THE OHIO STATE UNIVERSITY

The Food-Energy-Water-Waste Nexus in India

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POPULATION OF INDIA

Year	Population (10^6)
1800	255
1850	283
1900	295
1950	350
2000	1014
2010	1170
2020	1304
2030	1432
2040	1630
2050	1706
2100	1660

Populstat (2003); UN (2015)

URBANIZATION IN INDIA

	Population (10^6)		
City	1950	2025	Growth Factor
New Delhi	1.4	28.6	20.4
Calcutta	4.5	20.1	4.5
Bombay	2.9	25.8	8.9
Pune	0.6	6.6	11.0
Hyderabad	1.1	8.9	8.1
Bangalore	0.7	9.5	13.6
Madras	1.5	9.6	6.4
% of population living in cities of > 1 million	3.1	15.6	5.0

(Adapted from Kazmin, 2011)

SOIL DEGRADATION IN INDIA

Type	Land Area (10^6 ha)
Water erosion	93.7
Wind erosion	9.5
Water logging	14.3
Salinity/Alkalinity	5.9
Soil acidity	16.0
Complex problems	7.4
Total	**146.8**

Bhattacharyya et al. (2015)

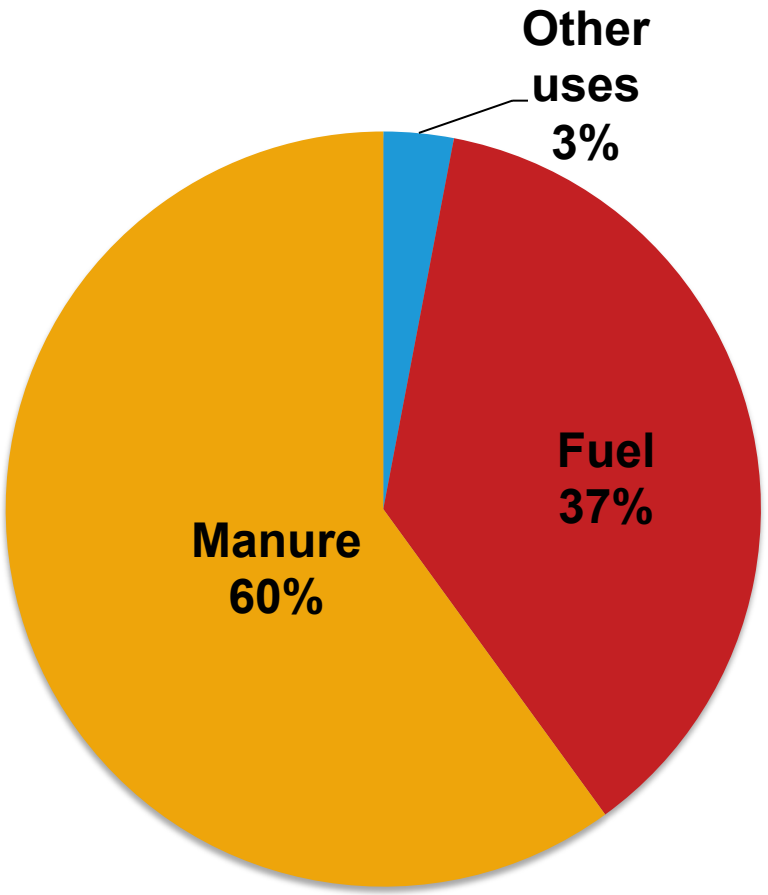
LIVESTOCK IN INDIA (2014)

Livestock	Millions
Cattle	187
Buffalo	110
Goats	133
Sheep	63
Pigs	10
Horses	0.63
Camels	0.38
Total	**504**

FAOSTAT (2016)

ANIMAL DUNG IN INDIA

- Livestock = 504 million (2003)
- Total dung production = 681 million tons
- The use of firewood and dung cakes increased from 75% in2004/05 to 78% in 2007/08



Dikshit and Birthal (2010), Lohan et al. (2015)

Cow dung drying

COMPOSITION OF FRESH CATTLE DUNG

Biomass	(g/kg)					
	C	N	Fe	Mn	Zn	Cu
Dung	390	21.1	1.8	0.5	0.2	0.03
Gliricidia	414	27.6	1.0	0.14	0.06	0.014
Sunflower stalk	404	7.0	1.4	0.31	0.06	0.016

Sharma et al. (2017)

BIOGAS PLANTS IN INDIA

Year	Biogas Plants (10^6)
1990	1.24
1995	2.19
2002	3.37
2008	4.13
2010	4.25
2012	4.55

Lohan et al. (2015)

THE FOOD DILEMMA IN INDIA

HUNGER IN A TIME OF PLENTY

I. According to the Global Hunger Index, India ranks 55 out of the world's 120 hungriest countries.

II. Despite self-sufficiency in food availability and being one the world's largest grain producers, about 25% of the total population in India is food insecure. Thus, India has more food-insecure population this all of Africa.

III. Both GDP and food grain production have risen faster than the growth in population over the last 50 years.

IV. Yet, malnutrition remains to be a serious problem in India.

   i. 46% children are malnourished, and >50% of women are anemic.
   ii. Number of poor in India is 78 million in urban areas and 236 million in rural areas.

The health of soil, plants, animals, people and ecosystems is one and indivisible.

PREVALENCE OF UNDER-NOURISHMENT IN INDIA

Year	Millions	% of Total Population
1990-1992	210	23.7
2000-2002	186	17.5
2005-2007	234	20.5
2010-2012	190	15.6
2014-2016	195	15.2

FAO (2015)

ANNUAL PRODUCTION AND UTILIZATION OF GRAINS IN INDIA

Crop	Total Production (10^6 Mg)	Utilization (%)	Surplus (10^6 Mg/yr)
Chickpeas	6.9	50-80	1.5
Cotton	41.5	31-46	21.1
Groundnut	19.6	41-84	3.4
Maize	36.1	64-80	7.6
Mustard	16.4	5-56	7.0
Paddy	168.5	35-80	41.7
Pearl Millet	14.6	53-84	3.2
Pigeon Peas	10.8	50-84	2.0
Sorghum	18.3	52-88	3.8
Soybean	13.7	52-67	3.8
Sugarcane	131.7	55-90	41.8
Tapioca	4.4	30	1.2
Wheat	147.1	55-80	31.0
Total	629.6		169.1

25-40 (34)%

Hilodhari (2014); Cordeon et al., (2015a,b)

ANNUAL POST-HARVEST LOSSES OF FOOD

Grains	% Lost	Amount (10^6Mg)
Chickpeas	7	0.42
Groundnut	10	0.71
Maize	10	1.8
Paddy	5-15	9.4
Pearl Millet	11-15	0.95
Pigeon Peas	8.5	0.23
Sorghum	7.5-15	0.84
Soybeans	10	0.97
Wheat	8-25	16.4
Total		31.7

Cardoen et al. (2015b)

ANNUAL POST-HARVEST LOSES FRUITS AND VEGETABLES IN INDIA

Crop	% Lost	Amount (10^6Mg)
Banana	20-30	5.6
Cabbage	20-30	2.6
Eggplant	10	1.2
Mango	25-40	4.3
Onion	10	0.7
Potato	8.5	0.23
Sugarcane	10	32.8
Tapioca	15	1.3
Tomato	20-30	2.5
Total		51.2

Cardoen et al. (2015b)

TOTAL CROP RESIDUES PRODUCED IN INDIA

Crops	Residues (10^6 Mg/yr)
Cereal	362
Fiber	122
Oilseed	29
Sugarcane	108
Total	621

Jain et al. (2010)

BIOMASS GENERATION IN INDIA

Waste	Amount
Bagasse	74-90
Rice husk	20-30
Rice straw	140-154
Wheat straw	120-131
Maize	35-40
Sorghum	15-20
Millet	20-25
Total	424-490

Hilodhari et al. (2014),
Cordeon et al. (2015a,b),
Pode (2016),
Pappu et al. (2007)

NUTRIENT CONCENTRATION IN CROP RESIDUES

Crop	Component	Concentration (%)				
		C	N	P	K	S
Groundnut	Shell	33.9	1.1	-	-	0.12
Maize	Stover	16.9	0.56	0.10	1.50	0.04
Maize	Cobs	41.4	0.14	-	-	0.01
Paddy	Straw	36.0	.70	0.09	1.48	0.10
Paddy	Husk	36.4	0.59	-	-	0.02
Soybean	Husk	43.1	0.80	0.21	-	-
Sugarcane	Bagasse	48.6	0.16	-	0.85	0.04
Sugarcane	Pressmud	30.4	2.0	1.3	-	2.5
Wheat	Straw	44.9	0.44	0.06	1.17	0.16

Cardoen et al. (2015a)

THE WASTE GENERATED IN MUMBAI

Total = 11×10^3 Mg/day
= 4×10^6 Mg/yr = 4 Tg/yr

- Population of Mumbai = 21.7 million
- Per capita solid waste = 0.51 kg/person.day

Waste Generation in the U.S.A. in 2013

Total waste = 230.4 Tg of trash
Recycled and composted = 78.9 Tg (34.3%)
Per capita waste = 2.0 kg/ha.day

USEPA (2015)

MUNICIPAL SOLID WASTE GENERATION IN INDIA

City	kg/person/day
Chandigarh	0.40 (57)
Coimbatore	1.57 (50)
Amritsar	0.45 (65)
Agra	0.51 (46)
Mumbai	0.40 (52)
Bangalore	0.39 (52)
Chennai	0.62 (41)
Delhi	0.57 (54)
Imphal	0.19 (60)
Kochi	1.67 (57)
Hyderabad	0.57 (54)

(% compostable)

Gupta et al. (2015)

COMPOSTING FOR SOLID WASTE MANAGEMENT

- India generated 50 million Mg of municipal solid waste/yr in 2000. Over 50% remained uncollected.
- Over 90% of the collected waste are taken to landfills or unregulated dumping grounds.
- However, biodegradable solid waste can be composited
- **The self-heating biological conversion can produce compost, substrate for mushroom cultivation, and biogas (methane).**

Srivastava et al. (2016), Sarkar et al. (2016), Bhattacharyya et al. (2007), Zurbrügg et al. (2004), Saha et al. (2010), Gupta et al. (2015)

ENERGY VALUE OF CROP RESIDUES

Residue	Component	MJ/kg
Rice	Straw/husk	15.5
Wheat	Stalk	17.2
Millet	Stalk	18.2
Sorghum	Stalk	18.2
Sugarcane	Bagassa	20.0
Cotton	Stalk	19.7

18.1 MJ/kg

Hilodhari et al. (2014)

RICE RESIDUE IN INDIA (10^6 Mg)

Production	2010	2014
Paddy	144	155
Rice Husk	59	31
Rice Ash	5.7	6.1

Pode (2016)

RICE HUSK ASH (RHA) FOR PURIFYING DRINKING WATER

- India produces 122 million tons of rice per year, and has 125,000 rice mills.
- For every ton of paddy processed, an average mill produces 230 kg of rice husk and 40 kg of RHA (14-20% by weight of husk)
- Thus, total amount of rice husk produced in India is 24-27 million tons and 4.5 million tons of RHA.
- Some RHA is used in industries (e.g., steel, cement and refractory bricks, the remaining is dumped on open land).

Chandrashekhar et al. (2006), Malhotra et al. (2012)

PROPERTIES OF RHA

RHA is useful for:

- Wastewater treatment,
- Thermal insulation,
- Mortars and concrete, and
- Soil amelioration of sandy soils

1. Surface area of 35-55 m^2/g, low ρ_b, poor flow characteristics, low ash melting point.
2. Mesoporous structure composed of an intricate network of Si and C.
3. RHA contains 63-98% Si and 3-6.5%C, and traces of K_2O, Na_2O, CaO, MgO, Fe_2O_3
4. Si in RHA has a negative surface charge, and is an ideal absorbant of heavy metals (Cd, Ni, Zn, As)
5. C in RHA as a positive charge and can absorb F and phenols.
6. Embeddding nan-silver particles in RHA can completely inactivate E. Coli

Malhotra et al. (2012); Natrajan et al. (1998); Chandrashekhar et al. (2003)

OTHER USES OF RICE HUSK

Industrial Uses	Reference
1. Cement production (reactive Pozzolanas)	Sharma (2014), Nair et al. (2006), Laskar and Talukdar (2008)
2. Ethanol biofuel[a]	Abbas and Ansumali (2010), Raj et al. (2015)
3. Energy potential: heating value 15 MJ/kg by combustion and gasification for electricity generation (Rs 2-7 kwh)	Nataraja, et al. (1998), Buragohain et al. (2010), Kapur er al. (1996), Pode (2016), Chauhan (2010), Bhattacharyya (2014),
4. Reactive Silica: silica gels, silicon chip, activated silica and C, light weight construction materials and insulation, catalysts, zeolites, ingredients for Li ion batteries, graphene, capacitors, pharmaceuticals, value-added silica-based materials	Chandrashekhar et al. (2005; 2006), Pode (2016), Umeda et al. (2007)

[a] Global potential is 20-25 GL/yr

GANDHI'S 7 SINS OF HUMANITY

1. Wealth without work
2. Pleasure without conscience
3. Knowledge without character
4. Commerce without morality
5. Politics without principle
6. Religion without sacrifice
7. Science without humanity

GANDHI'S 7 SINS OF HUMANITY
(CONTINUED...)

8. Technology without wisdom

9. Education without relevance

10. Humanity without conscience

Lal (2013)

SPIRITUAL BELIEFS IN SOIL AND ENVIRONMENT

Judaism	:	The word "homo" (man) is derived from the Latin word "humus" or the decomposed organic matter in soil, which is the essence of all terrestrial life. The Hebrew phrase "Tikkun Olam" means "repairing restoring the world".
Hinduism	:	Human body is made of "Kshiti (soil), Jal (water), Pawak (energy), Gagan (sky/space), Sameera (air)" (Prasna Upanishad)
Sikhism	:	Pau'ṇ gurū pāṇī piṯā māṯā ḏẖaraṯ mahaṯ. Ḏinas rāṯ ḏu è ḏā ī ḏā i ā kẖèlai sagal jagaṯ. (Gurbani)
Buddhism	:	"One should not break even the branch of a tree that has given one shelter" (Petavatthu II, 9, 3)
Christianity	:	The word "Adam" (man) is derived from the Hebrew word "adama" meaning "earth" or "soil"
Greek	:	The daughter of Earth goddess "Gaea" named Themis (goddess of Law), and her descendent Demeter was the goddess of agriculture and fertility
Romans	:	The Earth goddess (Tellus) was related to the goddess of fertility and harvest (Ceres), and named "Mater Terra"
Islam	:	"He created the man of clay like the potters" (Suhrah Al-Rhman, verse 14) "We made from water every living thing" (Quŕan 25:54) "Do not overuse water even if you are on a running river" (Prophet Mohammad)
Khalil Gibran	:	Trees are poems (rubbiat) that earth writes upon the sky. We fell them down and then turned them into paper, so that we may record our emptiness.

Lal (2014)