Farmland geology – an emerging field in sustainability science

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We now live in a human-dominated earth although it is a designer home for all forms of life. This is against the principle of democracy if we consider the population of carbon atoms in different species. Growth in terms of both greed and the number of human population, because of technological revolution, has taken place to the extent that we (some at least) wonder if we are consuming our own habitat, i.e. life-support systems of the earth. There is a general concern among well-informed earth scientists today on the problem of maintenance of natural carbon balances, stabilization of ground-water-table and conservation of soils, i.e. air, water and food – the basic needs of life. In industrialized countries there is an increasing awareness to include environmental issues in models of their own development through economic growth. Such genuine concerns, however localized they may be, are still lacking in poor countries (economically). It is altogether a different matter if development should include environment or environment should decide the scope of development, i.e. should the needs decide the means or should the means decide the needs? Some of us seem to believe that through development even the population growth can be arrested (well-to-do have small family-size!). The realities, however, are: (1) the present global population is ~ 6 billions and is growing, (2) there is increasing disparity in the distribution of benefits of development among the global population, and (3) environmental and social problems are also increasing. One such major problem is feeding the growing and greedy human population, i.e. food security. We do not have a humane answer for a cynic who could argue that because food security and population growth are connected by positive feedback processes, ensuring food security may not actually solve the problem.

Table 1 shows the present level of food grain production in India and in the world as well as projected levels by 2020. It has been estimated that with the prevailing farming practices the topsoil loss from farmland is on average 5–10 times the food production, the higher side for poor countries like India. From the presently cultivated cropland (1.5 billion hectares, worldwide) and assuming that 15 cm of organic-rich soil is useful for food production, an estimated 2.2×10^{18} g of soil is available for grain production. Data on sediment yield from cropland (32 tons/ha/year) and on soil formation (1 ton/ha/year) suggest a net soil loss of $\sim 4.3 \times 10^{16}$ g/year. We also calculate that food production alone accounts for only 25% of the soil loss (1.1×10^{16} g/year) and a very large part of the soil loss is due to construction and urbanization activities. The available topsoil with the present level of human activities and consumption may last only for a few decades to a century at the most. The impact of genetically modified organisms (GMO) on this soil erosion is not known. It is clear that the present land use density on a global scale made the topsoil in farmland a non-renewable earth resource just as mineral-fossil fuel ground-water resources. What will be left for the future generations other than the heavenly human ingenuity, is anybody's guess.

It is important to mention here that soil formation is a positive feedback process, i.e. the product of the process accelerates the production of the product. Therefore soils have to be kept in place to make more of them. The estimated rate of soil loss from farmland has a disastrous consequence for food production. Further, each harvesting removes the plant nutrients from the soils. In a self-sustaining small ecosystem these plant nutrients are essentially recycled back into the soil. However, urbanization of human population and globalization of markets cause permanent loss of nutrients from cropland. The only way of recycling the plant nutrients to any particular soil may not be acceptable to civilized people! Thus initial degradation and eventual loss of farmland soils have become a major threat to our food security and therefore for concern of well-informed people. For homeostatic and sustainable farming it is imperative to develop a sound scientific understanding of how inherently fertile soils in the farmlands were formed and how their fertility has been maintained after several millennia of farming.

It is well known that the world's farmlands are located in floodplains and deltas of major rivers and in areas of accumulation of loess which are wind-deposited sediments. Chesworth[1] had suggested that these farmlands were formed by Cenozoic geological processes such as tectonism, volcanism, glaciation and denudation. How these surface and subsurface earth processes created and sustained world's farmland remain largely yet unknown. In view of the threat to our food security, there is an urgent need to study these geological processes. It is even better known that river valleys are regions where human civilizations started, evolved, bloomed and occasionally perished also for various natural and anthropogenic reasons. Farmlands along river valleys were possibly made from original forestlands. Invariably the earth materials of these farmlands are water-borne sediments and or wind-reworked river sediments. The

Table 1. World's soil loss scenario

	India		World	
	Present	2020	Present	2020
Population	$\sim 10^9$	1.35×10^9	6×10^9	8×10^9
Food production (FP)	$\sim 220 \times 10^6$ t/yr	360×10^6 t/yr	1.9×10^9 t/yr	3.6×10^9 t/yr
Soil loss	7–10 t/t of FP		5 t/t of FP	–
Soil loss due to food production	1.8×10^9 t/yr		9.5×10^9 t/yr $\sim 1 \times 10^{16}$ g/yr	(20 to 25% of 6)
Estimated top soil (15 cm)	$\sim 2.85 \times 10^{17}$ g		2.2×10^{18} g	–
Estimated soil loss	$\sim 6.0 \times 10^{15}$ g/yr		4.4×10^{16} g/yr	–

Farmland soils are theoretically available for 50 more years and have become a non-renewable resource (a declining capital) by the present patterns and level of food grain production and Economic Growth (development). (Data sources: refs 3–5).

texture, mineralogy and geochemistry of these sediments and their geomorphic disposition, and the prevailing climate of the region, all together in a synergistic manner, contributed to the suitability of the land for farming as well as to the fertility status of the sediments. It is noted that 12 out of 16 elements present in plants such as Ca, Mg, K, Na, Mn, Zn, P, S, Mo, B, and Cl come from weathering of crustal rocks which are also sources of farmland sediments. In geochemical terms, inherent fertility refers to the presence of nutrient elements hosting/holding minerals in rocks and sediments and their bioavailability by controlled weathering processes. In general, rock weathering involves physical disintegration and chemical decomposition of rock-forming minerals with accompanying loss of soluble elements (therefore, bioavailable) through flowing water and precipitation of insoluble oxides – oxyhydroxides and hydrous aluminosilicates, collectively known as clay minerals. The higher the degree of weathering the greater would be the loss of soluble elements and a general weathering trend for exposed crustal rocks is shown in Figure 1. The residual clay minerals also change in internal structures that can no longer accommodate nutrient cations, i.e. losing their base exchange capacity. Therefore, neither the residual clayey soils nor the sediments derived therefrom and deposited by rivers has the capacity to hold or host soluble nutrient elements. It follows that soils/sediments to be inherently fertile they should not have been subjected to intense chemical weathering as happens in regions of extensive rainfall such as, for example, Sahyadri mountains. Also, a good agricultural soil is required to have loamy texture with only < 20% clay and silt : sand ratio of ≤ 1. It is difficult to derive such loamy textured soils from extensively weathered terrain. Thus both physical and chemical aspects of farmland sediments require only a limited degree of chemical weathering of rocks. There is no such constraint for physical disintegration of rocks. These two aspects are simultaneously accomplished in river catchment regions that are subjected to tectonic uplift (as in the Himalayas and Western Ghats) or glaciation (again Himalayas) in geologically recent times. A possible landscape evolution scenario in a recently uplifted terrain is shown in Figure 2, where initial rapid uplift results in limited chemical weathering and enormous physical erosion of mass-wasted earth materials which were deposited by rivers to build their floodplains and deltas. When the orographic effect becomes significant, precipitation increases, leading to profuse vegetation and ecological maximum (biological hotspots[2]) in uplifted regions. The presence of a forest ecosystem in the upland catchment region results in significantly reduced sediment supply to rivers; the same vegetative cover promotes extensive and deep chemical weathering providing nutrient-rich waters (I call it geofertilizers) to rivers. Thus tectonic processes initially created the farmland by supplying large quantities of sediments to build up the river floodplains and deltas and sustained farming subsequently by providing nutrient-laden river water (true to the term Mother-Earth or Ma-Bhumi!). In this scenario, though very tentative, the upland regions are the nutrient factories employing the silent majority (microbes) and the lowlands are the food-grain factories where 'civilized'

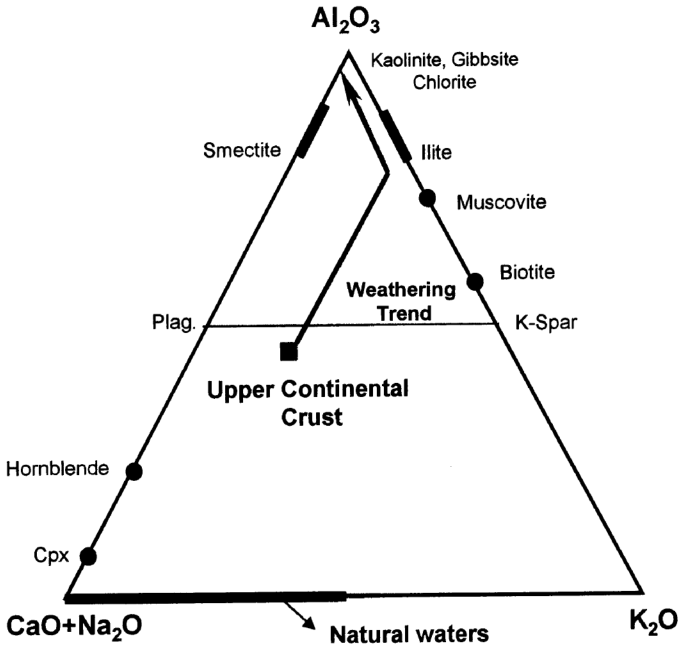

Figure 1. A generalized chemical weathering trend for average upper crustal rocks (ref. 6).

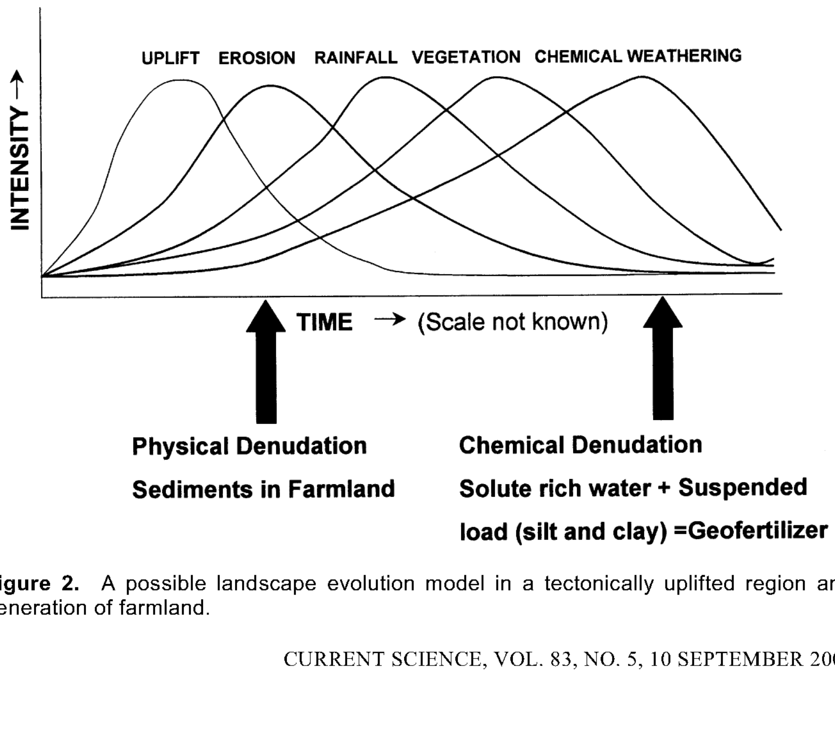

Figure 2. A possible landscape evolution model in a tectonically uplifted region and generation of farmland.

life forms have evolved. This interconnectedness also implies that geology not only determine the locus of civilization but also provides for only agroforestry methods of food grain production on a regional scale in a river basin. The complex interconnections among geologic, hydrologic, climatic and ecological processes need to be studied in detail as this knowledge is essential for better policy options of land and water uses and ensuring food security. This emerging field of research, I call Farmland Geology, is an important area of sustainability science.

The subject, applied geology, has been taught at the Master's degree level in many academic institutions to train manpower in the exploration of minerals, fossil-fuels and of groundwater. These earth materials have been the driving capital in the productive sector of world's economy. Economic development based on raw materials was initially responsible for industrial revolution, followed by agricultural revolution, which together led to human population growth and degradation of earth's life-supporting environment. One area of major global concern today is land degradation, soil erosion and, therefore, food security. The earth science community need to develop the science of Farmland Geology as this knowledge would save their own species, if not the entire mankind, from extinction.

1. Chesworth, W., *Geosci. Canada*, 1982, **9**, 54–61.
2. Kathuria, S. and Ganeshaiah, K. N., *Curr. Sci.*, 2002, **81**, 76–81.
3. Food and Agriculture Organization (FAO), Message of the International fertilizer association to the FAO World Food Summit, November 1996, pp. 1–9.
4. Daniel, R. R., *Curr. Sci.*, 2000, **79**, 1051–1053.
5. Raitan, P. H. and Raitan, E. H., *Proc. Indian Acad. Sci.* (*Earth Planet. Sci.*), 2002, **110**, 269–285.
6. Nesbitt, H. W. and Young, G. M., *J. Geol.*, 1989, **97**, 129–147.

ACKNOWLEDGEMENTS. Discussions with Jayant K. Tripathi, Pramod Singh, Anupam Sharma and G. Krishna Prasad helped in refining ideas presented here. Prof. K. S. Valdiya is thanked for encouraging me to publish this article after hearing my formal talk on this aspect of Geosciences.

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FROM THE ARCHIVES

[Vol. VIII] October 1939 [No. 10]

The Mettur Dam fisheries

The Cauvery Irrigation System dates from time immemorial. Improvements to the system under the British rule date from 1801 when the *East India Company* took over the Tanjore District: reforms on modern lines may be stated to have commenced from 1836 when Sir Arthur Cotton, the father of most of the irrigation systems of South India, built the upper anicut. Further improvements followed which rendered the distribution of water when available in the river complete. But there still remained the problem of fluctuating supplies and long periods of drought. The solution was a storage reservoir and the Stanley Reservoir was finally decided on in 1910. The construction of the Mettur Dam, the second largest in the world, was commenced in 1925 and completed in 1934. The lake comprises a thirty-three mile length of the river and has an area of sixty square miles. It holds 93,500 million cft of water and is expected to irrigate no less than 1,352,000 acres.

Unfortunately the effect of the Dam on the fisheries of the river below was disastrous. The number of valuable Indian Shad or Hilsa, the most important sea-fish ascending the Cauvery for breeding purposes, has seriously declined as the high floods which enabled them to ascend the river no longer occur. The heavy scores and the consequent deep pools all along the river caused by natural floods are gradually disappearing and the breeding fish of all kinds which sheltered in them are gradually decreasing in number. The serious decline of the fisheries of the Cauvery will be evident from the fact that the fishery rentals of the river below the Dam in the Salem, Coimbatore, Trichinopoly, Tanjore and South Arcot Districts which used to amount to over 80,000 rupees annually has steadily declined since the formation of the Dam to about 42,900 rupees. When these fisheries which used to be under the control of the respective District Boards were taken over by the Fisheries Department for scientific organization and development two decades ago, the average annual rentals used to be only about Rs. 41,000 which was paid as compensation every year to the five District Boards concerned. . . .

If the problems of development necessitated by the formation of the Reservoir are complex and difficult, equally so are those of judicious exploitation. From time immemorial our inland fishermen have never fished deep and perennial lakes. Their methods and implements are poor and suited only for fishing shallow or transient waters, especially when the rivers and tanks dry up in the hot weather. If a lake with a capacity of 93,500 million cubic feet and a depth of 165 feet is to be fished to maximum advantage, all known methods of fishing deep waters have to be introduced by the Department by demonstration and the nets perhaps even supplied by subvention. It is hoped that the Co-operative Society which has just been formed will form the nucleus of a scientifically organized agency for the fishing and marketing of the produce of the lake.

To prevent the advent of large capitalists who are apt to monopolise the profits to the detriment of the actual workers, it has been decided to license coracles and tackle and not to auction the fishery.

The system of licensing will, it is hoped, enable a closer control of these new and great fisheries in the early years, help the Department in educating the fishermen individually and through the medium of Co-operative Societies in improved methods of fishing and wean them from the clutches of middlemen. . . .

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