	71	128	26	225
Northern America	94	136	28	258
Central America and Caribbean	7	8	2	17
Southern America	41	77	10	128
Western Asia	4	34	23	61
Central Asia	0.3	32	13	45.3
South Asia	57	84	60	201
East Asia	25	72	53	150
Southeast Asia	28	54	16	98
Western and Central Europe	50	54	27	131
Eastern Europe and Russia	59	102	12	173
Australia and New Zealand	4	26	21	51
Pacific Islands	0.1	0.1	0.1	0.3
Total (million ha)	443	816	298	1558
Total (%)	28%	52%	19%	100%

Source: FAO. 2011. *The state of the world's land and water resources for food and agriculture (SOLAW) – Managing systems at risk*. Food and Agriculture Organization of the United Nations, Rome and Earthscan, London. https://doi.org/10.4324/9780203142837

To illustrate spatial dimensions of marginality at continental and regional levels, Graw and Husmann, (2014) adopted a parallel context and mapped marginality as a "multidimensional" concept using Gurung and Kollmair (2005) indicators presented in Table 1 utilizing national and subnational data published by the World Bank, FAO, Harvest Choice and others. For each dimension, a cut-off point along with a range of indicator values were used to define the threshold below which an area could be considered as marginal. Indicator layers for each of the different dimensions of marginality were overlaid to find the areas where multiple layers of marginality overlap. A 'marginality hotspot' was defined as an area in which at least three dimensions of marginality overlapped. As evident in Figure 5, hotspot areas were identified in South Asia (11percent of land area) and Sub-Saharan Africa (nearly 27 percent of land area), especially Central and Eastern Africa (Eritrea, Mozambique, Central African Republic, the Democratic Republic of the Democratic Republic of the Congo, The Sudan, and large areas of Niger). Moreover, 1 percent of the total Sub-Saharan Africa area was identified as extremely marginal affected by five overlapping dimensions of marginality, and thus should be prioritized by research and development programmes.

Figure 5: Marginality hotspots - overlapping dimensions of marginality



Source: Graw, V. & Husmann, C. 2014. *Mapping Marginality Hotspots*. *In* J. von Braun & F.W. Gatzweiler, eds. *Marginality*, pp. 69–83. Dordrecht, Springer Netherlands. https://doi.org/10.1007/978-94-007-7061-4_5
Note: the original map was reproduced using the same data sources to comply with UN. 2020. Map of the World. https://www.un.org/geospatial/file/3420

3.2. Spatial demography of marginal lands

Barbier and Hochard, (2014) use a variety of spatially referenced datasets from the GAEZ study to approximate spatial distribution of global rural population within two classification that could be equated with marginal agricultural areas in several dimensions. These are: a) concentration of populations on less favoured agricultural lands (LFAL): includes irrigated land on terrain greater than 8 percent median slope; rainfed land with a length of growing period (LGP) of more than 120 days but either on terrain greater than 8 percent median slope or with poor soil quality; semi-arid land with LGP 60-119 days); and arid land (land with LGP < 60 days); and b) concentration of rural populations in: include all LFAL plus favoured agricultural land with limited market access (more than five hours of travel time to a market or city with a population of 50,000 or more).

By 2010, As many as 1.75 billion people worldwide (about 38 percent of the rural populations) lived on remote less favoured agricultural areas, up from 1.56 billion people in 2002, mainly attributed to the 13.4 percent growth in global population. Table 4 shows that. nearly 1.6 out of 1.75 billion) people are in marginal areas of developing countries. This is slightly lower than the earlier estimate by CGAIR/TAC (2000) that reported nearly 1.8 million people lived on less favoured marginal lands of which 36 percent are extremely poor.

Table 4: Rural population on less favoured agricultural lands and areas (2000-2010)

	Rural Population (1)	Rural Population on less favoured agricultural land (LFAL) (2)	Percent share (2)/(1)	Rural Population on less favoured agricultural Areas (LFAA) (3)	Percent share (3)/(1)
Rural population on less favoured agricultural lands and areas, 2000 (in thousands)					
East Asia and Pacific	1,398.40	645	46.10%	672.9	48.10%
Europe and Central Asia	173.8	96.4	55.50%	97.1	55.90%
Latin America and Caribbean	294.1	94.9	32.30%	97	33.00%
Near East and North Africa	195.6	44.9	23.00%	45.2	23.10%
South Asia	1,090.40	269	24.70%	291	26.70%
Sub-Saharan Africa	554.6	164.3	29.60%	179.5	32.40%
Developing country	*3,706.80*	*1,314.50*	*35.50%*	*1,382.70*	*37.30%*
Developed Country	*404.7*	*171.8*	*42.40%*	*173.8*	*42.90%*
World	**4,111.50**	**1,486.30**	**36.10%**	**1,556.40**	**37.90%**
Rural population on less favoured agricultural lands and areas, 2010 (in thousands)					
East Asia and Pacific	1,499.10	709.4	47.30%	739.7	49.30%
Europe and Central Asia	180.7	97.7	54.10%	98.4	54.50%
Latin America and Caribbean	336.1	109.2	32.50%	111.7	33.20%
Near East and North Africa	237.2	50.4	21.30%	50.9	21.40%
South Asia	1,284.00	309.7	24.10%	335.3	26.10%
Sub-Saharan Africa	711.4	223.2	31.40%	243.8	34.30%
Developing country	*4,248.60*	*1,499.70*	*35.30%*	*1,579.80*	*37.20%*
Developed Country	415.3	166.9	40.20%	168.7	40.60%
World	**4,663.90**	**1,666.60**	**35.70%**	**1,748.60**	**37.50%**

Source: Barbier, E.B. & Hochard, J.P. 2014. Land Degradation, Less Favored Lands and the Rural Poor: A Spatial and Economic Analysis. A Report for the Economics of Land Degradation Initiative. www.edwardbbarbier.com/Projects/ELD/Economics_of_Land_Degradation_Initiative_Barbier_and_Hochard_abridged.pdf

Notably, between 2000 and 2010, rural population rose nearly 13 percent globally, around 3 percent in high-income economies and almost 15 percent in developing countries. In high-income countries, the rural populations in less favoured agricultural areas fell by 3 percent, while in low and middle-income economies the rural populations on marginal agricultural lands and in less favoured agricultural areas grew at 14 percent. However, this critical population group expanded over 33 percent in Sub-Saharan Africa. Although population movement is a dynamic phenomenon and land management practices influence changes in marginality, these numbers suggest that the concentration of rural populations on marginal lands is predominantly a developing country problem with significant implications for Sub-Saharan Africa.

4. Socioeconomic dimensions of marginal environments

The socioeconomic dimension of marginality involves several aspects that drive the expected social and economic outcomes to lag behind. In the context of agricultural economy, Peterson and Galbraith, (1932) used "margins of cultivation" to describe economically marginal agricultural lands where revenue from optimal production just equals (or lower than, in some instances) the costs of production leading to zero, negative- profit or economic loss. To capture the specific economic context, FAO and UNEP, (2010) have classified lands supporting a yield of up to 40 percent of its crop potential as marginal. This definition considers temporal dimension (i.e. seasonal and interannual variability), since climatic parameters are a major determinants of revenues from optimal production. Dauber *et al.* (2012) identified marginal lands as areas where "cost-effective production is not possible under given conditions, cultivation techniques, agriculture policies as well as macroeconomic and legal settings. In this context, economically marginal land can be thought of as land that would not be cultivated at current output and input prices without the availability of government support programmes (Deal, 2006).

Marginality is closely related to the vulnerability of both people and environment as it victimizes location and communities that are characterized by one or more factors of vulnerability. The intended use of the land under assessment also needs to be considered so this human factor including the economic and cultural context are important in determining potential of land resources (Warren, 2002). The most commonly recognized vulnerability elements appear to be a poor location and scarcity of natural resources, and people's inability to anticipate, cope with, resist and recover from daily life struggles (Mehretu, Pigozzi and Sommers, 2000; Gurung and Kollmair, 2005). At the core of socioeconomic dimension of marginality, demographic pressure accelerates the environmental degradation-poverty process. When high population growth is combined with other socioeconomic factors, land and resource scarcity become more acute, poverty become more prevalent and poor people living under marginal conditions begin to favour immediate economic benefits regardless of environmental consequences.

Demographic pressure on land resources is linked to reduction in agriculture as well as overall economic growth, especially in areas where agriculture plays a strategic role in achieving economic growth and poverty alleviation. Most marginal areas in Asia and Sub-Saharan Africa have the lowest per capita land holdings and therefore realize the lowest growth in terms of per capita agricultural GDP (World Bank, 2008). This implies that demographic pressure on natural resources have direct implications for socioeconomic marginality. Achieving growth in productivity and subsequently enhancing growth in agricultural value added is yet further undermined and threatened by biophysical constraints in such economically marginal areas.

Food crisis influences greatly agriculture in marginal areas, as rising food and commodity prices lead to the cultivation of additional fraction of marginal lands. In most less favoured marginal agricultural areas, adverse agro-ecological conditions and thin markets contribute to high producer price risk (Kuyvenhoven, Pender and Ruben, 2004). When agricultural prices go up as a result of the policy reforms, farmers with net surpluses to sell gain, but often at the expense of the poor who are net buyers of food. Besides, farmers in marginal areas are unlikely to benefit from more favourable prices because they have poorer access to markets and pay substantial transport and marketing costs when purchasing inputs and selling products (Hazell *et al.*, 2007). Hence, future market policies in economically marginal areas must aim at well-functioning markets together with a pricing structure and stabilization policies for resource-poor areas to provide economic incentives for small-scale farmers to increase productivity in ways that do not degrade the environment.

4.1 Poverty traps in marginal areas

Poverty is a state of economic, social and psychological deprivation occurring among people or countries lacking sufficient ownership, control or access to resources to maintain minimal acceptable standards (Coudouel, Hentschel and Wodon, 2004). Poverty is a concept which indicates absolute or relative welfare deprivation (Scherr, 1999) and depending on the concept and context, it is measured using different indicators such as income, consumption, economic distance, GINI index for inequality, etc. Poverty could be the lack of command over commodities in general but alternatively, it could be the lack of command over some basic goods (e.g. food and housing) (Lorenzo and Paolo Liberati, 2005). More generally, poverty is the lack of «capability» to function in a given society. All these definitions point to poverty as a status in which a reasonable standard of living is not achieved. The World Bank defines poverty in absolute terms, whereby extreme poverty occurs when a population lives on less than USD 1.90[1] per day and moderate poverty between USD 1.90 and USD 3.10 a day.

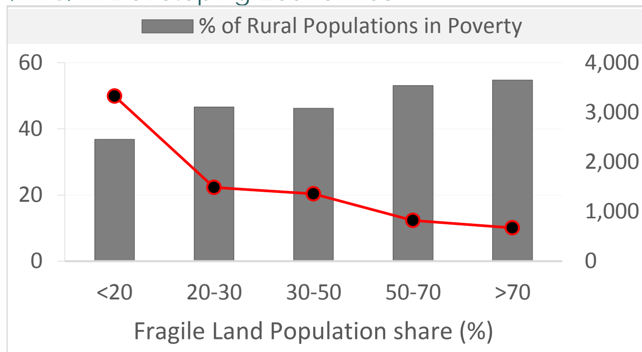
In contrast, relative poverty views poverty as socially defined and dependent on social context which may involve many aspects with income inequality aggravating socioeconomic marginality. Moreover, though poverty can be observed in different forms and caused by different factors, all forms of poverty can be described through the concept of marginality. Someone who is poor will always be marginalized in one or more dimensions. Furthermore, the socio-cultural context and individual perception will define in which and in how many dimensions someone needs to be marginalized in order to be considered poor (Gatzweiler and Baumüller, 2014).

Using poverty data from the World Bank's PovCalNet, Figure 6 shows prevalence of global poverty in percentage (Left hand side - LHS) and the number of extremely poor (Right hand side - RHS) living on less than USD 1.90 and USD 1.25 per day. The percentage of population

[1] As of October 2015, the World Bank shifted the threshold of poverty from USD 1.25 per day to USD 1.90 per day. Accordingly references to report prior to the date will be referring to the old cut-off.

inhabiting below extreme poverty dropped from 36 percent in 1990 (equivalent to 1.8 billion people), to 10 percent in 2015 (equivalent to 0.736 billion people). It should be noted that these estimates for global poverty are based on the Purchasing Power Parity (PPPs[2]) for household consumption in 2011.

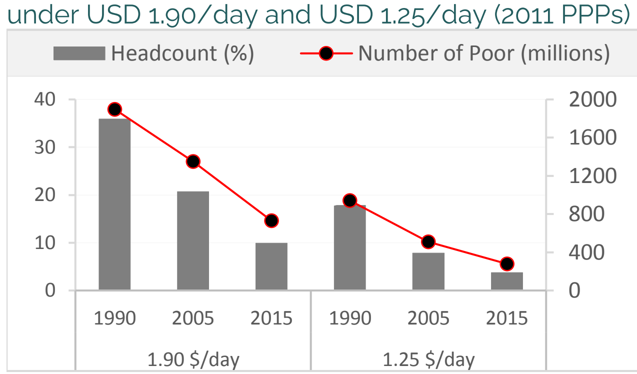
Figure 6: Rural poverty (LHS) and GDP per capita (RHS) in Developing Economies



Source: Barbier, E.B. 2010. *Poverty, development, and environment*. Environment and Development Economics, 15(6): 635–660. https://doi.org/10.1017/S1355770X1000032X

United Nations' Millennium Development Goal of halving poverty by 2015 required low- income countries to grow at 3.6 percent per capita per year. However, these countries have large proportion of marginal areas which proved challenging and though significant progress was achieved, poverty is still an everyday reality to hundreds of millions of people. Many attribute this to weakness of conventional poverty reduction and development programmes in responding to the needs of poorest, leading to uneven technological progress and exacerbating regional inequality. Furthermore, studies show that the typology of poverty is explicitly linked to environment whereby areas with the greatest potential for land and water degradation and areas with highly weathered soils, steep slopes, inadequate rainfall and high temperatures appear to correspond closely with areas of the highest rural poverty and malnutrition (Scherr, 1999; Molden, 2007).

Figure 7: Poverty (LHS) and world's poor (RHS) under USD 1.90/day and USD 1.25/day (2011 PPPs)



Source: Authors' calculation from PovCalNET (World Bank's Development Economics Division)

Barbier, (2010) showed the tendency of rural poor to be clustered on marginal environment (Figure 7). Developing economies with high concentrations of their populations living on fragile lands not only display high rates of rural poverty but also are some of the poorest countries in the world today. For a sample of 76 developing economies in the analysis by Barbier, (2010), poverty rates and number of rural poor were found to rise with higher share of populations living on marginal environments. GDP per capita greatly fluctuates with

[2] Purchasing Power Parity (PPP) is a way to measure the cost of a given consumption basket in different countries so that variations due to differences in price levels and the exchange rate do not distort comparisons across countries. A PPP could also be thought of as an alternative currency exchange rate but based on actual prices such that it would cost exactly the same number of, for example, US dollars to buy Euros and then buy a basket of goods in the market as it would cost to purchase the same goods directly with US dollars.

resource dependency in marginal areas of developing world, whereby the poorest countries show a higher concentration of population in fragile marginal lands. For example, if we examine economic growth and income inequality within Africa and Asia where poverty and inequality is high, we observe that areas that are likely marginal and dry exhibit more severe signs of poverty-environment traps.

Table 5: Poverty rates (headcount in percent) and severity (poverty gap) by region

Region	USD 1.90/day					
	Headcount (%)			Poverty gap (%)		
	1990	2005	2015	1990	2005	2015
Sub-Saharan Africa	54.7	50.8	41.1	24.6	21.6	15.7
South Asia	47.3	33.7	12.4	13.2	7.9	2.2
East Asia and Pacific	61.3	18.9	2.3	22.4	4.9	0.5
Latin America and the Caribbean	14.9	9.9	3.9	6.1	4.1	1.3
Near East and North Africa	6.2	3.1	4.2	1.2	0.5	1.0
Europe and Central Asia	2.9	4.9	1.5	0.9	1.4	0.4
Other high-income countries	0.5	0.5	0.7	0.3	0.4	0.5
World Total	**35.9**	**20.7**	**9.9**	**12.7**	**6.3**	**3.1**

Source: Author's calculation from PovCalNET (World Bank's Development Economics Division)

Correspondingly, using the World Bank's data on headcount ratio and poverty gap index,[3] Table 5 presents region-specific information on the persistence and severity of poverty using USD 1.90 line[4] demonstrating the uneven progress in global poverty rates. While East Asia and Pacific, Europe and Central Asia have reduced poverty to below the 3 percent target, Sub-Saharan Africa and South Asia lag behind. Today 90 percent of the world's extreme poor living in these two regions, with a staggering 80 percent living in the marginal areas in Sub-Saharan Africa. If these trends continue, by 2030, nearly 9 out of 10 extreme poor will be in Sub-Saharan Africa (Wadhwa, 2018).

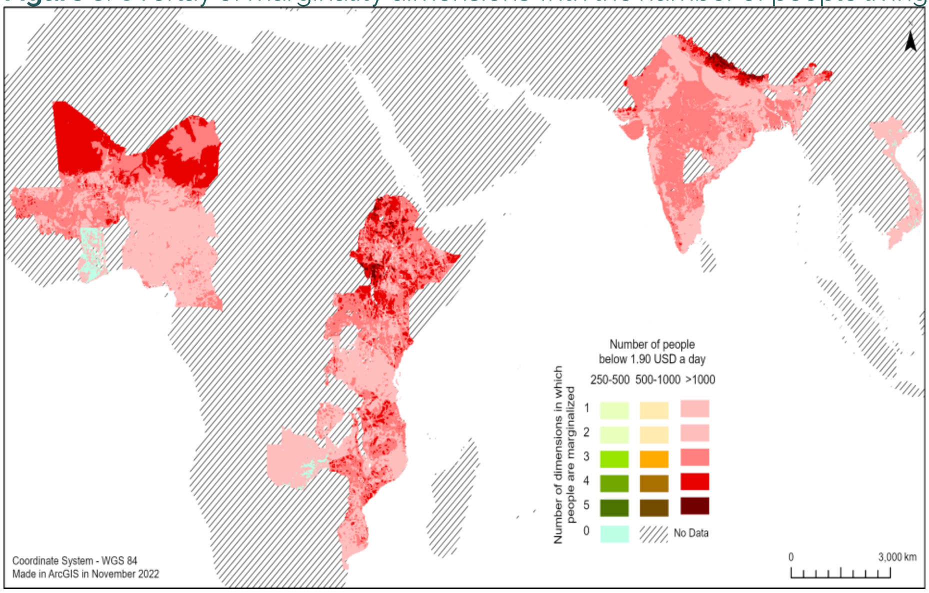
To illustrate the distribution of poverty at the regional level, Graw and Husmann, (Graw and Husmann, 2014) overlaid identified marginality hotspots (presented in Figure 5) with subnational poverty data to show the overlap of marginality hotspots with those living below the poverty line of USD 1.90/day. The generated map (Figure 8) demonstrates that marginality and poverty largely overlap in South Asia and Sub-Saharan Africa with the highest number of marginalized poor in South Asia being in India and Bangladesh and in Sub-Saharan Africa in Ethiopia, South-eastern Africa and some parts of western Africa. While poverty rates

[3] The poverty gap index is a measure of the intensity of poverty. The headcount ratio which simply counts all the people below a poverty line, in a given population, and considers them equally poor. Poverty gap index estimates the depth of poverty by considering how far, on the average, the poor are from that poverty line. Two regions may have the similar headcount ratio, but distinctly different poverty gap indexes. A higher poverty gap index means that poverty is more severe.

[4] As differences in the cost of living across the world evolve, the global poverty line must be periodically updated to reflect these changes. While historically the poverty line was USD 1.25, the new global poverty line, as of October 2015, is updated and set to USD 1.90 based on 2011 prices. The real value of USD 1.90 in today's prices is the same as USD 1.25 was in 2005.

in India were not as high as in other regions, large populations were affected, particularly in central and western parts of the country.

Figure 8: Overlay of marginality dimensions with the number of people living on less than USD 1.90/day

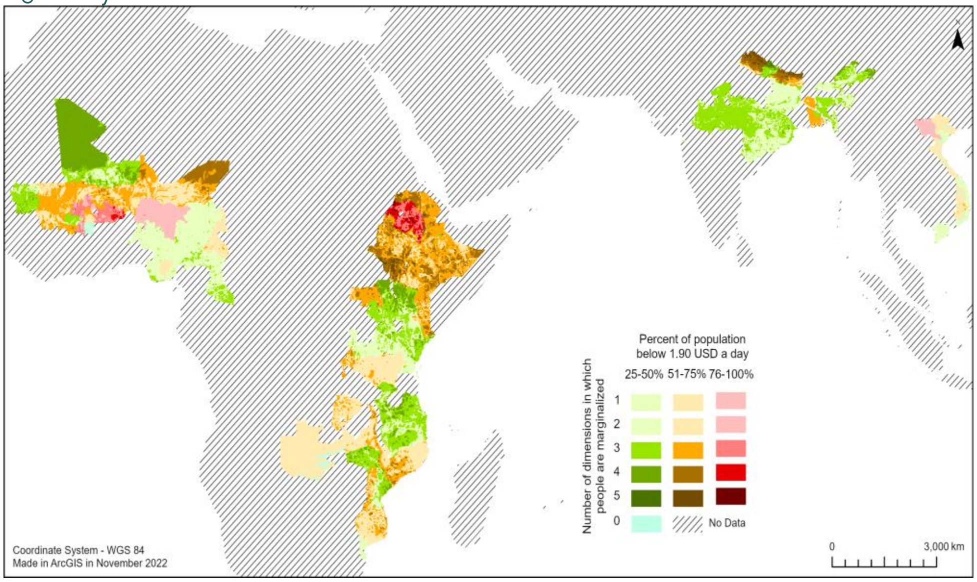


Source: Graw, V. & Husmann, C. 2014. *Mapping Marginality Hotspots*. *In* J. von Braun & F.W. Gatzweiler, eds. *Marginality*, pp. 69–83. Dordrecht, Springer Netherlands. https://doi.org/10.1007/978-94-007-7061-4_5

Note: The original map is reproduced using the same data sources. This map is based on poverty line of 1.90 USD. It was also modified to comply with UN. 2020. Map of the World. https://www.un.org/geospatial/file/3420

On the other hand, areas where a high percentage of poor people coincided with marginality hotspots (Figure 9) were found in Central and Southeast Africa, especially the northern parts of Niger and in Chad, the Central African Republic, the Democratic Republic of the Congo, Mozambique, Malawi and Burundi. In South Asia marginality hotspots coincided with high poverty rates, particularly in Bangladesh and Nepal (Graw and Husmann, 2014). Comparing the number of poor and poverty rates in Figures 12 and 13, Graw and Husmann (2014) concluded that while the percentage share (in total population) of the poor and extremely poor is higher in Sub-Saharan Africa, the total number of poor living in poverty is higher in South Asia. These results are reinforced by the World Bank's PovCalNet data (2015 estimates) indicating that half of the global total 736 million extremely poor, about 368 million, lived in just 5 countries: India (171 million), Nigeria (85 million), Democratic Republic of Congo (55 million), Ethiopia (31 million) and Bangladesh (24 million). The severity or depth of poverty being too high in these countries requiring significantly more resources to fight poverty. A subsequent study by Max Roser and Esteban Ortiz-Ospina (2019) utilizing the Poverty Index (MPI) by the Oxford Poverty & Human Development Initiative (OPHI) to map the global population living in multidimensional poverty by country confirmed these findings by demonstrating acute poverty levels across the countries in Sub-Saharan Africa and South Asia.

Figure 9: Overlay of marginality dimensions with percentages of populations living on less than USD 1.90/day



Source: Graw, V. & Husmann, C. 2014. *Mapping Marginality Hotspots*. *In* J. von Braun & F.W. Gatzweiler, eds. *Marginality*, pp. 69–83. Dordrecht, Springer Netherlands. https://doi.org/10.1007/978-94-007-7061-4_5

Note: The original map is reproduced using the same data sources. This map is based on poverty line of 1.90 USD. It was also modified to comply with UN. 2020. Map of the World. https://www.un.org/geospatial/file/3420

Disparities in social and economic status and distortions in markets are the root causes of economic marginality, slow or declining growth in agricultural productivity attributed to the socioeconomic status of marginalized farmers (e.g. poor access to markets and infrastructures, poor access to services and agrifinance, etc.) is likely to further increase their vulnerability, further marginalizing and isolating them from the economic environment. For marginalized farmers to be part of the solution and contribute to the economic engine to drive the growth process and alleviate poverty, future policy should strive to understand the economic roots of poverty and reassess interventions aimed at facilitating the structural transformation of agricultural marginality.

4.2. Access and spatial aspects of agricultural marginality

Marginality is a condition experienced by individuals or communities who are marginalized primarily on the basis of their social or geographic proximity. According to (Gurung and Kollmair, 2005), spatial marginality is linked to the geographical remoteness of an area from major economic centres, and refers to areas that are difficult to reach (access) in the absence of appropriate infrastructure and are therefore isolated from mainstream development. Differences in accessibility, both in terms of asymmetric distribution of cities and vast inequalities in infrastructural development creates marginalization and isolation of certain societies or communities. Highly accessible areas include those with abundant transport infrastructure and/or many spatially disaggregated cities, suggesting that accessibility to cities can be increased by improvements in infrastructure as well as polycentric urban development (Weiss *et al.*, 2018). This implies that spatial marginality is a dynamic phenomenon; that is with improvement in connectivity such areas will no longer be considered as spatially marginal.

Agricultural marginality can be severely influenced by relative access to markets. Marginal farm households must have access to productive technologies and low-cost access to competitive and well-functioning markets to be able to produce a marketable surplus and become part of the boarder agricultural economy (Barrett, 2008). Physical access (to commercially developed areas) is a significant determinant of market participation and market-oriented agricultural economy (Ahmadzai, 2018). The time that agricultural commodities take to reach markets affects households' decisions to participate in markets and propensity to consume, and therefore affect food production as well as food security.

Weiss *et al*. (2018) showed that in 2015 roughly 80.7 percent of the world's population (equivalent to 5.88 *billion people) r*eside within one hour of cities, however accessibility is spatially heterogeneous and unevenly distributed across the development spectrum. Notably, countries in Sub-Saharan Africa followed by the Near East and North Africa representing regions with the largest fraction of populations, have the least access. Accordingly, in 2000, roughly 430 million people in developing countries lived in rural areas with restricted market access (World Bank, 2008).

Physical remoteness and lack of access further compound the income-earning potential of households in such areas. Geographical isolation raises substantially the costs of agricultural commerce and crop production in remote markets, distorts or insulates these markets from economy-wide policy changes, and thus discourages smallholder market participation and investment in improved farming systems and land management (Barret, 2008). This outcome may also have economy-wide implications. Developing countries with a larger share of their rural populations on marginal land are likely to be developing less rapidly and thus display lower rates of long-run economic growth compared to economies with smaller concentrations of rural households on this type of land (Barbier, 2010; Barbier and Bugas, 2014).

4.3. Food and nutrition insecurity: a growing concern in marginal areas

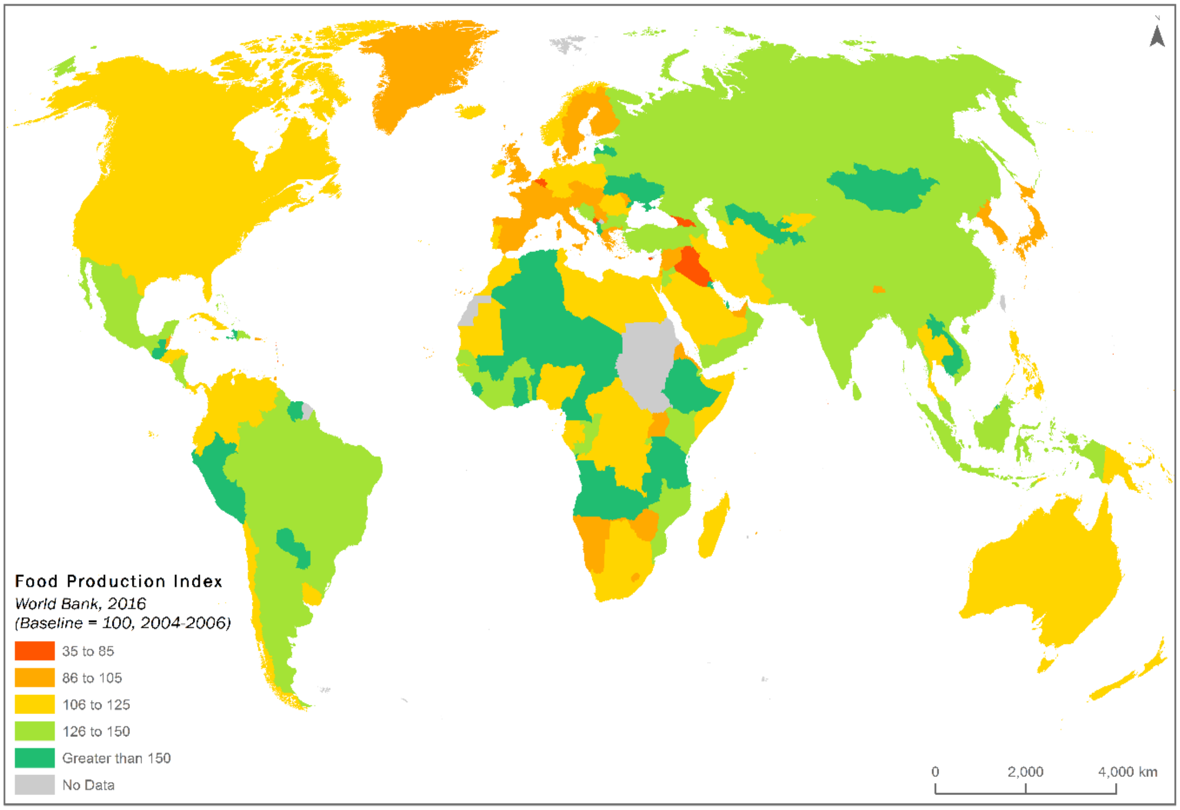
After decades of steady decline, hunger is on the rise again. Between 720 and 811 million people (equivalent to 9.9 percent of the global population) in the world are still hungry today, underscoring the immense challenge of achieving the Zero Hunger target by 2030 (FAO, IFAD, UNICEF, WFP and WHO, 2019; Willett *et al.*, 2019). In addition, 149.2 million children are stunted, 45.4 million suffer from wasting, and more than 2 billion people are micronutrient deficient (Willett *et al.*, 2019). Childhood malnutrition is a cause of death for more than 2.5 million children every year (McKenzie and Williams, 2015). The number of people who suffer from hunger has slowly increased in all regions of the world with Africa and South Asia facing the highest prevalence of undernourishment at almost 20 percent and 15 percent respectively. South Asia has the largest number of food insecure people, while Sub-Saharan

Africa has the highest proportion, as well as the highest rates of child underweight and infant and child mortality.

With world population projected to reach 9.15 to 10 billion in 2050 (Springmann *et al.*, 2018; Willett *et al.*, 2019) the expected growth in global food demand is 1.1 percent per year from 2005/07-2050 which implies a 56 percent increase over the period (Alexandratos and Bruinsma, 2012; McKenzie and Williams, 2015). However, to match the predicted 1.1 percent annual growth in global food demand, global food production in 2050 would need to be approximately 60 percent higher than that of 2005/2007 (Alexandratos and Bruinsma, 2012; McKenzie and Williams, 2015). Fischer *et al*. (2015) suggests that it would be prudent to have crop yields increase at around 1.2 to 1.3 percent per annum with a 10 percent increase in area cropped which will likely deliver around a 45 percent increase in staples over 2010 yields. Achieving these target yields or productivity using current production methods is a greater challenge in the face of climate change as studies predict that up to 25 percent of world food production can be lost during the 21st century due to climate change, water scarcity, invasive pests and land degradation (McKenzie and Williams, 2015). Agroecology experts propose a different approach that is more climate resilient, restores productive ecosystems, stabilizes farm incomes and improves food security (Altieri and Nicholls, 2020b). To meet the annual 1.1% growth in food demand does not necessarily require more land but a different type of production. Increasing farm biodiversity has realized an increase in grain yields by almost 20% through intercropping with beans and legumes rather than simple monocrop systems (Zou *et al.*, 2021). Additional environmental and economic benefits are achieved by appropriate intercropping (Xiao *et al.*, 2018; Zou *et al.*, 2021).

Regional estimates show lower food production precisely in countries where food insecurity and malnutrition are highly prevalent. While few countries have high growth in terms of food production (e.g. score of over 125 per capita net food production index number), Figure 10 shows interesting differences by country, as well as by region. Africa has the most countries with per capita food production index less than or equal to 105. Much of Central and Southern Africa has food production index below 105, while several countries in East and West Africa are above 105. Note that any value above 100 of the index signifies production is increasing relative to the base year 2007.

Figure 10: Food production across the regions



Source: Authors' composition based on the data from the World Bank.

Notes: Final boundary between the Sudan and South Sudan has not yetbeen determined.Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

In summary, demographic pressure coupled with climate change, water scarcity and depletion of soil resources will add to the challenge of advancing global food security. This is particularly more so, in marginal environments where food production is significantly low due to various biophysical and socioeconomic factors with the biggest concern being in parts of Asia and Sub-Saharan Africa. Sub-Saharan Africa per capita food production has seen an annual decline of at least 3 percent since 1990 (McKenzie and Williams, 2015).

5. Biophysical drivers of agricultural marginality

Agricultural marginality is a multifaceted issue, being related to place-specific socioeconomic contexts and highly-variable technological conditions (Sallustio *et al.*, 2018). Biophysically agricultural marginal environment is one in which crops do not grow well consistently and/or which requires major inputs to achieve reasonable levels of production (Smit et al 1991) for it features poor and badly drained soils, restricted nutrient and water availability and steep slopes, which affect overall productivity levels (Lewis and Kelly, 2014; Sallustio *et al.*, 2018). Vulnerability of the natural environment in marginal lands have become issue of paramount concern especially that the growing global population, deteriorating agroclimatic conditions and global SDG goals related to alleviating poverty and ensuring food will necessitate sustainable intensification of agricultural production, and expansion into less developed areas and marginal lands with lower fertility and higher risk of adverse weather events (McKenzie and Williams, 2015). Climate change is likely to aggravate the situation so agriculture production also needs to be adaptive to meet these challenges (Aguilera *et al.*, 2020). Sustainable intensification may not necessarily depend solely on high input and advanced technologies, but may involve diversification, resilience, improvement in efficiency, agricultural innovations and building synergies enhances key functions across food systems.

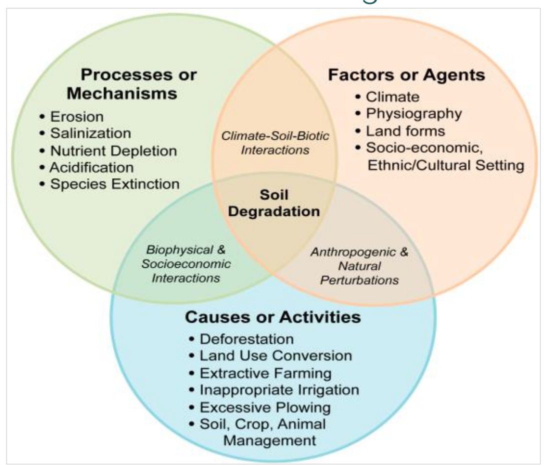
Today, global agriculture feeds over 7 billion people but is also a major cause of multiple types of environmental degradation, for agricultural activities emit 25 percent to 33 percent of greenhouse gases; occupy 40 percent of earth's land surface; account for more than 70 percent of freshwater withdrawals (Clark and Tilman, 2017). In fragile marginal production environments, the process and factors generating environmental vulnerabilities tend to reinforce each other leading to a complex production environment. Adverse environmental and biophysical constraints contribute to low productivity and pose high production risk, which ultimately lead to subsistence orientation and dissuade investments in technological options to boost productivity. The relationship between poverty and environmental degradation is long-standing and described as a two-way interactive process. In the following sections, we expend on key biophysical dimensions that are likely to lead to marginality.

5.1 Land degradation: a threat in marginal lands

The term land degradation refers to some measurable loss of the biological or economic productivity and complexity of cropland arising from either human activities and habitation patterns or due to natural process (Barbier and Hochard, 2016). The IPCC (IPCC, 2019a) defines land degradation as a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic, climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity, or value to humans.

Land degradation is one of the world's most serious environmental issues, and it will only get worse unless immediate action is taken. According to the Global Environment Facility, nearly a quarter of the world's total land area has been degraded. Land degradation releases soil carbon and nitrous oxide into the atmosphere, making it one of the most significant contributors to climate change. Scientists recently warned that unsustainable agriculture methods were causing the loss of 24 billion tons of valuable soil each year, and by 2050, 95 percent of the Earth's land areas might be degraded if current trends continue. Land degradation affects around 3.2 billion people, primarily rural communities, smallholder farmers and the impoverished (GEF, 2019). The FAO reported that arable land per person is shrinking. It decreased from 0.38 ha in 1970 to 0.23 ha in 2000, with a projected decline to 0.15 ha per person by 2050. South Asia is using 94 percent of its potentially arable land. In contrast, in Sub-Saharan Africa only 22 percent of potentially arable land is under cultivation (FAO, 2020).

Figure 11: The process–factor–cause nexus as a driver of soil degradation



Source: Lal, R. 2015. *Restoring Soil Quality to Mitigate Soil Degradation*. *Sustainability*, 7(5): 5875–5895. https://doi.org/10.3390/su7055875

Soil degradation implies a decline in soil quality, which is essential for strengthening and sustaining ecosystem functions and services upon which economic growth depends particularly in countries dependent on agriculture (Lal, 2015). The FAO defines soil degradation as a change in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries. Degraded soils have a health status such, that they do not provide the normal goods and services of the particular soil in its ecosystem. Lal (2015) identifies four types of soil degradation: i) physical degradation which effects the soil structure, causing susceptibility to crusting, compaction, reduced water infiltration, increased surface runoff, wind and water erosion, greater soil temperature fluctuations and an increased propensity for desertification; ii) chemical degradation including acidification, salinization, nutrient depletion and reduced cation exchange, iii) biological degradation, reflecting depletion of the soil organic carbon pool, loss in soil biodiversity and subsequent increased greenhouse gas (GHG) emissions into the atmosphere; and iv) ecological degradation, reflecting a combination of the three and leads to disruption in ecosystem functions such as elemental cycling, water infiltration and purification, perturbations of the hydrological cycle and a decline in net biome productivity.

The Global Environmental Facility reported that Soil degradation process is exacerbated by the interaction between processes, factors and causes of soil degradation which could be either human-induced or natural (Figure 11). Hence, understanding the relationship or connectivity between the soil degradation process, factors involved in degradation and the underlying causes is key to mitigating degradation and restoring soil quality (Lal, 2015). The principle 8 in Status of World's Soil Resources Report states that soil degradation leads to marginality because it inherently reduces or eliminates soil functions and ability to support ecosystem services essential for human well-being. Therefore, controlling soil degradation is essential to maintain the services provided by soils and is substantially more cost-effective than rehabilitating soils after degradation has occurred (FAO and ITPS, 2015).

Accelerated soil degradation has reportedly affected as much as 500 million ha in the tropics, and globally 33 percent of earth's land surface is affected by some type of soil degradation. Some sources suggest that globally, 5 to 10 million ha of agricultural land are being lost annually to severe degradation (World Bank, 2008). The extent and severity of degraded lands largely varies across the regions. Table (6) presents land degradation by Stavi and Lal, (2015) across regions disaggregated according to severity levels. Degradation severity is obtained by combining the degree of degradation with its spatial extent. In developing countries degradation might be the outcome of both environmental factors and human activities, however, in developed world, for instance, in Europe soil degradation processes is mainly attributed to accelerated degradation exacerbated by human activity.

Table 6: Land degradation severity by region (percent of area by severity class)

Region	percent of area by severity class by				
	Light	Moderate	Severe	Very severe	Total degraded
Near East and North Africa	17	19	28	7	71
Sub-Saharan Africa	24	18	15	10	67
Asia and Pacific	12	32	22	7	73
North Asia	14	12	17	4	47
South and Central America	27	23	22	5	77
Europe	21	22	36	12	91
North America	16	16	16	0	48

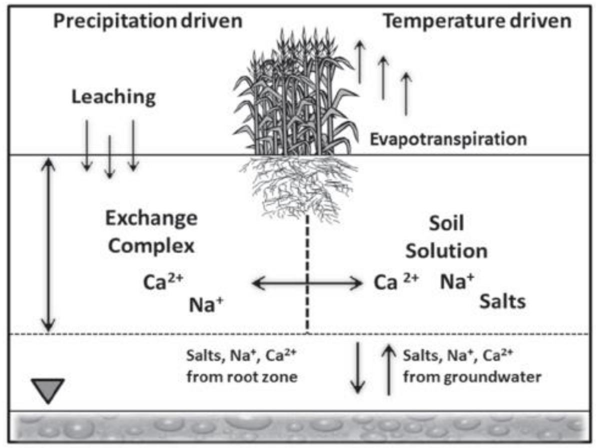
Source: Stavi, I. & Lal, R. 2015. *Achieving zero net land degradation: challenges and opportunities*. Journal of Arid Environments, 112: 44–51. https://doi.org/10.1016/j.jaridenv.2014.01.016

Most of the global rural population living on degraded agricultural land is in developing countries where the share of degraded land cultivated by the poor is the greatest. The global extent of populations living on degraded lands increased from 1.3 billion in 2002 to 1.5 billion people in 2010 (Barbier and Hochard, 2014). This represents a 15 percent change in rural populations, mostly rural poor, that rely entirely on degraded lands for their subsistence. The continuation of this trend greatly diminishes chances of sustainable development and poverty eradication. Investments targeting the underlying factors of land degradation in favoured and marginal areas, that aim to restore these agriculture lands will advance global food security, poverty eradication and climate change mitigation and adaptation.

5.2 Salinization: a growing global constraint

Salt accumulation in soil makes water unavailable to plants resulting in yield decline, with the effects amplifying as soil salinity and sodicity increases (Bhardwaj *et al.*, 2016). Figure 12 schematically explains the salinity mechanisms and processes leading to transient salinity in root zone layers. The availability and distribution of soil water responds to climate change due to changes in hydrological patterns which alter precipitation patterns or drought events. High rainfall intensity decreases downward movement of water whereas low rainfall, conjugated with high temperature, aggravates the problem of soil salinization because of increased rate of evapotranspiration and increased capillary movement of water and salts to the surface of soil. Climate change affects evapotranspiration due to its effects on air temperature, wind speed, humidity, cloudiness and atmospheric turbidity affecting the radiations. High temperatures accelerate evapotranspiration causing upward movement of salt to upper horizons (Bhardwaj *et al.*, 2016). Consequently, climate change is likely to have greater adverse effects on saline and sodic soils.

Figure 12: Illustration of salt development mechanisms in soil



Source: Bhardwaj, A.K., Nagaraja, M.S., Srivastava, S., Singh, A.K. & Arora, S. 2016. A framework for adaptation to climate change effects in salt affected agricultural areas of Indo-Gangetic region. *Journal of Soil & Water Conservation*, 15(1): 22–30. http://krishi.icar.gov.in/jspui/handle/123456789/10800

Salinity problems are encountered in all climates and are a consequence of both natural and human-induced processes (FAO-ITPS-GSP, 2015) typically triggered by water table-level rise driving salts to the surface. The literature on salinity offers different figures on the extent of global salinity, which partly depend on the estimation method that they use. About 33 percent of the world's potentially arable land and 20 percent of the irrigated area is salt affected (Qadir *et al.,* 2014; Assouline *et al.*, 2015). The global extent of salt-affected land amounts to approximately 1.12 million ha (Wicke *et al.*, 2011), slightly higher in comparison to the estimated 1,030 million ha (with 412 million ha affected by salinity and 618 million ha by sodicity) reported by the FAO Status of World's Soil Resources report in 2015 (FAO and ITPS, 2015). The magnitude and scope of complexities related to salinity is predicted to increase, not only because of changes in the climate but also as a result of human interventions and poor management of agriculture practices such as poor irrigation methods and practices which do not allow for proper drainage.

The estimates on global salt-affected areas by the level of severity are reported in Table 7 with 60 percent being saline, 26 percent sodic and 14 percent saline-sodic soils. In terms of severity, majority of salt-affected soils is either slightly or moderately affected and a relatively smaller percent are extremely and highly salt-affected.

Table 7: The world Salt affected area by the level of severity (million ha)

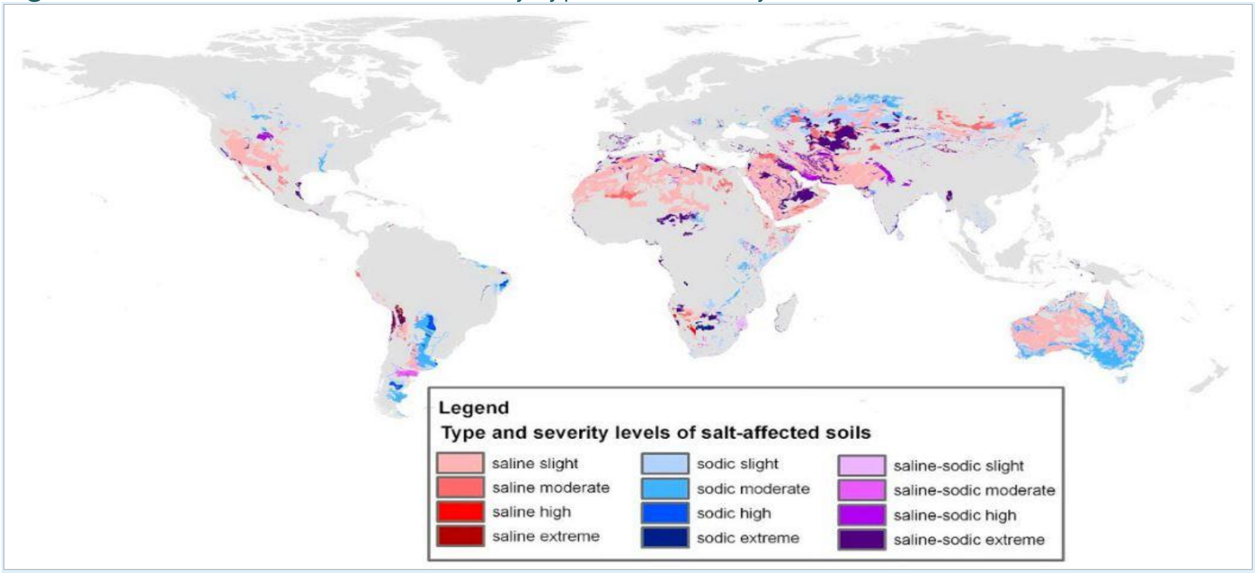
Severity level	Type of salt affectedness (in 1000 ha)				
	Saline	Sodic	Saline-sodic	Total	Share (%)
Slight	606	124	6	735	65
Moderate	69	147	11	228	20
High	4	13	36	52	5
Extreme	4	5	105	113	10
Total	**683**	**288**	**157**	**1,128**	
Share %	60	26	14		

Note: salinity classifications include: <2 ds/m=non-saline, 2 to 4=slightly saline, 4 to 8 ds/m=highly saline, & >16 ds/m extremely saline.

Source: Wicke, B., Smeets, E., Dornburg, V., Vashev, B., Gaiser, T., Turkenburg, W. & Faaij, A. 2011. *The global technical and economic potential of bioenergy from salt-affected soils*. Energy & Environmental Science, 4(8): 2669–2681. https://pubs.rsc.org/en/content/articlelanding/2011/ee/c1ee01029h

Salinization is a changing and dynamic process, and the problem of salinity has enormously changed over time and space. The map in Figure 13, by Wicke *et al*. (2011) using data from Harmonize World Soil Database (HWSD), elaborates on the distribution of saline, sodic and saline-sodic soils all over the globe showing the Near East (189 million ha), Australia (169 million ha), North Africa (144 million ha) and Russian Federation (the) and Central Asia (126 million ha) as regions with the largest salt-affected land areas.

Figure 13: Global salt-affected soils, by type and severity



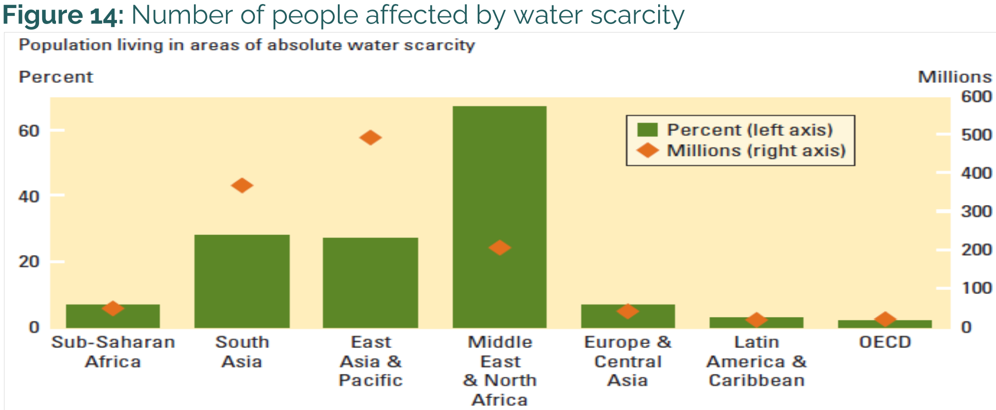
Source: Source: Wicke, B., Smeets, E., Dornburg, V., Vashev, B., Gaiser, T., Turkenburg, W. & Faaij, A. 2011. *The global technical and economic potential of bioenergy from salt-affected soils*. Energy & Environmental Science, 4(8): 2669–2681. https://pubs.rsc.org/en/content/articlelanding/2011/ee/c1ee01029h

The inflation-adjusted cost of salt-induced land degradation in 2013 was estimated at USD 440 per hectare (Assouline *et al.*, 2015). The total estimated economic losses (in terms of crop value) from the 62 million ha irrigated lands affected by salinity may reach up to USD 27 billion (inflation-adjusted) on annual basis (Qadir *et al.*, 2014; Assouline *et al.*, 2015). For all important crops, average attainable yields are only a fraction – somewhere between 20 percent and 50 percent of record yields; these losses are mostly due to drought and high soil salinity (Shrivastava and Kumar, 2015). A case study by Tripathi (2009) from Indo-Gangetic Basin in India reinforces this argument and report yield losses for different crops (45 percent loss in rice, 39 percent loss in wheat, 63 percent loss in cotton and 48 percent in sugarcane yields) bearing a significant decline on productivity of the farm. In addition to productivity losses, soil salinity also causes other damages including loss in biodiversity, abandonment or desertification of previously productive farmland, soil erosion and contamination of drinking water.

5.3 Water scarcity: driving marginal areas even more marginal

Lack of water due to low precipitation and high evapotranspiration levels is a biophysical constraint of marginal environments that can severely restrict crop and livestock production (Lipper, Pingali and Zurek, 2007). As per the Comprehensive Assessment of Water Management in Agriculture (2007), one in three people today face water shortages. Approximately 1.2 billion people live in river basins with absolute water scarcity, 478 million live in basins where scarcity is fast approaching; and a further 1.5 billion suffer from inadequate access to water because of lack of infrastructure or the human and financial capital to tap the available resources (World Bank, 2008). Near East and North Africa, with about 60 percent of its population living in absolute water scarcity, is the most water scarce region in the world (Figure 14). Nonetheless, around 30 percent of south Asia, East Asia and the pacific are affected by water scarcity problems and these are home to 2/3 of the global population. The global picture of water scarcity in Figure 15 confirms these findings, with high water risk score in Sub-Saharan Africa which require substantial future investments to handle water scarcity issues in the region.

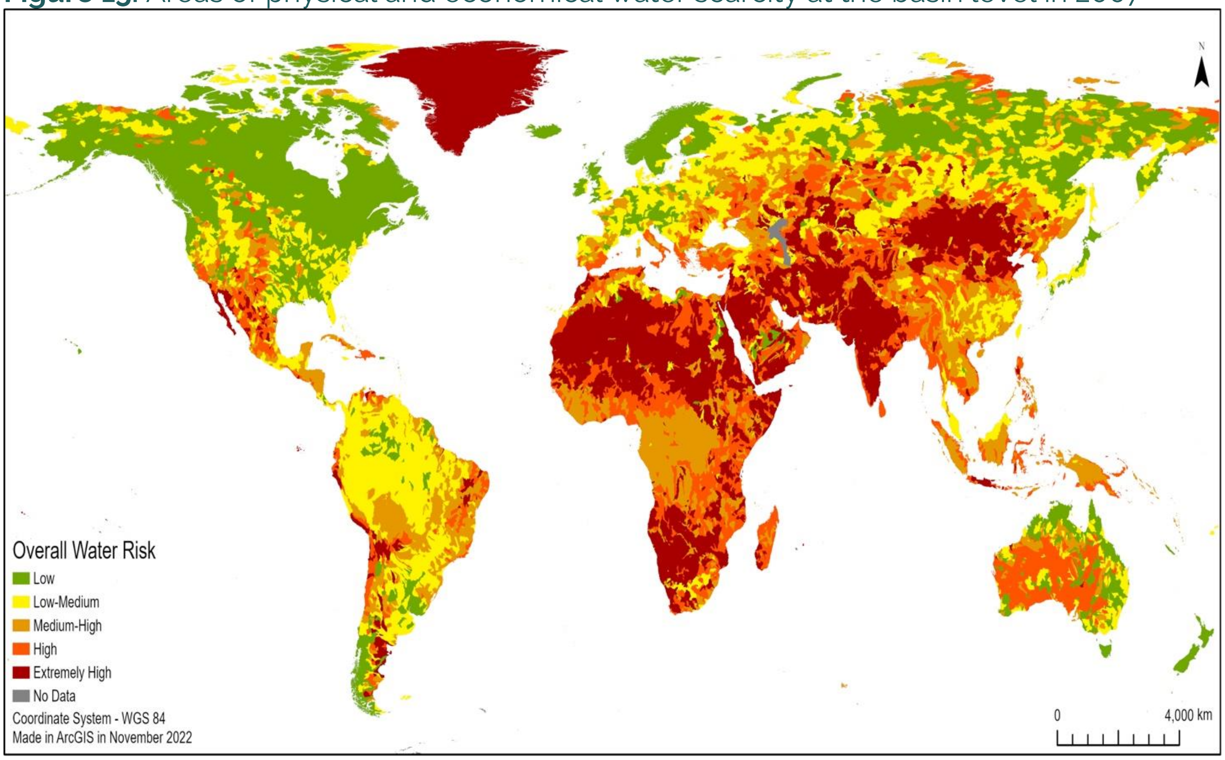
Figure 14: Number of people affected by water scarcity



Source: World Bank. 2008. Word development report 2008: Agriculture for Development. The World Bank Washington, DC. The World Bank, Washington. http://hdl.handle.net/10986/5990

The pressure on the global fresh-water resources is steadily increasing and will be amplified in countries chronically short of water. About one fourth of the world's population live in areas categorized as physically water scarce and one sixth in areas of economic water scarcity (Fischer *et al.*, 2011). The expected rise of the global population growth rate points out the inevitable increase of food demand, with an immediate impact on farming water use. Fischer *et al*. (2007) estimated future increases in irrigation water requirements by over 50 percent in developing regions and by about 16 percent in developed regions. In this study, the largest relative increase of irrigation water requirements are projected to occur in Africa and Latin America from 2000 to 2080. Degradation of surface and underground water quality is another major dimension of water scarcity (Assouline *et al.*, 2015; van Vliet, Flörke and Wada, 2017). There are two major types of marginal-quality water: wastewater from urban and peri-urban areas, and saline and sodic agricultural drainage water and groundwater (Qadir *et al.*, 2007).

Figure 15: Areas of physical and economical water scarcity at the basin level in 2007



Source: Authros' own composition based on the data from Aquaduct 3.0 Water Risk Atlas, World Resources Institute (WRI)

Notes: To generate the overall water scarcity map, World Resource Institute's 2019 Aqueduct 3.0 dataset was used. This subnational open source dataset includes numerous input data from 1960-2014 to generate long-term maps of water related issues. Specifically, they generated 13 spatial layers with scores related to the severity of hydrological, ecological, infrastructural, and governmental water issues globally. A cumulative Overall Water Risk was generated, The scores for risk range from 0-5 corresponding to the five severity levels shown on the map.

Water scarcity is a major constraint for agriculture production effectively adding to the biophysical marginality of regions where increased crop production is most needed, preventing the expansion of irrigated agriculture. With the majority of the world's freshwater use going to agriculture, water scarcity remains a serious global challenge to achieve the global hunger eradication and the food security goals (Figure 15). Alternative water resources for irrigation must be developed and supported by advanced and environmentally sustainable irrigation water management schemes (Assouline *et al.*, 2015; Grant *et al.*, 2012). Currently, millions of small-scale farmers around the world irrigate with marginal-quality water, often because they have no alternative. This can pose a serious future problem given that the application of saline water containing high concentrations of sodium affects soil hydraulic properties and reduces soil permeability.

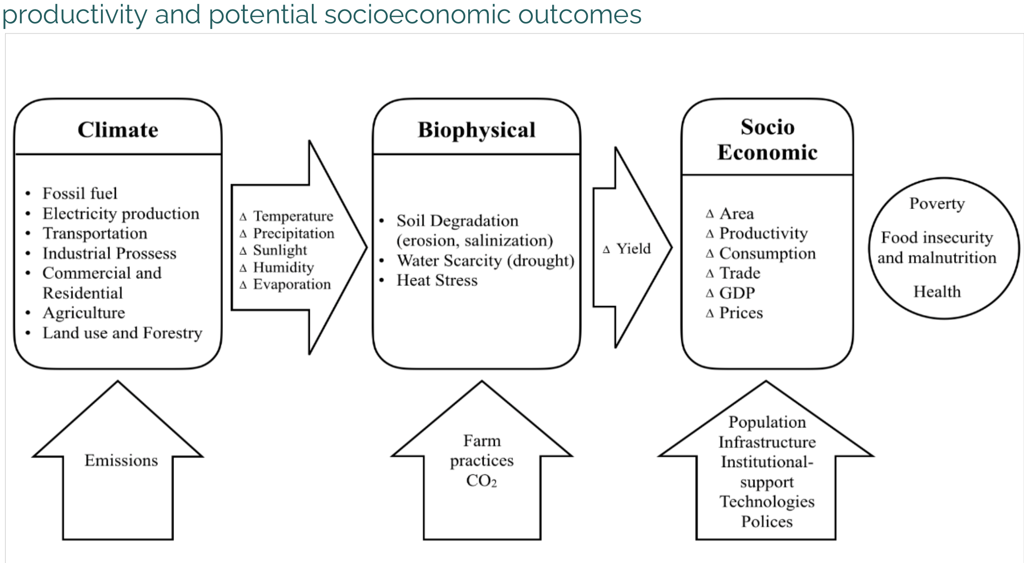
6. Cross-cutting dimensions of agriculture and marginality

While socioeconomic and biophysical aspects are the main underlying drivers of marginality, the climate change effects and the loss of biodiversity especially the extinction of traditional and neglected and underutilized crops exacerbate the condition of marginality and undermine food production. These threats are posing greater risk to agriculturally marginal areas due to the fragility of marginal areas. Hence, we briefly explore these aspects in this section.

6.1. Marginal areas in the face of climate change

Climate change alters weather conditions with projected increases in temperatures, changes in precipitation patterns, increased frequency and intensity in extreme weather events and reductions in water availability. Agriculture responds to climate change through biophysical changes in the farm environment that ultimately reduce aggregate global agricultural productivity, disrupt food availability, reduce access to food and affect health and other dimensions of the human welfare (Figure 16). This threat to regional and global food security will particularly affect the extremely poor who rely on local agricultural production for subsistence.

Figure 16: A schematic representation of links between climate change effects, agricultural productivity and potential socioeconomic outcomes



Source: Nelson, G.C., Valin, H., Sands, R.D., Havlík, P., Ahammad, H., Deryng, D., Elliott, J. *et al.* 2014. *Climate change effects on agriculture: Economic responses to biophysical shocks*. Proceedings of the National Academy of Sciences, 111(9): 3274–3279. https://doi.org/10.1073/pnas.1222465110

Several studies have examined the effects of climate change on global agriculture productivity and other economic parameters showing differing impacts among crops and regions, with potential yield increase in areas characterized by low temperatures and yield decrease in other areas The world could observe the effect of climate change on the production of maize and wheat as early as 2030; maize crop yields are projected to decline 24 percent, while wheat could potentially see growth of about 17 percent (Jägermeyr *et al.*, 2021). The general consensus among the scientific community is that overall agricultural yields are likely to decline over the course of the next 50 years (FAO, 2017). Climate change has likely led to about 1 percent average reduction in consumable food calories and in nearly half of food insecure countries; that is the estimated caloric availability decreased. These impacts vary depending on geographical regions with mostly negative effects in Europe, Southern Africa and Australia but generally positive in Latin America and mixed in Asia and Northern and Central America. (Ray *et a*l., 2019).

The socioeconomic impacts of climate change are predicted to be critically different on regional basis depending on the socioeconomic development scenarios of regions. Such heterogeneity and asymmetries in impact due to both climate and socioeconomic structures may deepen current production and consumption gaps between developed and developing world, as a result climate change effect will have different implications for food security.

Marginal areas are exposed to higher climate risks and climate change is therefore expected to have greater risk on agriculture in these areas already constrained by erratic and volatile conditions together with biotic stresses that adversely affect agricultural production. Increased heat waves during the cropping seasons will increase crop water requirements, already a scarce resource in marginal regions. Climate change and variability may result in irreparable damage to arable land and water resources in marginal regions, and with serious local consequences for food production. These losses will be felt most profoundly in developing countries with low capacity to cope and adapt (Fischer *et al.*, 2005). Of particular concern is the marginal lands in Sub-Saharan Africa, where a growing share of undernourished people reside (Fischer *et al.*, 2005; Brown and Funk, 2008).

Given that climate change is a major driver of rising hunger levels, projected to increase in the future, putting in place early warning systems and development programmes to mitigate consequences is critical (Brown and Funk, 2008). These include increasing the scale of investments in crop improvement, and increasing the emphasis of these investments on global change factors to sustain yield growth over the next few decades (Lobell and Gourdji, 2012).

6.2. Agriculture as a driver and inhibitor of climate change

Food production is the largest cause of global environmental change. Agriculture occupies about 40 percent of global land, and food production is responsible for up to 30 percent of global greenhouse-gas (GHG) emissions and 70 percent of freshwater use (Willett *et al.*, 2019).

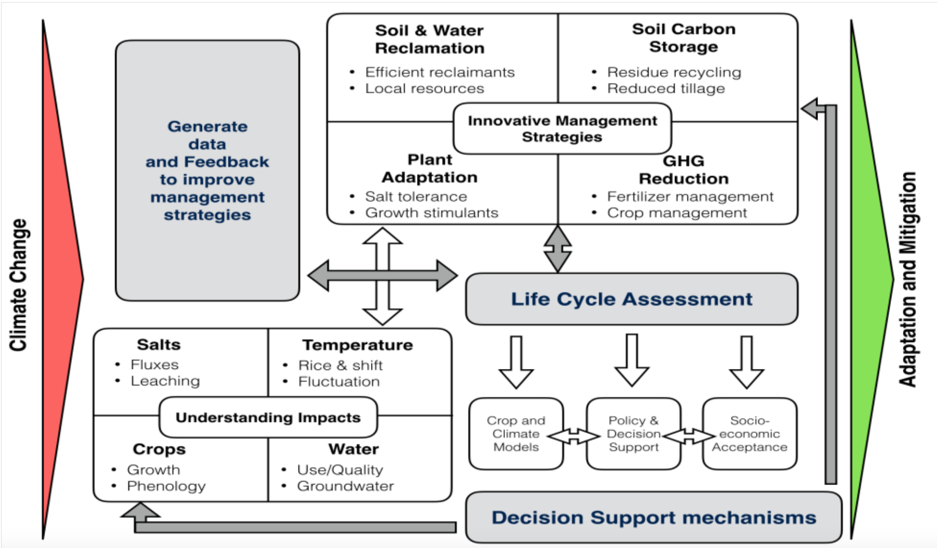
At the same time natural land processes absorb carbon dioxide equivalent to almost a third of carbon dioxide emissions from fossil fuels and industry (IPCC, 2019a). Hence, agriculture is both a source and a sink of GHG with increasing evidence that agriculture can play an important role in climate mitigation through sequestering atmospheric carbon dioxide into long-lived pools and storing it securely, so that it is not immediately reemitted.

Globally, agricultural soils can offset about 15 percent of global GHG emissions Lal, (2004b). Carbon sequestration in agricultural soil has been identified as a potential win-win strategy to offset greenhouse gas emissions (Kragt *et al.*, 2012) particularly for degraded agricultural soils in the dryland regions of developing countries (Tschakert, 2004). The increased depletion of soil carbon is accentuated by soil degradation and exacerbated by land misuse and soil mismanagement, especially in marginal agricultural areas. Lal (2004b) argues that a considerable part of the depleted SOC pool can be restored by rehabilitating marginal lands and degraded ecosystems through adopting restorative land use and recommended management practices.

Carbon sequestration on agricultural lands could be substantial with widespread implementation of various strategies that vary in effectiveness across different climates, soil types and geographies (Kane, 2015). Conventional no-till and minimum tillage, cover crops and crop rotations, rotational grazing, perennial cropping systems are some of the recommended strategies that can be adopted to increase soil carbon storage (Kane, 2015; Tang *et al.*, 2016). Switching from conventional to conservation tillage, including no-till and minimum-till, could decrease carbon oxidation and carbon dioxide emission from soil as well as increase carbon sequestration. Continuous cropping shortens the fallow period and thus decreases the rate of soil organic carbon decomposition and can lead to an increase in soil carbon stocks. Therefore, crop rotation can decrease carbon oxidation and increase aggregate stability and the concentration of soil carbon (Tang *et al.*, 2016). Nutrient cycling including the use of compost, biochar, animal manure and other systems of sustainable management of soil and water resources is another potential strategy (Lal, 2004b).

Understanding salt development mechanisms in soils under altered water and temperature regime is key to developing sustainable management. Given the expected upsurge in climate-induced land degradation under future climate change scenarios, more so under high global warming scenarios, the rehabilitation of salt-affected lands offers an opportunity to mitigate the consequences of climate change and advance global food security. By enhancing the primary productivity of saline soils through improving the soil physical and chemical properties, we can enhance food security while increasing carbon storage in soils contributing to climate mitigation (Bhardwaj *et al.*, 2016). The diagram in the Figure 17 presents a comprehensive conceptual framework for adaptation to climate change effects and restoration of salt affected lands. The first and immediate step is to recognize the threat posed by climate change and understand potential consequences for agricultural and ecosystems in salt affected soils. This helps develop informed sustainable strategies to meet the challenge of mitigation and adaptation to climate change. Subsequently, life cycle assessment for the proposed strategies are carried and the generated information is incorporated into crop, climate and socioeconomic models to inform decisions and ensure long-term benefits, rather than short term yield-based goals. The generated data and feedback on performances under large scale production systems and varied climatic conditions needs to be fed to farmers and policy makers on continuous basis to lead to further improvements of the management strategies (Bhardwaj *et al.*, 2016).

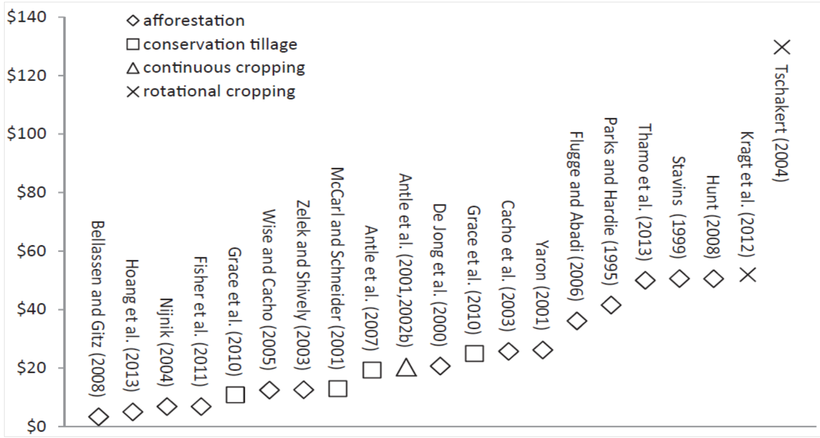
Figure 17: Framework for adaptation to climate change effects in salt-affected areas



Source: Bhardwaj, A.K., Nagaraja, M.S., Srivastava, S., Singh, A.K. & Arora, S. 2016. *A framework for adaptation to climate change effects in salt affected agricultural areas of Indo-Gangetic region*. Journal of Soil & Water Conservation, 15(1): 22–30. http://krishi.icar.gov.in/jspui/handle/123456789/10800

Carbon farming is believed to lead to a number of potential co-benefits including biodiversity protection, water retention and soil fertility (Kane, 2015; Tang *et al.*, 2016). At the farm level, farmers are likely to adopt carbon farming practice if it is profitable. The economic feasibility of carbon sequestration in agricultural soils largely varies depending on the adaptation or management strategies applied. Tang *et al.* (2016) overviewed 62 studies published between 1995 and 2014 investigating the economics of agricultural GHG mitigation showing that the estimated costs of agricultural sequestration strategies vary widely; between USD 3 and USD 130/t CO2e in 2012 US dollars (Figure 18). The estimated mitigation costs depend on the region of analysis, the farming system and the mitigation strategy analyzed. Developed countries may achieve a relatively low-cost carbon sequestration by adopting conservation tillage and continuous cropping while in developing countries, continuous cropping and afforestation are potentially viable agricultural sequestration strategies.

Figure 18: Mitigation costs (($/t CO2e) of different carbon sequestration strategies (in 2012 USD $)



Source: Tang, K., Kragt, M.E., Hailu, A. & Ma, C. 2016. *Carbon farming economics: What have we learned?* Journal of Environmental Management, 172: 49–57. DOI: 10.1016/j.jenvman.2016.02.008

From this study one concludes that agricultural GHG mitigation is potentially economically attractive, though depending on the farming system, location and mitigation practices. In areas where the biophysical effectiveness of soil restoration measures are high, while implementation cost low, this coupled with the other environmental and social co-benefits, should serve as motivation for increased action (Kane, 2015). Given the differential resource-endowment of local smallholders, carefully designed cost-sharing mechanisms would be necessary to achieve equitable and efficient local participation in carbon sequestration schemes (Tschakert, 2004). Furthermore, the provision of positive incentives for farmers to change their land management offers another opportunity for substantial carbon sequestration in agricultural soils at a low carbon price (Kragt *et al.*, 2012).

6.3. Agrobiodiversity: neglected and underutilized crops and marginal areas

According to numerous high-level reports, a profound holistic and systemic transformation is needed to address climate change as well as achieve the Agenda 2030, and the four dimensions of food security and nutrition: availability, access, utilization and stability (HLPE, 2109; IPCC, 2019b; Sachs *et al.*, 2019). There is significant evidence and growing consensus, that the industrial food system is failing people, the planet and the very climatic systems that support life on Earth (Global Alliance for the Future of Food, 2021). Future approaches to natural resource management must be tailored and adapted in a site-specific way to highly variable and diverse farm conditions typical of resource-poor farmers. Agroecology provides promising means for meeting adaptation and mitigation targets and for achieving effective transformational change in the agricultural sectors (Leippert *et al.*, 2020). it provides the scientific basis to address the production by a biodiverse agroecosystem able to sponsor its own functioning (Altieri, 2002). Agroecology is based on applying ecological principles to agriculture and ensuring a regenerative use of natural resources and ecosystem services while also addressing the need for socially equitable food systems within which people can exercise choice over what they eat and how and where it is produced. The principles and concept of agroecology best fit, serve and agree with the socioeconomic and biophysical requirements needed for marginal lands restoration and development needs in marginal lands (FAO, 2014). Using agroecological processes maximizes the utilization of locally available and renewable resources as well as enhances social and human capital (Leippert *et al.*, 2020). This allows agricultural production systems to take advantage of ecosystem benefits including pest control, pollination, soil health and erosion management while still maintaining productivity. Biodiversity conservation and sustainable utilization leads to strong ecosystem services and long-term agriculture.

Agroecological practices harness, maintain and enhance biological and ecological processes in agricultural production, in order to reduce the use of purchased inputs that include fossil fuels and agrochemicals (Mier y Terán Giménez Cacho *et al.*, 2018) and to create more diverse, resilient and productive agroecosystems. Agroecological farming systems value, inter alia: diversification; mixed cultivation; intercropping; cultivar mixtures; habitat management techniques for crop-associated biodiversity; biological pest control; improvement of soil structure and health; biological nitrogen fixation; and recycling of nutrients, energy and waste (HLPE, 2109).

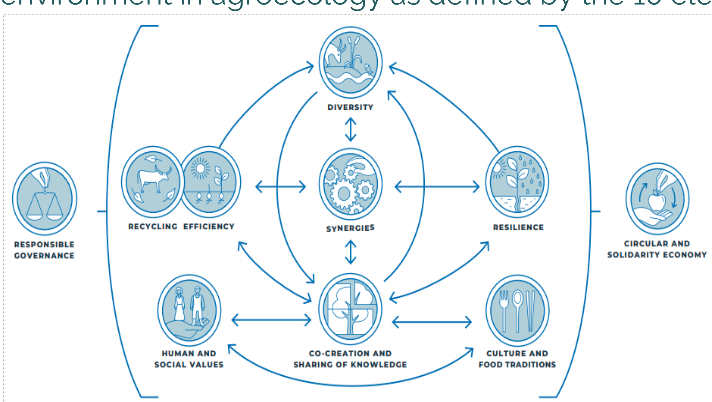
Agroecology has significant advantages over traditional agronomic or agro-industrial approaches. First, to manage variety, incorporate biological principles and resources into farming systems, and intensify agricultural productivity, agroecology relies on indigenous farming expertise and selected modern technologies. Second, it is the sole practical solution for restoring agricultural lands that have been degraded by traditional agronomic practices. Third, it provides a cost-effective and ecologically friendly solution for smallholders to increase productivity in marginal areas. Finally, it has the ability to counteract the anti-peasant bias of methods that focus on purchased inputs rather than the advantages that small farmers already have, such as low labour opportunity costs (Altieri, Rosset and Thrupp, 2020).

Despite the fact that researchers and policymakers have given little attention to these systems, there is enough evidence to suggest that agroecological technologies have the potential to contribute to food security on multiple levels. Critics of agroecological production systems point to lower crop yields than in high-input conventional systems. Yet, all too often, the focus on yield as a measure of a single crop's performance blinds analysts to broader measures of sustainability and the higher per unit area productivity and environmental services obtained in complex, integrated agroecological systems that include multiple crop varieties, animals and trees. Furthermore, in many circumstances, single crop yields are higher in agroecological systems that have completed the full conversion process (Altieri, 1999). Agroecology not only allows for more sustainable production of healthier food but also considerably improves farmers' incomes. It equally carries the promise of re-enlarging productive agricultural (and related) employment and increasing the total income generated by the agricultural sector, at both regional and national levels (van der Ploeg *et al.*, 2019).

There is enough evidence that agroecological approaches are able to contribute to transforming food systems, in particular to deliver agriculture that is regenerative in its use of renewable resources and ecosystem services (HLPE, 2109).Data show that over time agroecological systems exhibit more stable levels of total production per unit area than high-input systems; produce economically favorable rates of return; provide a return to labour and other inputs sufficient for a livelihood acceptable to small farmers and their families; and ensure soil protection and conservation and enhance agrobiodiversity (Altieri, Rosset and Thrupp, 2020). However, transitions to sustainable food systems that reconcile human and ecosystem health with social welfare will not happen without major shifts in policies at international, national and local levels and the active encouragement of innovation across these scales (HLPE, 2109).

The FAO has approved the 10 Elements of Agroecology as an analytical framework (FAO, 2018b) to support the design of differentiated paths for agriculture and food system transformation, allowing policymakers, practitioners and other stakeholders to make better decisions in a variety of contexts at various levels and scales. Biodiversity, consumers, education and governance are recognized as viable entry points for developing a structured process employing visual narratives that graphically dissect prospective social-ecological transition trajectories using the 10 Elements of Agroecology (Barrios *et al.*, 2020; Wezel *et al.*, 2020). The ten Elements are intertwined and depending on one another (Figure 19). Each component is necessary, showing agroecology's holistic and interconnected nature. The framework recognizes that transformative change could be taking place simultaneously through many routes, at multiple locations, starting from different baseline conditions and progressing at different rates. The diversity of trajectory options further highlights its flexibility and major opportunities for adapting actions to local realities. This suggests that the pace of transformative change of agriculture towards desired sustainability outcomes could possibly be faster than anticipated and hence hold greater prospects to achieving the SDGs by 2030 (Barrios *et al.*, 2020).

Figure 19: System components, key interactions, emergent properties and desired enabling environment in agroecology as defined by the 10 elements of agroecology framework



Source: FAO. 2018b. *The 10 Elements of Agroecology: guiding the transition to sustainable food and agricultural systems*. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/3/i9037en/i9037en.pdf

Traditional food systems are susceptible, as evidenced by the recent COVID-19 disasters. Concerns of widespread food shortages and price rises have been raised as a result of the pandemic's effects on farming and food supply systems. As a result, a shift to more socially equitable, ecologically robust and locally based food systems is critical (Altieri and Nicholls, 2020a).The long-standing problems in the food system, which have been exacerbated by the COVID-19 crisis, could be addressed, among other things, by a 'Green Stimulus' plan, which was proposed by a group of mostly urban activists and intellectuals to accelerate the creation of a twenty first century green economy (Green Stimulus Proposal, 2020).

In the reconstruction of a post COVID-19 new food system, agroecology as a transformational science, practice and movement that is openly committed to a more equitable and sustainable future by transforming power relations from farm to table is of critical importance. Under the banner of food sovereignty, significant transnational agrarian and food justice movements are advocating agroecology in opposition to the corporate-dominated global agrifood system (Mier y Terán Giménez Cacho et al., 2018). They advocate for a fundamentally different perspective on food and how we produce and consume it, as well as for the development of local, inclusive and egalitarian food systems. Agroecology provides a path forward by laying out the principles for designing and managing agricultural systems that are best suited to endure future crises, including as insect outbreaks, pandemics, climatic disturbances and financial meltdowns. Agroecology is the greatest agricultural system for dealing with future issues because it has a high level of diversity and resilience while producing reasonable yields and providing ecological benefits (Nicholls, Altieri and Vázquez, 2016; Altieri and Nicholls, 2020a).

6.5. Nature-based solutions to marginal lands

Nature-based solutions, which are based on agroecology and conservation agriculture principles, offer sustainable long-term benefits, such as resilience to disturbance over variable time scales and minimal input requirements, as well as an aim toward general improved human well-being (Peter et al., 2017). The term `Nature-based Solutions´ is used as an umbrella concept to cover a range of ecosystem related approaches including ecosystem-based adaptation, natural climate solutions and green infrastructure (Iseman and Miralles-Wilhelm, 2021). Agriculture Nature-Based Solutions (Ag-NBS) are an effective, long-term, cost efficient approach to tackling sustainable land and water resources management and climate change (Sonneveld et al., 2018).

Nature-based Solutions have made tremendous progress in recent years, improving the ecological functions of environment and landscapes ravaged by agricultural practices and land degradation while also promoting livelihoods and other social and cultural functions. As a result, a variety of NbS options have emerged, each of which offers a viable answer for attaining conservation, climate and socioeconomic goals while maintaining healthy and productive agricultural systems. NbS can mimic natural processes and expand on land restoration and operational water-land management principles to boost agricultural output while also improving vegetation and water quality (Sonneveld et al., 2018; Miralles-Wilhelm, 2021). According to the World Water Assessment Programme (WWAP), NbS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or the creation of natural processes in modified or artificial ecosystems (UNWWAP, 2018). NbS can be used in agricultural landscapes to improve soil health, soil moisture, carbon mitigation (via soil and forestry), downstream water quality protections, biodiversity benefits and agricultural production and supply chains to achieve net-zero environmental impacts while achieving food and water security and meeting climate goals (Miralles-Wilhelm, 2021).

Multiple global frameworks and policy initiatives including the UN Framework Convention on Climate Change, the Convention on Biological Diversity, and the Sustainable Development Goals all encourage the use of natural or ecosystem approaches to reduce climate change and enhance the environment. Agriculture can use Nature-based Solutions to help with this transition, which turns productive landscapes into environmental solution providers rather than environmental effect drivers. When employed efficiently, NbS can boost agricultural production and resilience, alleviate climate change and improve nature and biodiversity. Agriculture can start using Nature-based Solutions (NbS) to reduce environmental impacts and, in certain situations, boost agricultural productivity. However, in order to fully utilize Ag-NbS's potential to have a beneficial impact on these issues, new funding models that are commensurate with the magnitude of the opportunity are required (Hallstein and Iseman, 2021). Advancing implementation of NbS for climate and conservation purposes needs to emphasize gains in agricultural production and socioeconomic benefits to food producers (Miralles-Wilhelm, 2021).

A key challenge for applying NbS as an umbrella concept is its vagueness concerning which interventions in landscapes would qualify as NbS, and which actions would not. A more precise definition of NBS is needed, particularly for use in scientific and planning settings, in order to provide structure and comparability between studies (Albert et al., 2019). According to recent study, there are three requirements for putting these solutions into action, all of which will increase the concept's importance in improving policy on well-defined societal challenges: (i) nature-based solutions must benefit society, the economy and nature at the same time; ii) the term should be understood as a transdisciplinary umbrella that encompasses experience from existing concepts such as 'blue–green infrastructure' in engineering, 'natural capital' and 'ecosystem services' in economics, and 'landscape functions' in environmental planning; and iii) a nature-based solution must be implemented gradually to allow time for adaptation (Albert, Spangenberg and Schröter, 2017).

Though many nature-based solution attempts in Europe have been urban-centric (Nesshöver et al., 2016), the underlying sustainable intensification concepts have a wide range of applications. Smallholder farming systems in rural Africa, where land availability and fertilizer supply are generally restricted, may benefit from the sustainable cropping methods and synergistic crop selections promoted by nature-based solutions. As arable, fertile land becomes scarcer and population growth drives up demand for goods, proactive solutions for enhanced and sustainable production must be addressed (Peter et al., 2017).

7. Discussion and way forward

A wider concept of marginality was assessed to understand the characteristics and dimensions of marginality in a broader context. A major body of the literature on marginality in consensus concludes that marginality is a complex and multidimensional phenomenon driven by multiple interlinked factors. Subsequently, the paper attempts to present a working definition for agricultural marginality. Considering the most relevant dimensions pertinent to agricultural marginality, biophysical constraints coupled with socioeconomic limitations in a given context were identified as the main drivers pushing agricultural. societies towards marginalization. We have also discussed the temporary and dynamic nature of marginality and the potential to overcome observed marginality with targeted support and forward-looking polices.

From the extensive review of literature on marginality, we find that globally marginal lands make up about 21 percent (2.74 billion ha) of the total land resources (13.5 billion ha). However, about 1,558 million ha of the total land resource is used for agriculture, out of which about 224 to 300 million ha is classified as agriculturally marginal areas. From a demographic perspective, nearly 1.75 Billion people worldwide (equivalent to 38 percent of the rural populations) live on remote less favoured and marginal agricultural and nearly 1.6 (out of 1.75) billion people are inhabiting in marginal areas based in developing countries. From a socioeconomic perspective, hunger, food insecurity and poverty remain predominately rural. About 10 percent of the world's population or 734 million people living on less than USD 1.90 a day (2015 est.) and more than 820 million people (11 percent of the global population) remain undernourished, majority of whom are based in marginal areas in the low-income countries. With 27 percent and 11 percent of the total land area, the major marginality hotspots are identified in South Asia and Sub-Saharan Africa, respectively. In 1 percent Sub-Sahara 5 dimensions of marginality overlap. Ideally, areas categorized as extremely marginal should be prioritized for future research and development followed by other areas that are moderately marginal to be able to effectively contribute to archiving achieving SDG 1 and 2 goals.

The agricultural productivity potential under marginal environments is undermined by various biophysical constraints including extreme weather events, drought and land and resource degradation. Some 40 percent of the world's arable land is likely degraded effecting nearly 1.3 billion people, with a significant concentration of the affected populations inhabiting under marginal conditions. Salinization stands out as a major element in the land degradation phenomenon; today around 1.12 billion ha of agricultural lands are affected by salt alone.

Despite the substantial drop in poverty incidence worldwide, the progress in achieving the overarching goal of poverty remains largely uneven; while most favoured areas significantly benefited from the technological progress, the rural poor, especially those in marginal areas benefited the least, consequently, in some regions the number of poor have even increased. A large body of the recent literature documents that typology of poverty is explicitly linked to environment, with marginal areas representing the highest concentration of extreme poor.

While agriculture is strategically the backbone of the economies in these marginal areas, the productivity of agriculture is undermined by several biophysical and socioeconomic constraints, making marginal lands more fragile and different for policymakers to make successful investments. However, the negative consequences of marginality can serve as the starting point of innovations and potential for change. In fact, numerous empirical research studies have corroborated competitive economic returns on investments in parts of India and China.

In spite of the economic hardships facing agricultural producers in marginal lands, a growing body of research in consensus have advocated that the expected future gains in food productivity in marginal areas are critical because it is unlikely that increased productivity in high potential favoured environments alone will be adequate to meet projected growth in demand in the coming decades. In addition, for the world to successfully eliminate hunger and poverty, marginal environments offer the best avenue (if not the only) to target extreme poverty, as marginal areas are home to the world's majority of extreme poor. Though development and investments in the high potential agriculture areas to some extent benefited marginal poor in some regions but failed to contribute to the SDGs hunger and poverty goals in major regional marginal hotspots. This line of thinking increasingly recognizes the strategical importance of investing in marginal lands.

It is in this spirit that marginal lands have increasingly attracted more research and policy interest in the hunt for a shift in developmental paradigm aiming to feed the world as well as to build resilience to adverse climate effects. It has been established throughout this review that marginality and poverty are complex and multidimensional phenomena driven by multiple interlinked factors. A renewed policy outlook recognizing the developmental potential and environmental dimensions is therefore necessary to transform agriculture in such constrained areas to unfold the multifaceted dimensions of the persistent and chronic poverty.

Innovative policies need to be different in focus and target. A holistic and all-inclusive policy approach is needed to advocate for a collective action engaging research institutions, policymakers, farmers and consumers and other stakeholders to unlock the untapped potential of the marginal farms where production is not yet cost-effective or economically viable due to environmental constraints or inefficiencies that could be managed if suitable technologies and appropriate policies are in place. Deploying policy instruments targeting individual aspects of farming in isolation entails "leaving too many loose ends" and therefore is less likely to achieve the strategic developmental goals, hence an all-inclusive, integrated and participatory policy approach is indispensable to engage all parties to align synergies and join forces in targeting productivity enhancement of marginal lands, whilst improving the fragile resource base in the face of severe climate change.

Agricultural and other public investments should be prioritized geographically in accordance with the characteristics of the marginality hotspots. As a starting point in future polices and research engagement, recognizing and identification of the global marginality hotspots is fundamental in guiding and formulating or reforming future development policies. The diverse and heterogenous conditions typical of marginal areas may well represent a comparative advantage that could be utilized to the benefit of extreme poor as well as broader societies if proper investments are made and supportive policies are in place. Hence, major breakthroughs in productivity-enhancing agricultural technologies are central in targeted and context-specific policies to reverse resource degradation and put marginal lands into an optimal use. For instance, research for marginal areas must focus on promoting biosaline agriculture through suitable salinity-resistant crop varieties to enhance productivities in areas where marginality is driven primarily by salinity.

Given the growing threat posed by climate change, investment in marginal environments where climate change is expected to have amplified impact on the livelihood of the poor, may offer a practical way out of poverty without having to degrade further resources due to overexploitation of currently limited agricultural areas. The research on marginal areas recognizes the potential of marginal lands for restoring agricultural lands, water resources and carbon sequestration. Carbon sequestration in degraded soils, particularly drylands in marginal areas is increasingly promoted as a potential win–win strategy to mitigate atmospheric greenhouse gas concentrations and enhance biomass production. Future policies therefore must pursue and encourage transformation of agriculture practices towards building low-carbon agricultural economies. Low carbon agriculture holds significant climate change mitigation potential and offers opportunity to deliver simultaneously on building agricultural resilience to climate change through reductions of GHG emissions and enhancement of sequestration and boosting food production to meet the global food security goals.

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This paper presents the potential of marginal lands for food security and poverty reduction through sustainable and regenerative agriculture. It presents the outcome of a systematic review on the multidimensional and complex nature of marginality and the factors that drive or characterize marginality in the broader context. The aim of the paper is to draw a working definition for agricultural environments that are considered as marginal in the context of a given agricultural economy and use it to identify the extent of global and regional marginal areas and its hotspots. Moreover, the paper attempts to explore the combinations of underlying causes of agricultural marginality and proximate factors that correlate with marginality as well as opportunities and barriers faced by the rural poor living on marginal lands.

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