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Abstract

Intensive farm animal production (IFAP) is being increasingly implemented to meet the rising demand for animal source foods in South Asia. The siting of IFAP facilities in urban or peri-urban areas leads to large proximate animal populations, increasing human exposure to pollutants and pathogens. Improperly managed wastes from IFAP facilities and abattoirs can contaminate water with excess nutrients, pathogens, veterinary pharmaceuticals, antibiotics, heavy metals, and hormones, and can release ammonia, hydrogen sulfide, volatile organic compounds, bioaerosols, and particulate matter into the air compartment. The unregulated nature of IFAP in South Asia creates a risk for zoonotic transmission, including anthrax, brucellosis, *Campylobacter*, *Cryptosporidium*, cysticercosis, *E. coli*, *Giardia*, Highly Pathogenic Avian Influenza, leptospirosis, *Salmonella* and Nipah Virus. Recommendations to mediate adverse human health consequences include improved veterinary care, prohibition of confinement facilities that facilitate pathogen transmission and evolution, prohibition of nontherapeutic use of antibiotics, implementation of proper management of animal wastes, zoning for IFAP and abattoir facilities, and surveillance of slaughtering facilities to limit carcass contamination and reduce the burden of foodborne disease in South Asia.

Introduction

Statistics from the Food and Agriculture Organization of the United Nations (FAO) show that from 1960 to 2000, global meat production tripled, milk production nearly doubled, and egg production nearly quadrupled.¹ The FAO, International Food Policy Research Institute (IFPRI), and International Livestock Research Institute (ILRI) have termed this rapid expansion in the production and demand of animal source foods (ASF) the “Livestock Revolution.” This revolution is being driven primarily by increased ASF demand in developing countries, and from the early 1970s to the mid-1990s meat consumption in these regions rose by 70 million metric tons—nearly three times that of developed countries. The rapid global increase in production to meet this demand has been accomplished largely by an increase in the number of animals, which in turn has led to high concentrations of animals and people, often in urban areas and with little regulation or governmental oversight for livestock production.²

These intensified farm animal production (IFAP) facilities are high throughput farms that house thousands of animals of a single breed for a single purpose, often in indoor and confined conditions,³ and now supply the majority of meat and poultry products to the global market, replacing traditional, small, independently owned and operated farms.⁴ These systems increase production yield and decrease cost by utilizing economies of scale, standardization of processes, and vertical integration.⁵ Globally, IFAP is growing at a rate of 4.3% each year, twice that of mixed-farming systems and over six times that of grazing systems.⁶

While much of the demand for ASF in developing countries is being driven by just a few densely populated countries such as China and Brazil,⁷ South Asian countries are quickly following suit. From 1980 to 2010 in South Asia (Iran, Afghanistan, Pakistan, India, Bangladesh, Bhutan, Nepal, and Sri Lanka), meat production

tripled, egg production increased by a factor of five, and milk production quadrupled.⁸ Because of cultural and religious practices in the region the increase in meat consumption has been slower than would be predicted by income,⁹ and could explain why dairy and egg production has grown more rapidly than meat production. In addition, at least 54% of milk production comes from buffalo, while only 45% comes from cows.¹⁰

The increase in dairy production in India, termed the “White Revolution” and spawned by India’s Operation Flood initiative,¹¹ has led to India becoming the world’s largest producer of milk¹² with Pakistan following their lead.¹³ Because India’s Operation Flood originally supported dairy cooperatives and limited private investment, 70% of India’s milk producers are landless small and marginal farmers whose production comes from only one to two animals.¹⁴ However, policy changes subsequent to the liberalization of dairy markets in 1991 have tended to put small farmer cooperatives at a disadvantage.¹⁵

In contrast, India’s poultry industry has become rapidly industrialized. Today in India the poultry industry is one of the country’s fastest growing sectors,¹⁶ and broiler facilities with less than 5,000 birds are becoming rare. Most broiler and layer facilities house between 10,000 and 50,000 birds.¹⁷

In developed countries, where the effects of IFAP systems have been more extensively studied, the rapid spread of these systems has been known to contribute to significant animal welfare issues, as well as human health concerns for workers and residents of nearby communities.^{18,19} The poor waste management practices, widespread use of pesticides, antibiotics, and the confinement and feeding practices customary to IFAP are responsible for these negative consequences to environmental and public health.^{20,21} Although the adverse health effects related to exposure to IFAP pollutants among workers and nearby communities in developed countries, where the transition to IFAP occurred on a large scale roughly five decades ago^{22,23} have been well-documented, the human health effects of IFAP in developing countries remains largely undocumented, likely because reporting and surveillance in these regions are significantly lower and because the transition to intensified systems is currently less extensive. For this reason, the existing infrastructure of IFAP and its accompanying implications for human health in developed countries must serve as an important model for understanding the effects of intensification in developing countries and for guiding the generation of policies that attenuate these concerns.

In addition to what is already known from developed countries, several factors exist in the developing world that may exacerbate public health risks. IFAP facilities in developing countries tend to site themselves urbanly or peri-urbanly due to minimal technology and/or transportation infrastructure in developing countries,²⁴ thus bringing high concentrations of humans and animals within close contact. As the 2001 report by researchers at IFPRI states:

“Growing concentrations of animals and people in the major cities of developing countries also notably increased the incidence of zoonotic diseases such as infections from *Salmonella*, *E-coli*, and Avian Flu—diseases that can only be controlled through enforcement of zoning and health regulations... Greater intensification of livestock production has caused a build-up of pesticides and antibiotics in the food chain in places of both the developed and developing world. Furthermore, as the consumption of livestock products increases in tropical climates, food safety risks from microbial contamination become more prevalent.”²⁵

Other factors include a lack of regulatory framework or enforcement^{26,27,28} and depletion and pollution of critical water resources.²⁹ As South Asian countries continue to develop livestock systems to meet their growing demands, it is imperative that they utilize the experiences of developed countries to anticipate risks and generate livestock policies that protect human and environmental health.

IFAP Related Exposures

IFAP systems negatively affect public health by exposing the community to pathogens and chemical contaminants through soil, water, and air pollution, as well as through animal source foods themselves. The former two pathways are largely precipitated by the abundant and ever-increasing production of animal wastes.^{30,31} At least 150 enteric pathogens are known to be present in untreated animal wastes, and during the last decade at least one new enteric pathogen has been discovered each year.³² The populations most at risk from environmental contamination are the young, elderly, pregnant, and immunocompromised.³³

Although waste production varies according to species, diet, and age, the United States Environmental Protection Agency (USEPA) has estimated that for each animal unit (1000 pounds of animal) 50-60 pounds of manure are created each day and that a single facility housing 2,500 dairy cows can produce as much waste as a city exceeding 400,000 people.³⁴ In the small country of Bangladesh alone, poultry is estimated to produce 1.5 million metric tons of manure every year.³⁵

As animal production intensifies, it is uncoupled from crop production, with the result that standard nutrient cycles between plants, soil, and animals are severely altered.^{36,37} In developed countries such as the United States, more manure is now produced than can be assimilated by the soil and thus other manure management strategies such as lagoons may be used.^{38,39} In India cattle wastes have traditionally been used for cooking fuels, but this use is on the decline.⁴⁰ India reportedly uses the majority of manure for fertilizer, while only one percent of bovine manure is managed in slurry form and lagoon use remains negligible.^{41,42,43} Manure waste in India is commonly stored on the surface in countryside ditches prior to use as manure.⁴⁴ Bangladesh now reports that more poultry manure is now being produced than can be spread onto the available land.⁴⁵

Regardless of the methods used, both the storage and application of untreated manure as fertilizer has been shown in developed countries such as the U.S. to present a human health hazard as certain nutrients, contaminants, heavy metals, and pathogens can volatilize and become airborne or can leach into water supplies.⁴⁶ It is likely that similar issues may arise in developing countries, as waste management can be a significant hurdle for some developing areas. For example, the city of Karachi, Pakistan produces 6,600 tons of waste per day. Roughly one-third of this waste is not managed and ends up “in drains, water ways or [is] indiscriminately dumped in open spaces in air and water causing environmental pollution.”⁴⁷

Additionally, it is of particular concern that IFAP facilities tend to cluster together, as well as site themselves in urban or peri-urban locations.⁴⁸ Because urban demand for animal source foods tends to precede adequate transport infrastructure in developing countries, IFAP facilities must locate themselves near demand to ensure food safety. This trend can be illustrated by the intensive pig sector of Vietnam, where most feed mills, pig farms, and slaughterhouses can be found within 40 kilometers of the center of Ho Chi Minh City.⁴⁹ In India, roughly 98% of dairy production occurs rurally. However, 75% of egg production and nearly all broiler production occurs in India’s urban areas.⁵⁰ In Nepal at least 11% of the country’s animal source foods are produced in Kathmandu,⁵¹ a city of 990,000 people.⁵²

Because industrial livestock production is detached from the land and concentrated in certain areas, nutrient cycling through the use of manure as fertilizer is no longer occurring, allowing nutrients to accumulate in limited space or be expelled without treatment into waterways.⁵³ The close proximity and high concentration of human and livestock populations, such as that which occurs in urban and peri-urban IFAP in South Asia, creates human health hazards by exacerbating disease transmissions, accelerating pathogen evolution,⁵⁴ and causing serious problems of pollution and surface water contamination.^{55,56}

Globally, livestock intensification is occurring in a “policy and institutional void.”⁵⁷ The inability of regulations and enforcement to keep up with the rapidly changing livestock sector can lead to a significant increase in risk to public health. The rise in human pork tapeworm infection (cysticercosis) in Eastern and Southern Africa that followed the development of swine production highlights the importance of policy and regulation to establishing and protecting public health standards.⁵⁸

Soil Contamination

Manure has traditionally been used as a highly efficient fertilizer. It is not only a rich source of nutrients to replenish soil used for crops, but it also sustains many physical soil properties such as structure and moisture retention, and prevents soil erosion.⁵⁹ However, when soil is subjected to repeated over-applications of manure, as often occurs when storage and weather considerations rather than agronomic interests determine timing and rates of application,⁶⁰ the accumulation of macronutrients such as nitrogen, phosphorous and potassium can exceed the uptake ability of plants leading to leaching and run-off of nutrients and contaminants.⁶¹

Manure can contain a variety of potential contaminants including pathogens, growth hormones, antibiotics, animal blood, copper sulfate,⁶² heavy metals, and chemicals used as additives to the manure or to clean equipment.⁶³ The fundamental consequence stemming from soil pollution is the interaction between the soil compartment with air and water compartments. Once soils become nutrient saturated, nitrates and other compounds can leach into ground or surface waters. In other cases, the complex processes of nitrification, denitrification, and breakdown or transformation of organic matter allows contaminants to volatilize and enter the air compartment.⁶⁴

Contamination and Depletion of Critical Water Resources

Ground and surface water resources are highly susceptible to pollution from IFAP effluent. The contaminants that can be found in water sources contaminated by IFAP effluent are nutrients such as nitrogen, phosphorous, potassium,^{65,66} pathogens,⁶⁷ veterinary pharmaceuticals (including antimicrobials),^{68,69,70} heavy metals,⁷¹ and hormones.^{72,73,74,75} In the U.S., the agricultural sector, including IFAP, is the largest source of contamination in lakes, rivers, and reservoirs,⁷⁶ and in the livestock farming areas of the U.K., nutrient loss and farm effluents are the leading cause of surface and ground water quality degradation.⁷⁷

The presence of coliform bacteria in water indicates that it has been contaminated with either human or animal sewage.⁷⁸ Burkholder et al (1997) detected fecal coliform bacteria, anoxic conditions (low oxygen levels), high ammonium concentrations, and phosphorus as far as 30 kilometers from an IFAP effluent spill.⁷⁹ Improper disposal of animal carcasses and abandoned livestock facilities also have the potential to contribute to the degradation of water quality.⁸⁰ Rainfall can contribute to nutrient losses.⁸¹

According to a 2012 report, South Asia has water sanitization coverage of only 41%,⁸² and water associated diseases contribute to the top ten causes of death in the region.⁸³ Even in India, wastewater treatment plants are decentralized and have no government support.⁸⁴

When present in surface waters, nitrogen and phosphorous contribute to the process of eutrophication.^{85,86,87} Eutrophication can also lead to the proliferation of cyanobacteria,^{88,89} a type of algae that produces microcystins, which are known neuro- and hepatotoxins.⁹⁰

Additionally, nitrates can have direct effects on human health. The World Health Organization (WHO) has set the guideline value for drinking water nitrate concentrations at 50mg/L,⁹¹ although nitrate levels exceeding this limit have been documented in Punjab, south-western Haryana, Rajasthan, and Kashmir, India.^{92,93,94,95} In Rajasthan concentrations of almost 500mg/L, ten times the WHO standard, are not unusual.⁹⁶ Nitrate pollution is projected to be a potential problem for Bangladesh in the future as well.⁹⁷

Non-point-source from fertilizer application and point-sources such as IFAP facilities are two of three main sources of nitrate pollution.⁹⁸ The nitrate safety levels of 50mg/L in drinking water was set as a measure to prevent methemoglobinemia, a potentially fatal condition commonly known as blue baby syndrome.^{99,100,101} Research conducted in India found that while infants were highly susceptible to the disease, under the high nitrate concentrations present in the region, individuals over the age of 18 were also highly likely to develop methemoglobinemia.¹⁰²

Exposure to nitrate concentrations exceeding 50mg/L can also cause increased thyroid gland volume^{103,104} and frequency of subclinical thyroid disorders.¹⁰⁵ The presence of nitrates in drinking water has also been implicated as a potential promoter of insulin-dependent diabetes mellitus (IDDM).¹⁰⁶ Parslow et al (1997) found a correlation between concentrations of at least 15 mg/L and IDDM development.¹⁰⁷ Other studies have found no correlation between low-level nitrate exposure and IDDM development.^{108,109} Further study of concentrations in excess of 25mg/l is warranted.¹¹⁰

The carcinogenic effects of nitrates in drinking water have also been examined. Several epidemiological studies have found little conclusive evidence between cancer and nitrate concentration in drinking water,^{111,112,113,114} however, it is important to note that several of these studies have been conducted in areas where nitrate levels are already low. Zeegers et al (2006), for example, reported an average nitrate concentration of 1.68 mg/L in the region where they conducted their study.¹¹⁵ A 2010 publication by the WHO International Agency for Research on Cancer (IARC) concluded that while the carcinogenic effects of nitrates in the current literature are inconclusive, the studies are limited because of the low levels of nitrates examined and that under certain conditions that alter nitrate metabolism (such as vitamin C deficiency) nitrate ingestion is “probably carcinogenic.”^{116,117} One study conducted on populations consuming water nitrate concentrations upwards of 50mg/L found positive correlations between nitrate concentration and bladder, gastric, and prostate cancers.¹¹⁸

The neural tube defect anencephaly has also been correlated with nitrate concentrations above 45 mg/l.¹¹⁹ Several studies from high nitrate regions of India have also found positive correlations between the presence of high water nitrate concentrations and recurrent stomatitis,¹²⁰ respiratory tract infections,¹²¹ and diarrhea.¹²²

Water can also be a source of pathogens,¹²³ especially in developing countries.¹²⁴ Water that is contaminated with human or animal feces serves as a source of bacteria, viruses, protozoa, and helminthes.¹²⁵ Of these, the diseases most likely to disperse away from IFAP facilities and affect human populations beyond farm-workers include cryptosporidiosis, giardiasis, campylobacteriosis, salmonellosis, colibacillosis, leptospirosis, listeriosis, and yersiniosis.¹²⁶

High concentrations of animals, such as occurs in IFAP facilities, increases the possibility for pathogen spread both within the herd and to other species as well,¹²⁷ and the large amount of waste produced in conjunction with a lack of waste management regulation increases the probability that waste will be improperly managed and introduced to the environment.¹²⁸ Without proper treatment, microorganisms will only be disseminated more readily into the environment during storage, application as fertilizer, or disposal. To prevent bacterial contaminants from entering the drinking water supply, conventional water treatment is needed.¹²⁹ Additionally, protozoan cysts tend to be resistant to standard water filtration,¹³⁰ thus in areas where *Cryptosporidium* or *Giardia* has been documented (such as West Bengal, India^{131,132}), filtration through sand filters should be considered to remove the pathogens.¹³³

One factor that can worsen the human health outcomes of bacterial pathogen contamination is the widespread use of antibiotics in livestock. The use of antibiotics as growth promoters in livestock is in part responsible for the evolution of antibiotic resistant bacterial populations, which can then leach into waterways.¹³⁴ Aquatic ecosystems have been shown to act as reservoirs of antibiotic resistant bacteria and antibiotic resistance genes and can even aid in transmission of antibiotic resistant genes between bacteria.¹³⁵ A 2007 study in Turkey identified fifty-five antibiotic resistant strains of *Escherichia coli* in drinking water,¹³⁶ and Vignesh et al (2012) identified a high frequency of antibiotic resistance in four genera (including *E. coli* and *Salmonella*) due to water contamination off the southern coast of India.¹³⁷ The concern associated with antibiotic resistant strains of bacteria is that conventional antibiotics can no longer be used for treatment.¹³⁸

In arid locations IFAP can place stress on the local water supply through both pollution and the large volume of water usage. Twenty-seven percent of the global water footprint comes from use of water in animal agriculture, while only four percent of the footprint comes from home use of water.¹³⁹ Three thousand five hundred liters of water are required to produce one kilogram of grain fed broiler chicken, and, on average, the production of one

kilogram of animal protein requires 100 times more water than the production of one kilogram of vegetable protein.¹⁴⁰

Water resources in South Asia tend to be unequally distributed in space and time.¹⁴¹ Scarcity and pollution of surface waters in South Asia means that countries rely heavily on ground water sources, which are responsible for up to 80% of the water supply in rural India.¹⁴² However, these groundwater sources are becoming increasingly scarce and water resources are generally mismanaged.¹⁴³ In regions of South Asia such as the Ganges River Basin in India and Bangladesh, where water disputes have already become contentious,¹⁴⁴ further use and pollution of water resources by the developing livestock sector may exacerbate existing water issues.

IFAP contamination of water resources should be a serious consideration for South Asian countries, as exceedingly high nitrate levels and waterborne pathogens have been shown to pose a serious health risk to humans in the region. Additionally, in India and other developing countries, groundwater for agricultural and domestic use is rising and placing these water resources under increasing stress. Drought has been common in much of India over the last decade, especially in areas such as Andhra Pradesh, Karnataka, Maharashtra, Madhya Pradesh, and Rajasthan, and drops in groundwater level and quality have been remarkable.¹⁴⁵ Future policies in the region should aim at conserving both the quantity and quality of water resources.

Airborne Contaminants and Pathogens

A 2012 air quality and human health effects study by Yale University ranked India as having the worst air quality in the world.^{146,147} Following immediately behind India were Bangladesh, Nepal, and Pakistan, respectively.¹⁴⁸ Of the 32 Indian cities monitored by the Indian government's Central Pollution Control Board, 27 cities have particulate matter 10 (PM₁₀) concentrations over four times the WHO's Air Quality Guideline value of 20 µg/m³. The cities of Delhi, Kanpur, and Ludhiana are notably high, with concentrations of 198, 209, and 251 µg/m³, respectively.¹⁴⁹ The WHO estimated in 2008 that globally more than a million deaths could be prevented by meeting Air Quality Guideline values.¹⁵⁰ This overwhelming pollution problem is due, in large part, to the immense population (India alone has a population of over one billion people¹⁵¹) with a growing number of vehicles, a heavy reliance on coal power, a large, urban, brick-making industry, and the burning of biomass.^{152,153} While the contribution of IFAP to air pollution is largely overshadowed by other air pollution sources in South Asia, the effects of the growing industry on air quality should be accounted for in future air quality policy measures.

The decomposition of IFAP wastes such as manure, waste feed, and bedding dust produces air emissions. The generation of these air emissions can be affected by the type of housing in which animals are confined, the type of animals used, waste management systems, and weather conditions. The prominent airborne contaminants produced by IFAP operations include ammonia, nitrous oxide, methane, carbon dioxide, hydrogen sulfide, volatile organic compounds (VOCs), and particulate matter (PM).¹⁵⁴ Of these compounds, nitrous oxide, methane, and carbon dioxide are significant greenhouse gases implicated in global climate change.^{155,156} Animal agriculture alone is responsible for 18% of global greenhouse emissions,¹⁵⁷ thus the production of these gases is not without consequence.

The two most hazardous chemical compounds produced by IFAP are ammonia and hydrogen sulfide. The largest source of ammonia in most regions is from livestock waste management practices.^{158,159,160} Urine and uric acid are major sources of ammonia, but additional ammonia can be produced during microbial decomposition of organic wastes.¹⁶¹ India is one of the largest producers of ammonia in the world, second only to China, producing 1.3 megatonnes annually, while Pakistan and Bangladesh together produce approximately 0.5 megatonnes.¹⁶² Cattle produce the largest proportion of ammonia in India, followed by buffalo.¹⁶³ In the region, the Ganges delta appears to contain the highest concentrations of atmospheric ammonia,¹⁶⁴ and in India, Uttar Pradesh, Madhya Pradesh, and West Bengal have the highest ammonia emissions from livestock.¹⁶⁵

The high solubility of ammonia in water means that it is rapidly absorbed into the human upper airways, potentially damaging the airway epithelium, and is known to act as an eye and respiratory irritant, even at the

typical concentrations found in livestock facilities (less than 100ppm). Exposure to concentrations over 150 ppm can cause scarring of the upper and lower airways. The inflammatory responses to ammonia exposure can lead to reactive airway dysfunction syndrome and persistent airway hyper-responsiveness. Very high concentrations can cause eye and chemical burns, and 500 ppm can be fatal.¹⁶⁶

Hydrogen sulfide is a potentially lethal, colorless gas that in an agricultural setting is produced by the bacterial decomposition of proteins or other organic matter containing sulfur. The most prominent agricultural production of hydrogen sulfide occurs in liquid manure, such as those used in swine and dairy production of developed countries. Much like ammonia, it can act as an eye and respiratory irritant. It can be identified by its rotten egg odor and because it is heavier than air it can accumulate in low-lying areas. When found in concentrations under 10ppm hydrogen sulfide is not harmful; however, if slurries are agitated concentrations can reach as high as 1000 ppm. At concentrations over 150 ppm, hydrogen sulfide may impair sense of smell, limiting detection of the gas. Because it is a chemical asphyxiate, both chronic and acute exposure above 100 ppm can cause loss of consciousness, shock, acute respiratory distress syndrome, pulmonary edema, coma, and death.¹⁶⁷

Volatile organic compounds (VOCs) are produced during bacterial fermentation of IFAP wastes and include compounds such as acetone, benzene, chloroform, formaldehyde, and methanol.¹⁶⁸ Additionally, odiferous compounds are ubiquitous to IFAP, and in developed countries odor has been cited as having multiple negative effects on the quality of life of the surrounding community.^{169,170} According to Schiffman et al (2000) the most common symptoms include eye, nose, and throat irritation, headache, nausea, diarrhea, hoarseness, sore throat, cough, chest tightness, nasal congestion, palpitations, shortness of breath, stress, drowsiness, and alterations in mood.¹⁷¹ These symptoms can be even more persistent in sensitive individuals, such as those with asthma, and may exacerbate existing medical conditions.¹⁷²

Particulate matter (PM) may be composed of animal bedding, fecal matter, litter, feed materials, animal byproducts such as skin cells or feathers, and the products of microbial action on feces and feed, bacteria, fungi, viruses, metals, and hormones.¹⁷³ PM can absorb and contain gases, odorous compounds, and microorganisms.¹⁷⁴ Thorne et al (2009) found that much of the PM observed in and near animal housing was comprised of bioaerosols including bacteria and endotoxins.¹⁷⁵ Levels of PM are typically high in livestock houses, and are particularly high in intensive pig and poultry houses.¹⁷⁶

While it has long been known that livestock farmers exposed to high PM concentrations have a higher prevalence of respiratory diseases,¹⁷⁷ PM can also negatively affect the health of nearby residents when emitted into the environment. PM penetrates deep into the lungs, and can irritate the respiratory tract, reduce respiratory disease resistance, and deliver pathogenic and non-pathogenic microorganisms to the respiratory tract.¹⁷⁸

Bioaerosol PM is recognized as a vector for endotoxins and many microorganisms, including bacteria and fungi.^{179,180,181} Endotoxin, a compound derived from the outer membrane of bacteria such as *Escherichia coli* and *Salmonella* spp,¹⁸² has been found in high concentrations around IFAP areas and is known to cause lung infections and airway related inflammatory responses. Though Gram-negative bacteria may only constitute up to only five percent of the total bacteria in livestock houses, they are of particular concern since the vast majority of the identified Gram-negative bacteria are pathogenic.¹⁸³ When zoonotic pathogens attain airborne transmissibility due to adherence to PM, the health of the nearby community is threatened.^{184,185,186}

Antibiotics are also capable of adhering to and being dispersed by PM.¹⁸⁷ At least one study has identified as many as five different antibiotics in 90% of the study's PM samples from a swine facility,¹⁸⁸ which could contribute to antibiotic resistance and further human health issues.

In developed countries, the air pollution emanating from IFAP facilities has been shown to be a hazard not only to IFAP workers, but also to surrounding communities. In the developing countries of South Asia, where many IFAP facilities exist in urban or peri-urban locations, this can put an even larger number of people at risk. Although there are a number of air quality issues in South Asia that may surpass the emissions from IFAP, disease-causing vectors such as bioaerosols and the growing contribution of ammonia, hydrogen sulfide,

greenhouse gases, and particulate matter from IFAP must be taken into consideration in future air quality policies.

Food-borne Illness

The WHO defines foodborne diseases (FBD) as diseases that are associated with the ingestion of contaminated food.¹⁸⁹ Contamination can encompass not only microbial and parasitic contamination, but chemical contamination as well.¹⁹⁰ The burden of FBD is poorly defined in many developing countries and on a global level.¹⁹¹ However, it is known that animal source foods (ASF) are one of the most prominent vectors of FBD, especially in developing countries where little food safety measures are in place.

One of the less commonly recognized types of FBD is that of chemical contamination of food. In ASF chemical contamination is often the result of animal feed practices, a concern only recently recognized in developed countries. Of primary concern is the bioaccumulation of persistent organic pollutants (POPs) such as dioxins, furans, and polychlorinated bromides (PCBs) in the fat stores of food animals.^{192,193,194}

POPs are widely used as pesticides in agricultural settings and when forage, soils, and feed of food animals is contaminated, these POPs accumulate in the animals' fat stores.^{195,196,197} In some IFAP cases that have been well documented in developed countries such as the United States, animal fat is fed to food animals, thereby allowing POPs to become highly concentrated in food animal fat stores.^{198,199,200} When these animals are used for human consumption, the POPs present in the fat stores can be carcinogenic, toxic to nervous system development in fetuses and young children,²⁰¹ cause immune and endocrine system impairment, and negatively affect reproductive organs.²⁰² In many tropical countries such as India, the pesticide DDT is still used to control malarial insect vectors,²⁰³ and thus this point of entry by DDT into the human diet warrants further investigation.

Additionally, heavy metals are routinely added to animal feed in IFAP facilities.²⁰⁴ A 2013 study of poultry in the United States identified arsenic, an approved animal dietary supplement, in chicken tissues and recommended that this pathway be taken into account when assessing human exposures to arsenic.²⁰⁵ While these exposure pathways are likely of minor importance in developing countries, these studies outline the importance of animal feed components to human public health,²⁰⁶ and should be taken into account as developing countries establish IFAP standards and guidelines.

The more widely recognized class of FBD is that of bacterial, viral, or parasitic contamination of food products. Often, these exposures result in diarrheal disease, causing 3 to 5 billion cases globally and leading to 1.8 million deaths annually. The majority of these deaths are children.²⁰⁷ Diarrheal disease is a leading killer in India, surpassing mortalities from tuberculosis, HIV/AIDS, malaria, and childhood diseases such as pertussis, polio, diphtheria, measles, and tetanus combined.²⁰⁸ Although there are no official statistics for foodborne illness in Bangladesh, it is widely perceived to be a major problem,²⁰⁹ as is likely in nearby countries such as Bhutan, Nepal, and Sri Lanka.

The major source of diarrheal disease is from food and water contamination, although it remains difficult to differentiate between the two sources²¹⁰ as reporting and surveillance are poor in developing countries.²¹¹ Major factors for susceptibility to food-borne infections include age, HIV/AIDS, and malnutrition.²¹² Diarrheal diseases in infants are very common in developing countries and account for a high percentage of mortality and morbidity.²¹³ Emerging foodborne pathogens associated with animal source foods in South Asia include non-typhoidal salmonellosis and other *Salmonella* spp, *Campylobacter*, *Escherichia coli*, *Clostridium perfringens*, and methicillin-resistant *Staphylococcus aureus* (MRSA).²¹⁴ The *E. coli* serotype O157:H7 is of great public health concern, as it can cause bloody diarrhea, hemorrhagic colitis and uremic syndrome, and central nervous system dysfunctions.²¹⁵ Antibiotic resistance has been identified in *E. coli*,²¹⁶ *Salmonella* spp, *Campylobacter*, and *Staphylococcus aureus*.²¹⁷

During the scaling up of dairy operations, the hygienic aspects of milk production are not always adequately considered²¹⁸ and strains of human pathogenic bacteria has been known to originate even from clinically healthy animals.²¹⁹ Microbes can enter milk from subclinical or clinical mastitis, from the farm environment, utensils used during storage, and transport. There are at least 21 known milk-borne diseases.²²⁰

In Karachi, Pakistan, ice cream was the exposure medium for a significant number of typhoid fever (*Salmonella typhi*) cases.²²¹ In India, multiple studies have examined the bacterial colonies present in different types of milk products in different locations throughout India.^{222,223,224,225,226,227} In the Warangal District of India, 28% of raw milk samples were very poor in quality, an additional 27% were just poor in quality, and only 19% were considered good in quality. Pasteurizing milk was found to greatly increase the quality of milk, but still only 82% of the samples tested were considered good quality. *Lactobacilli*, *Staphylococcus aureus*, *E. coli*, *Salmonella typhi*, and fecal coliforms were detected in the contaminated samples.²²⁸

In a study of 60 raw milk samples from Madurai, 90% were found to contain coliforms, 70% contained *E. coli* strains, 65% contained *E. coli* O157:H7, 61.7% contained *Staphylococcus aureus*, and 13% contained *Salmonella* spp.²²⁹ High counts of *E. coli* were found in 6 of 10 raw milk samples in Tarakeswar. *E. coli* was also isolated in 3 out of 10 pasteurized milk samples from the same region.²³⁰ Out of 135 samples of various dairy products in Pantnagar, 14 were found to contain *S. aureus* and 11 contained *E. coli*. The highest rate of contamination was found in “Burfi” while the lowest rate was seen in ice cream. It was also found that 20% of the milk from dairy farms was contaminated, as compared to 7 percent in milk from and for a single household.²³¹

Another study in Tamil Nadu tested 132 samples from dairy related sources such as manure, milk utensils, raw milk, khoa, channa, cream, cheese, and ice cream. They identified 69 *E. coli* isolates, six of which were *E. coli* O157:H7 (found in manure, milk utensils, milk, and ice cream).²³² Researchers examining ice cream in Mumbai, India found contamination with *Staphylococcus aureus* in all samples and significant contamination with *Listeria* and *Yersinia*.²³³ A study in rural and urban southern India on antimicrobial resistance among *E. coli* strains found that 42% of commensal *E. coli* had acquired antibiotic resistance, and that in infecting strains of *E. coli* antimicrobial resistance is likely to be even more common than in commensal *E. coli*.²³⁴

Poultry, poultry meat and eggs also can act as a bacterial vector, particularly in the case of *Salmonella*. The prevalence of *Salmonella* in poultry is particularly troubling in India,^{235,236} given that most poultry IFAP facilities are located in urban areas,²³⁷ putting more people at risk of infection. One study characterizing the serovars present in Indian poultry identified *Salmonella gallinarum*, *pullorum*, *typhimurium*, *enteritidis*, and *worthington*. Of these, *Salmonella gallinarum* and *pullorum* are adapted to avian species and have little health consequences to humans; however, *Salmonella typhimurium* and *enteritidis* are of significant human health concern.²³⁸ *S. worthington*, a unique serovar that has been linked to numerous fatalities in newborn babies,²³⁹ was also isolated.²⁴⁰

A year-long study of eggs and egg cartons in the retail markets of Coimbatore, South India found that 7.7% of the eggs and 7.5% of the trays tested were contaminated with *Salmonella* spp, the majority of which were *S. enteritidis*. A high prevalence of multiple antimicrobial resistance was also identified, suggesting that antimicrobials are commonly used in India’s egg production industry.²⁴¹

Foodborne disease is a serious public health threat for many countries and poses a particular risk to children,²⁴² however, reporting and surveillance of the problem is typically low.²⁴³ In South Asian countries dairy and poultry products are major pathways of disease exposure.^{244,245,246,247} While pasteurization of milk reduces the risk of bacterial contamination, several studies have indicated that bacterial pathogens are present even in pasteurized samples.^{248,249} While there are many recognized foodborne diseases in the region, *Salmonella* and *E. coli* appear to be the best studied. The presence of virulent strains has been documented from various locations,^{250,251,252,253,254,255,256} especially throughout India, and antimicrobial resistant strains are now widespread^{257,258}

Zoonotic Disease Transmission

Zoonoses are diseases that can be transmitted from animals to humans.²⁵⁹ During the period from 1990 to 2000, three out of four emerging pathogens capable of causing human infection originated from animals or animal products.²⁶⁰ While zoonoses can arise in wild populations (such as avian influenza), the transition from traditional farming methods to IFAP is a significant factor in the increase of global disease risk.²⁶¹ All divisions of animal production, including transport, manure handling, veterinary medicine, meat processing, and animal rendering, can contribute to zoonotic disease. Animal crowding, poor hygiene, temperature and ventilation, and animal stress affect the ability of animals to resist disease,²⁶² and the close proximity of thousands of confined animals at IFAP facilities can lead to pathogen evolution through rapid selection and amplification.^{263,264} These pathogens can be transferred to the surrounding community through the previously discussed methods of air emissions, water pollution, consumption of animal products, and direct contact with animals or their wastes, as well as through insect vectors.^{265,266,267} The high concentrations of humans and animals in close proximity that occurs in urban and periurban IFAP in developing countries increases the possibility of transmission of microorganisms between individuals and populations.²⁶⁸

Eighty percent of India's population lives in close contact with animals.²⁶⁹ The rate of antimicrobial resistance (AMR) in human pathogens, as well as multiple-drug resistant bacteria, is of particular concern. The use of antibiotics as growth promoters by the livestock sector has been largely implicated in the observed increase in AMR. In some cases, workers can become colonized with resistant organisms after contact with animals or wastes, and then pass these resistant strains on to the community at large.²⁷⁰ In addition, many areas of the developing world struggle with issues of overcrowding, inadequate infrastructure, poor sanitation and water supply, and poverty, all of which exacerbate disease transmission.²⁷¹

Anthrax

Anthrax is a bacterial disease caused by *Bacillus anthracis*, a Gram-positive, spore-forming bacteria that is primarily a disease of herbivores.²⁷² Animals can become infected by anthrax through several means, but the uptake of spores from the environment is a primary pathway.²⁷³ Spores are generally shed by dying or dead animals and become a major source of infection to other animals, including humans.²⁷⁴ Incidence of the disease is decreasing in many developed countries, but remains a threat in many farming communities of the developing world. Anthrax spores from the carcasses of dead animals can contaminate soil and spores can survive and remain a source of infection for decades.²⁷⁵ Furthermore, humans can contract anthrax through direct contact with infected animals or products.²⁷⁶

Anthrax infection remains a significant problem in southern and eastern India.²⁷⁷ However, incidence of anthrax in India may be fairly isolated events because a large proportion of the population does not consume beef. Ray et al (2009) discusses several anthrax outbreaks that occurred in West Bengal, India in 2007. These outbreaks were isolated to Muslim communities following the slaughtering of cows.²⁷⁸ Vijaikumar et al (2002) discuss an earlier outbreak in southern India that affected 23 people, most of whom were children. Most of the patients in this outbreak reported the death of infected animals in the nearby area. Only one of these cases was fatal.²⁷⁹

Until 2009, anthrax had not been reported in humans in neighboring Bangladesh for 25 years.²⁸⁰ Outbreaks in 2010 were preceded by animal outbreaks and affected 607 people. An investigation of the outbreak indicated that it was caused by slaughter of infected cattle and selling of or eating the meat. Fortunately, this outbreak did not cause human mortality.²⁸¹

Brucellosis

Brucellosis affects some 500,000 people worldwide each year, making it the most common zoonosis in the world.²⁸² It is caused by Gram-negative bacteria that enter the host through inhalation, ingestion, or skin abrasions. Brucellosis may be transmitted from domestic animals through the processing of milk and milk products and certain animal husbandry practices. Individuals and veterinarians that work as or with livestock

producers or in slaughterhouses or packing plants are at particular risk of infection through skin abrasions or inhalation. Although the disease is most common in rural areas with livestock production, the disease can also be transported to urban areas via contaminated dairy products.²⁸³

In India, brucellosis is increasingly a public health and veterinary consideration and has been reported in cattle, buffalo, sheep, goats, pigs, dogs, and humans.^{284,285} There is concern that an increase in intensive dairying will further exacerbate the disease transmission, as commercialization of the sector has led to an increase in transport of animals, which in turn disseminates the disease over a wider area.²⁸⁶ An outbreak of brucellosis was profiled in a dairy farm housing 290 cows in Himachal Pradesh, India, in 2003.²⁸⁷ Slaughterhouse workers are also at an increased risk of contracting brucellosis, and a study in Delhi, India found that 25% of abattoir personnel tested positive for exposure to the pathogen.²⁸⁸

Campylobacter

Campylobacter is a diarrhea causing Gram-negative pathogen that has been on the rise in many developing countries over the last 20 years.^{289,290} *Campylobacter jejuni* is the most common strain of the bacteria, followed by *Campylobacter coli*. It is estimated that *Campylobacter* affects anywhere from 5-20% of the general population of developing countries, and children under the age of five tend to have a higher incidence. One study of rural areas of northern India found that children under five were twice as likely to suffer from *Campylobacter* infections as individuals over the age of five.²⁹¹ The study found that resistance to ampicillin, ciprofloxacin, and tetracycline had increased significantly since a previous study by Prasad (1994). Multidrug resistance was identified in 30.6% of the samples tested.²⁹² This resistance is of concern because outbreaks with multidrug-resistant strains has the potential to cause high morbidity and mortality.²⁹³

The most common source of *Campylobacter* infection is from food sources such as poultry, unpasteurized dairy, and other food items that may have become cross-contaminated.²⁹⁴ However, in the developing world, waterborne transmission and direct contact with animals also play a significant role.²⁹⁵ One study of rural areas of northern India found those working in the agricultural sector were at increased risk.²⁹⁶

Campylobacter spp are most commonly carried by chickens, but research in the European Union shows that other domestic species, such as cattle, pigs, sheep can also be carriers. In Italy, a study of 190 water buffalo identified one infected animal.²⁹⁷ The frequency of infection of poultry is of concern given the rapid intensification of the poultry sector in South Asia, as well as the siting of these facilities near or in urban centers.

Cryptosporidium

The protozoan parasite *Cryptosporidium* is a major source of diarrheal disease globally,^{298,299} and can be transmitted through fecal oral contamination or can be waterborne.³⁰⁰ While four species of *Cryptosporidium* are routinely found in cattle, one species, *Cryptosporidium parvum*, has proven to be a serious pathogenic risk to humans.^{301,302} A Canadian study suggests that *Cryptosporidium* species carried by dairy cattle and calves are more likely to be zoonotic, posing a more significant risk to human populations than beef cattle.³⁰³

In West Bengal, India, the potential for zoonotic transmission of *Cryptosporidium* has been recognized, and pathogenic species have been detected both on dairy farms and in dairy farm workers.³⁰⁴ All four species of *Cryptosporidium* have been identified from dairy calves in the south Indian territory Puducherry, and states Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu.³⁰⁵ A study in Calcutta, India, found *Cryptosporidium* infection in cattle, buffalo, and humans. While this indicates zoonotic transmission, the study did not determine if the strains present were pathogenic.³⁰⁶ A 2012 study in Nepal found that *Cryptosporidium* was detected in cattle, water buffalo, and swamp deer, but did not detect the presence of *Cryptosporidium parvum*.³⁰⁷

The Indian Council of Agricultural Research maintains a research centre to “maximize [the] economic contribution” of mithun (*Bos frontalis*), a ruminant found in northeast India, Bhutan, and Bangladesh. The research centre found a general prevalence of pathogenic *Cryptosporidium parvum* of 56%. Alarmingly, the

prevalence of the parasite was 24% higher when mithun were held in semi-intensive conditions, as compared to free-range.³⁰⁸

Cysticercosis

Cysticercosis is an infection of tissue that results from infiltration with cysts from the pork tapeworm *Taenia solium*. While humans are the final host for the two species *Taenia solium* and *Taenia saginata*, it is only when humans become the intermediate host for *T. solium* that cysticercosis occurs.³⁰⁹ The worms are usually contracted by consumption of improperly cooked or raw pork that contains the eggs,³¹⁰ but Shukla et al (2010) found that participating in pig rearing was a significantly associated factor for contraction of the disease. Normally, the worms live in the human intestine; however, the tapeworm can also develop in the central nervous system. Neurocysticercosis can result in headaches, learning difficulties, epilepsy, and convulsions. Treatment is difficult and results are highly variable.³¹¹

Cysticercosis is common to all states of India, with the exception of Kerala, Jammu, and Kashmir, and appears to be more prevalent in northern India. Anywhere from 9-50% of patients in India that present with seizures are found to be infected with neurocysticercosis,³¹² and one study of a pig farming region in northern India found a prevalence of the parasite in close to 18.6% of the population.³¹³ Additional studies of persons associated with pig slaughter in Bangalore found a *Taenia* spp. infection rate of 12-16%.³¹⁴ In Nepal, pig-raising farmers can have rates of taeniasis infection ranging up to 50%.³¹⁵

Escherichia coli

E. coli is a bacterium that is often found in the gut of humans and other animals. While most strains of *E. coli* are harmless, certain strains, such as enterohaemorrhagic causing *E. coli* O157:H7, is responsible for severe cases of foodborne disease. Cattle, as well as sheep, goats, and deer, are reservoirs of the strains of enterohaemorrhagic *E. coli* serotype O157:H7. The bacteria is most often transmitted through the consumption of contaminated foods such as undercooked ground meat products, raw milk, or faecal contaminated water and other foods.³¹⁶

Giardia

Giardia is a type of diarrhea-causing parasitic protozoa that inhabits and is typically transmitted through water.³¹⁷ Its concentration is directly related to faecal bacteria levels³¹⁸ and it is extremely difficult to destroy *Giardia* cysts and oocysts using traditional water treatment methods.³¹⁹ A review by Hunter and Thompson (2005) found that while the presence of *Giardia* in water supplies could be the result of contamination by animal wastes, zoonotic transmission (directly from animal to human), is a less important pathway for infection. In contrast, a 2011 study of *Giardia duodenalis* in dairy farm workers of West Bengal, India, indicated that there appeared to be significant potential risk of zoonotic transmission of the parasite between workers and cattle.³²⁰

Highly Pathogenic Avian Influenza (HPAI)

Between 2003 and 2004, the virus H5N1 highly pathogenic avian influenza (HPAI) first appeared in Southeast Asia.³²¹ The virus spread to Europe, the Middle East, Africa, and South Asia, killing over 300 people in its wake.³²² While most countries have eradicated H5N1 HPAI, the virus is now thought to be endemic to at least six countries, including India and Bangladesh, with sporadic outbreaks occurring in Nepal and Bhutan, as well as other countries outside of South Asia.³²³ The FAO has identified several factors that have inhibited elimination of the disease in these countries, the first of which is the largely unregulated structure of the poultry sector which is spurred by rapidly increasing demand for poultry products.³²⁴

The first cases of H5N1 HPAI in Bangladesh were reported in 2007 and in West Bengal, India in 2008.³²⁵ The virus has been identified in these regions each year since, and parts of the Ganges Delta covering Bangladesh and Pakistan are now considered to be endemically infected.³²⁶ Since 2005, Afghanistan, Bangladesh, India, and

Pakistan have reported cases of H5N1 HPAI infection, and the virus also appeared in Nepal in 2009 and Bhutan in 2010.³²⁷ Eighty-five percent of the cases reported in Bangladesh as of 2010 were related to commercial poultry operations.³²⁸ “Stamping out” has and remains the main method for controlling the spread of the virus, and entails detection of infected poultry and culling of the entire flock.³²⁹ More than one million birds were destroyed after India’s first outbreak in 2006 alone.³³⁰

Leptospirosis

Leptospirosis, a bacterial disease transmitted through contact with infected urine from rats, livestock, or dogs,³³¹ was once thought to be a rare disease in India.³³² However, it is suggested that the disease was simply underreported because of lack of disease detection.^{333,334} Disease severity can vary from flu-like symptoms to kidney damage, liver failure, respiratory distress, meningitis, or death.³³⁵ While there are few published reports of *Leptospira*, one study by Natarajaseenivasan (2011) found that leptospirosis was a major problem at dairy farms in Tamilnadu, India. This study found that the seroprevalence of the disease was 87% in cattle and 76% in farm workers, showing that transmission from cows to humans at dairy farms is probable.³³⁶

Nipah Virus

Nipah Virus (NiV) is a highly pathogenic virus capable of causing fatal inflammation of the brain.³³⁷ In 1998 and 1999 the first outbreak of NiV was identified in Malaysia and Singapore. In this outbreak 265 human cases and 105 deaths were recorded. The majority of these cases were linked with close contact to sick pigs, and the outbreak was curbed after over one million pigs were culled and all movement of pigs was stopped.³³⁸ As of February 2012, no cases of NiV have occurred in Malaysia or Singapore since this initial outbreak.³³⁹ However, between 2001 and 2007 NiV was introduced into human populations 23 times,³⁴⁰ and outbreaks occurred in India first in 2001, and later in 2007.^{341,342}

The outbreaks in Bangladesh are different from the initial human cases in Southeast Asia, involving foodborne and human-to-human transmission.^{343,344} The outbreaks in Bangladesh and India have had a mortality rate of roughly 70%, whereas the outbreak in Singapore and Malaysia had a mortality rate of only 40%.³⁴⁵ The exposure pathway associated with NiV infection in Bangladesh was found to be drinking raw date palm sap.^{346,347} Fruit bats are known carriers of NiV and frequently contaminate the collecting vessels for palm sap, and thus it is suggested that the virus has been transmitted to humans from fruit bats via palm sap. It is important to note that the Malaysia pig outbreak is thought to have been caused by transmission of NiV to pigs from bats.³⁴⁸ Therefore, it is possible that NiV could be transmitted to pig populations in Bangladesh and India in the same manner. If the virus were to reach large, confined pig populations, the virus could rapidly spread among pigs and to humans.

Conclusion

IFAP has far-reaching implications for human health, particularly for those who work in or live near these types of operations. The wastes created on these farms can contaminate water, air, and animal products with a panoply of toxins and pathogens detrimental to human health. While the effects of these farming systems have been well studied in developed countries where they have been in use for several decades, developing regions of the world, such as South Asia, should be aware of the potential issues that arise with increasing incursion of this type of farming.

South Asia is facing a rapid intensification of animal agriculture that will magnify existing water and air quality issues, and increase the prevalence of foodborne pathogens and zoonotic diseases. Many of the countries of South Asia have little to no disease surveillance or power to regulate animal agriculture in such a way to attenuate these problems. It is therefore imperative that South Asian countries use the experiences of developed countries to create policies that stem the spread of IFAP. South Asian countries should act proactively to safeguard and promote public health against the many detrimental effects of industrialized farm animal production. Some actions that should be considered by South Asia to at least mediate the impacts include:

- Countries should increase implementation of veterinary care and surveillance. Veterinary care is crucial to combating infectious and zoonotic diseases,³⁴⁹ but is underutilized in much of the developing world because of a lack of resources and a poorly organized national Veterinary Service.³⁵⁰ Improving veterinary care and animal health has the potential to reduce disease risk to humans and improve human public health in general.³⁵¹ Animal housing is a significant component to animal health and the spread of pathogens. As such, countries should phase out or prohibit confinement housing (such as battery cages for egg laying hens) and set standards for lower farm animal stocking densities.
- Nontherapeutic use of antimicrobials important for human health should be phased out and banned.
- South Asian countries should take seriously the need to treat and dispose of animal wastes in such a way that their citizens are protected from pathogens and contaminants. Water treatment should be a priority, as it would greatly decrease the burden of disease in South Asia.
- Regulations regarding zoning and siting of IFAP facilities would reduce risks to human health. The current trend of urban and peri-urban facilities poses an unnecessary threat to the communities surrounding such facilities.
- Regulation and monitoring of slaughtering facilities should be considered to prevent carcass contamination and more effective pasteurization of dairy products instituted.

Despite the fact that the increasing intensification of farm animal production is well documented in South Asia, research regarding the implications of IFAP on human health in South Asia is limited, and virtually no studies on community health surrounding IFAP facilities exist. It is clear that research, policy infrastructure, and regulations are desperately needed in this field in order to protect human populations in South Asia.

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