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**Introduction**

Limited sanitation infrastructure, poor hygienic practices, and unsafe drinking water negatively affect the health of millions of people in the developing world. Using sanitation interventions to interrupt disease pathways can significantly improve public health.<sup>1</sup> Sanitation interventions primarily benefit public health by reducing the prevalence of enteric pathogenic illnesses, which cause diarrhea. Health benefits are realized and accrue to the direct recipients of sanitation interventions and also to their neighbors and others in their communities. In a report to the United Nations Development Programme (UNDP), Hutton et al. (2006) estimate that the cost-benefit ratio of sanitation interventions in all developing countries worldwide is 11.2.<sup>2</sup> This literature review summarizes the risks of inadequate sanitation to public health and presents the empirical evidence on the public health benefits of complete, intermediate and multiple factor sanitation interventions.

The sanitation literature frequently uses inconsistent terminology to describe sanitation infrastructure, technologies and intervention types. Where feasible, we report study results using the original terminology of the authors, while also using consistent terminology to facilitate comparisons across studies. In this review and in much of the literature, sanitation interventions are defined as improvements which provide public or household fecal disposal facilities, and/or improve community fecal disposal and treatment methods.<sup>3,4</sup> Sanitation interventions are distinct from water interventions, which focus on increasing access to clean water or improving water quality at drinking water sources or points of use.<sup>5,6</sup> Sanitation interventions are also distinct from hygiene interventions, which focus on household or community behavioral changes in the handling of water or feces.<sup>7,8</sup> “Complete” or “total” sanitation systems are those systems which focus on both the provision of household and community defecation facilities, as well as feces removal and pathogen neutralization treatments.<sup>9,10</sup> The literature also references “intermediate” sanitation interventions which provide non-sewer sanitation facilities, although exactly what constitutes an intermediate intervention is often unclear, as we discuss in Section three of this literature review.<sup>11</sup> “Multiple factor interventions” or “simultaneous interventions” tend to refer to interventions that include a combination of water, hygiene and sanitation intervention components.<sup>12,13</sup>

In 2000, the World Health Organization (WHO) and United Nations Children’s Fund (UNICEF) began categorizing sanitation facilities as “basic” or “improved.”<sup>14, 15</sup> WHO and UNICEF define “basic” sanitation provisions to include no sanitation facilities, public defecation, service or bucket latrines (with manual excreta

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removal), public latrines and open pit latrines. “Improved” sanitation provisions include connection to a public sewer, connection to a septic system, pour-flush latrines, simple pit latrines or ventilated improved latrines.<sup>16</sup> In addition, the WHO has subsequently categorized composting toilets, which are discussed in section two of this review, as a form of “improved” sanitation.<sup>17</sup> Although the WHO/UNICEF categories are a useful paradigm, very little of the existing literature on the public health benefits of sanitation interventions differentiates interventions according to these distinctions.

This literature review begins with a discussion of the health risks of inadequate sanitation. Section two examines the public health benefits of “complete” sanitation interventions known to interrupt public exposure pathways for disease, while section three looks at the health benefits of intermediate or partial sanitation interventions. Section four looks at results from multiple interventions, which combine sanitation, hygiene and water improvements. Section five discusses environmental influences on the public health effects of sanitation interventions, including hydrological factors.

## **1. Public Health Risks of Inadequate Sanitation**

Inadequate sanitation creates public health risks through waterway contamination, person-to-person spread of disease, and other public exposure pathways leading to negative health outcomes, particularly diarrhea and stunted growth.<sup>18</sup> Diarrhea is a deleterious and common symptom of bacteria, virus and helminth infections. The World Health Organization estimates that 1.5 million children die from diarrheal symptoms each year worldwide, with 88% of these deaths due to inadequate sanitation, hygiene and drinking water.<sup>19</sup> Diarrhea accounted for at least eight percent of total lost disability-adjusted life years in developing countries in 1990.<sup>20</sup>

The United Nations’ Millennium Development Goals (MDG) include a target of reducing by 50 percent the worldwide population without access to sanitation by 2015.<sup>21,22</sup> By one estimate compiled for the UNDP, the universal provision of sanitation would prevent an estimated 592,339 diarrheal deaths annually, and achievement of the MDG would prevent 180,182 deaths annually.<sup>23</sup>

The health impacts of inadequate sanitation are also manifest in the stunted growth of children afflicted by waterborne infections. The World Health Organization estimates that half of global malnutrition is due to illnesses resulting from inadequate sanitation, hygiene and water quality.<sup>24</sup> In their study of sanitation infrastructure in peri-urban Lima, Peru, Checkley et al. (2004) found that children from households with no sanitation facilities were 0.9 centimeters shorter at 24 months of age than those from households with a sewer connection. The study controlled for several potential confounding variables including age, sex, breastfeeding, season and nutritional status.<sup>25</sup> The study did not assess whether the health benefits associated with sewer connection were due to improved sanitary conditions in individual households, or instead due to reduced local community pathogen exposure in geographically contiguous households served by sanitation infrastructure.

### Monitoring & Measuring Morbidity

Across the literature, diarrhea is a frequently measured health effect of inadequate sanitation. In addition to its importance as the most prevalent symptom of diseases acquired because of inadequate sanitation, researchers are able to conduct studies of diarrheal frequency at a community scale using self-reporting surveys.<sup>26</sup> Weight-for-height z scores (WHZ) can also be used to assess a child’s nutritional status. The WHZ measures the number of standard deviations from the mean of a child’s weight-height ratio. Diarrheal disease and other illnesses which limit nutrient retention negatively impact WHZs.<sup>27</sup> Weight-for-age and height-for-age are other dependent variables frequently measured in the literature to assess a child’s nutritional status.<sup>28</sup>

## Water Contamination

A variety of diseases can be transmitted via waterborne or water-based microbial pathogens. Bacteria are the most common microbial pathogens in human waste and wastewater. Bacterial infections can cause a variety of intestinal infections characterized by diarrhea, such as dysentery and typhoid, as well as ailments including ulcers and cancer.<sup>29</sup> Viruses are another pathogen spread through exposure to the fecal matter of infected humans. Viruses can be persistent in the environment and require low exposure thresholds to prompt infection.<sup>30</sup> Children and the elderly are particularly at risk of viral infection from contaminated wastewater. Helminths, which include nematodes and tapeworms, are intestinal parasites that cause diarrhea among other symptoms, and have especially long survival times in waste environments.<sup>31, 32</sup>

Waterway contamination due to inadequate sanitation exposes humans to infectious disease. Sewage contamination of water bodies utilized for drinking water, bathing, brushing teeth, recreation, and washing clothing, dishes or utensils provides a direct disease transmission route.<sup>33</sup> In their study of 104 households (representing 646 individuals) in Varnasi, India, Hamner et al. (2006) found that many of these unhygienic behaviors were correlated with increased risks of enteric waterborne diseases. All 33 cases of cholera recorded occurred in families that bathed or washed laundry in the Ganges River. Regular bathing in the Ganges multiplied the odds of an individual suffering from any enteric disease by 4.72. Washing laundry multiplied the risk of enteric disease by 3.02.<sup>34</sup> This study provides one example of how limited sanitation infrastructure may present health risks that would not be remedied by interventions focusing on the provision of safe drinking water.

## *Wastewater Irrigation*

Wastewater is used extensively in the agriculture of less developed countries because it provides a reliable source of water and nutrients.<sup>35</sup> Multiple public health dangers arise from agricultural applications of untreated wastewater, including exposure to toxic metals and fecal pathogens.

Separating industrial/agricultural and municipal wastewater is necessary in order for wastewater to be safely reused.<sup>36</sup> A study by Singh et al. (2004) found that a high concentration of pesticides and toxic metals in agriculturally-applied sewage treatment plant sludge was a human health risk. Sewage sludge and wastewater from treatment plants in Varnasi and Kanpur, India were sold to local farmers, who applied it to crop fields as a fertilizer. The authors tested this sewage sludge, and found that it contained elevated levels of the neurotoxic metals cadmium and nickel, as well as pesticides.<sup>37</sup> The authors then surveyed representative populations in areas where this sewage sludge was applied, and evaluated them on their health status and eight neurobehavioral functions that have been established to be affected by heavy metal exposure.<sup>38</sup> Based on the neurobehavioral function assessment and health survey conducted by the authors, exposure to the combined wastewater and sewage sludge was found to increase the likelihood of neurobehavioral symptoms such as decreased concentration and depression.<sup>39</sup>

Wastewater reuse also potentially exposes agricultural workers and consumers of crops to a variety of pathogens.<sup>40</sup> In peri-urban Marrakech, Morocco, Amahmid and Bouhoum (2005) found that children living in a region where wastewater was spread on fields for agricultural purposes were at greater risk for the presence of *ascaris* and *trichuris* helminths. Among the control groups, risk was 1.7% and 3.8%, respectively, compared to a 13.3% risk of each helminth for children in the study group.<sup>41</sup> Other studies also demonstrate an increased risk of typhoid fever, amebiasis, and other protozoan and helminthic infections with environmental persistence to agricultural workers and consumers of untreated wastewater-irrigated crops.<sup>42</sup> In contrast, the International

Water Management Institute suggests that untreated wastewater irrigation may have a potential public health benefit. The practice serves to divert waste discharges which would otherwise flow directly into rivers, lakes and other receiving water bodies, thereby potentially mitigating health risks to downstream communities.<sup>43</sup>

Because of the agricultural utility of wastewater irrigation, authors suggest changes to sanitation infrastructure should take local agricultural practices into consideration. To maximize the popular adoption of sanitation improvements, systems could be designed to allow for continued agricultural access to water and nutrient resources while simultaneously treating sewage to remove pathogens in order to lower public health risks.<sup>44</sup> Farmers who utilize wastewater irrigation may increase their income by up to 50 percent, and it is possible to design sewage treatment systems to preserve water and nutrient resources in a community.<sup>45,46</sup>

### Disease Pathways

While water contamination is the primary disease pathway of inadequate sanitation, infectious disease transmission pathways can occur within households, between households in an afflicted community, and between communities.<sup>47</sup> These disease pathways can be interdependent because the transmission of a disease via one exposure pathway can increase the likelihood of subsequent disease transmission via a different disease pathway. For example, an increase in pathogen concentration in the water increases the risk of exposure to contaminated water, which in turn increases the risk of person-to-person transmission within or between households.<sup>48</sup>

Reviews of past sanitation interventions suggest that providing sanitation can interrupt infectious disease transmission pathways. In a study of U.S. Indian reservations, Watson (2005) found that sanitation infrastructure providing clean water and decreasing the price of clean water led to a 50% reduction in the infant mortality rate.<sup>49</sup> The author also found decreased infant mortality in adjacent non-reservation populations due to interrupted disease transmission pathways between households.<sup>50</sup> Similarly, in their study of the prevalence of waterborne diseases, Otaki et al. (2007) found that the dysentery infection rate in Tokyo fell sharply with the introduction of modern sewage treatment systems.<sup>51</sup> In contrast, prior to the installation of Tokyo's modern sewage system, water quality improvements had given 70% of Tokyo inhabitants access to clean water, but this water supply improvement had not reduced dysentery or enteric fever rates. Using data from Singapore, the same study also suggested that 40% sewer coverage in a city might be a threshold required for a decrease in waterborne diseases.<sup>52</sup> The historical analysis of sanitation provision in Tokyo and Singapore thus aligns with Watson's study of U.S. Indian reservations in finding that infectious disease rates decreased when public exposure routes were sufficiently interrupted by the addition of sanitation infrastructure.

### Seasonal Variation in Exposure

Seasonal fluctuations in the local groundwater table can affect disease transmission. Contamination risks tend to rise during a region's wet season, depending on existing local drinking water and sanitation practices.<sup>53</sup> An exception is ecological sanitation systems, which are not water dependant and feature feces-containing vaults, and thus should not be susceptible to groundwater fluctuations.<sup>54</sup> During the wet season, existing wet sewage containment systems can become stressed beyond their capacity, leading to increased fecal contamination of groundwater resources and water bodies, as well as increased water volumes that disperse waste contamination faster and further.<sup>55</sup> This effect may be partially diluted by the increased water volumes. In Malawi, Pritchard et al. (2007) found that in the dry season, 50% of drinking water wells tested did not meet the country's drinking water standard ( $\leq 50$  fecal coliform colonies per 100ml of water) for fecal coliform bacteria levels. In the wet season, 94% of wells failed to meet the drinking water standard.<sup>56</sup>

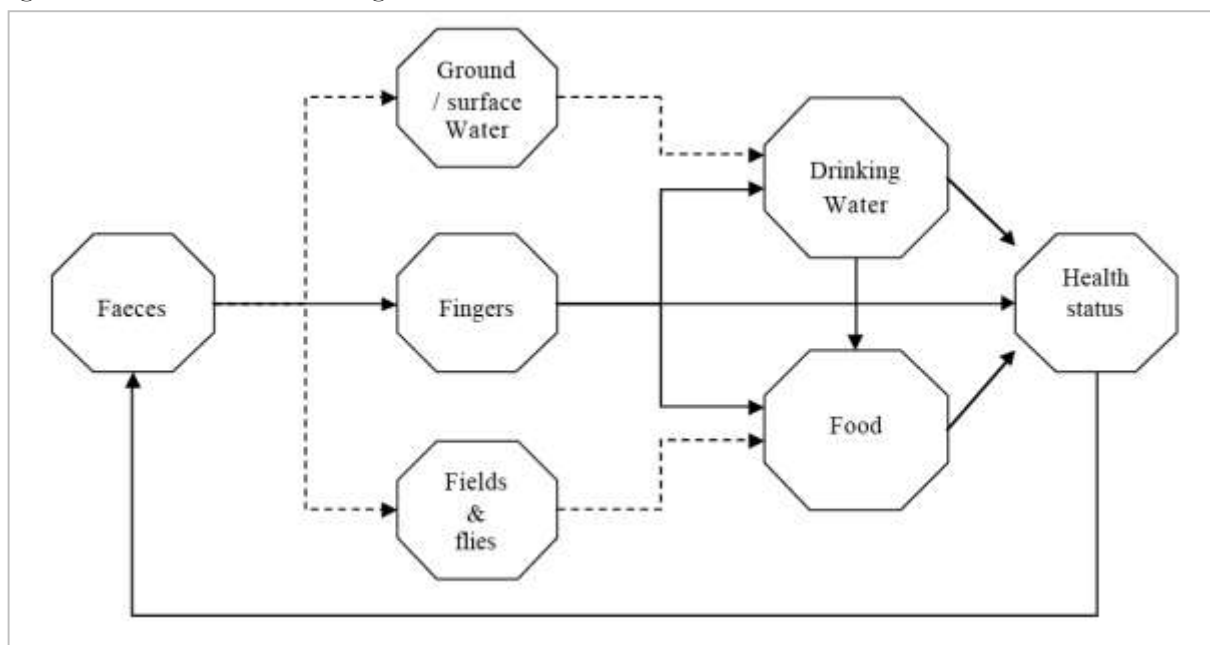
Seasonal groundwater table fluctuations affect disease transmission risks differently depending on the type of sanitation system. For example, in Florida Meeroff et al. (2008) found that where sewage was treated with septic tanks, water quality in coastal canals was susceptible to seasonal fluctuations in the groundwater table.<sup>57</sup> During times when the groundwater table was high, septic systems which normally percolated water safely into the soil instead ended up emitting waste into the groundwater, leading to elevated levels of microbial pathogens and nutrients. The authors noted that area beaches were not affected, likely because contaminated water in the 4-mile-long waterway had sufficient time to dilute and for pathogens to die.<sup>58</sup> In similar areas serviced by sewer systems, no changes in canal water quality during groundwater fluctuations were observed.<sup>59</sup> Complete sanitation systems, therefore, vary in susceptibility to seasonal groundwater table fluctuations that might increase risks of public exposure to pathogens contained in human waste.

## **2. Public Health Benefits of Complete Sanitation Interventions**

A “complete” sanitation system encompasses both a facility for defecation and a means of safe treatment and disposal of feces. Sanitation interventions such as building enclosed latrines or sewer systems primarily act to interrupt the household-to-water transmission pathway, but can also interrupt insect transmission pathways and agricultural exposure pathways in the case of wastewater irrigation.<sup>60,61</sup> *Figure 1* is one example of a model which illustrates the disease pathways interrupted by sanitation interventions, with the interrupted pathways shown by dotted lines.<sup>62</sup>

Sanitation interventions that reduce infection in a population group by interrupting the household-to-water pathway also have the potential to reduce the infection rates in neighboring populations that didn’t directly receive the sanitation intervention.<sup>63</sup> After nearby sanitation interventions, these indirect beneficiary populations will be consequently less exposed to non-drinking water disease pathways such as interpersonal exposure, insects, contaminated food and other disease-bearing inanimate objects.<sup>64</sup> By reflecting this interdependence of disease transmission pathways, it is possible to create disease transmission models to calculate predicted effects of water, sanitation and hygiene interventions.<sup>65</sup> One such model from Eisenberg et al. (2007) predicted water quality interventions to have minimal effects within a targeted community unless accompanied by the installation of complete sanitation systems. The model also predicted that in some instances, sanitation interventions alone should sufficiently interrupt pathways and reduce infectious disease frequency.<sup>66</sup>

Figure 1. Sanitation Barriers to Pathogen Transmission



Source: Waddington et al., 2009

### Direct Benefits of Sanitation Interventions

Sanitation interventions can provide direct health benefits to a community by reducing public exposure pathways to pathogens contained in fecal matter. In the most recent meta-analysis of 25 sanitation interventions, Norman et al. (2010) concluded that sanitation interventions which installed sewer connections resulted in a 30% reduction in diarrheal episodes in the targeted community, or up to 60% when starting sanitation conditions were very poor.<sup>67</sup> This finding echoes similar results from previous meta-analyses. Fewtrell et al. (2005) found that sanitation interventions reduced diarrheal episode frequency by 32%, while Esrey (1991) found that sanitation interventions reduced diarrheal frequency by 22%.<sup>68,69,70</sup> Esrey (1991) conducted a meta-analysis of 25 water-hygiene-sanitation studies and found sanitation interventions to be twice as effective at reducing diarrheal disease as water quality interventions.<sup>71,72</sup> However, both the Fewtrell et al. and Esrey studies reflected the effects of all sanitation interventions, including installing various types of latrines.<sup>73</sup>

Waddington et al. (2009) also conducted a meta-analysis that specifically studied the immediate public health benefits of improved sanitation systems. The authors divided sanitation facilities into “basic” and “improved” categories, based on the previously identified 2000 World Health Organization/UNICEF standards.<sup>74</sup> Waddington and colleagues identified eight sanitation interventions to include in their meta-analysis, with a total sample size of 13,500.<sup>75</sup> Sanitation hardware interventions which elevated sanitation facility quality from “basic” to “improved” were found to reduce the risk of diarrheal morbidity by 37%.<sup>76</sup> This meta-analysis of sanitation interventions provides evidence that the public health benefits of improved sanitation systems, which comprehensively reduce public exposure pathways, are greater than those of “basic” sanitation facilities.<sup>77</sup>

Although meta-studies of pooled data give a strong indication of the benefits of sanitation interventions, the World Health Organization advises that sanitation prioritization decisions be based on “local conditions and evidence from implementation.”<sup>78</sup> Several localized studies discussed below provide evidence for the benefits

of complete sanitation interventions, including reduced frequency of diarrheal episodes, reduced infant mortality, and increased child height.

Barreto et al. (2007) measured the public health effects resulting from installing a city-wide sewer system.<sup>79</sup> We did not find any other studies evaluating the health impacts of city-wide sewer systems, and Barreto et al. indicated that they believed that their study may have been the first of its kind.<sup>80</sup> This study in Salvador, Brazil, found a 22% reduction in diarrheal episodes among children as a result of the sewer connections, including a 43% reduction in areas with the highest pre-intervention rates of infection.<sup>81</sup> The reduction in diarrheal frequency was explained by connections to the sanitary sewer system, which reduced fecal contamination of the neighborhood. Reduction of diarrheal frequency was not directly correlated with the presence of household toilets, which, when not connected to the sewer system, actually served to increase community exposure to fecal matter.<sup>82</sup>

Studies that compare public health in neighborhoods with differing levels of sanitation service provide complementary evidence of the public health benefits accruing from sanitation infrastructure. The previously-mentioned Hamner et al. (2006) study of neighborhoods in Varanasi, India is one such comparison study. Hamner et al. found that rates of waterborne disease were 84% to 93% in two neighborhoods without toilets and sewers, as compared to 37 to 38% in two areas with sewage connections.<sup>83</sup> In reporting this result, however, the authors did not distinguish how much of this disease reduction was attributable to the sewer connection rather than concordant differences in hygienic behavior and water supply between the two groups. The same study found that the lack of sewer connection or septic tank in a home multiplied the odds of a household member suffering from enteric disease by a factor of 13.37.<sup>84</sup>

In summary, meta-analyses of sanitation interventions, studies of individual interventions, and studies which compare the effects of sanitation provision in similar populations all provide evidence that sanitation provision can produce strong public health benefits by reducing diarrheal frequency by anywhere from 22% to 60%.

### Ecological Sanitation Solutions

Ecological sanitation systems, also known as EcoSan, composting toilets or dry toilets, are intended to have the same ability to interrupt disease pathways as traditional complete sanitation systems, and WHO/UNICEF have categorized them as “improved” sanitation systems.<sup>85</sup> Ecological sanitation systems are designed to conserve water, contain fecal waste to prevent contamination, treat waste to remove pathogens and ultimately provide recycled waste nutrients for fertilizer.<sup>86</sup> Unlike traditional improved latrines, ecological sanitation systems typically divert urine away from fecal storage containers in order to keep the containers dry, which expedites pathogen die-off. Ecological sanitation systems also frequently feature solar energy components or other means of raising feces container temperatures to facilitate the destruction of fecal pathogens.<sup>87</sup>

In spite of the intended benefits of ecological sanitation models, the only study we found which assesses the health benefits indicates potential shortfalls in the ability of ecological sanitation systems to interrupt disease exposure pathways. Corrales et al. (2006) looked at disease frequency in eight communities in El Salvador, totaling 449 people in 107 households.<sup>88</sup> Four of the communities featured pit latrines or no latrines, while four communities used EcoSan latrines. Of the EcoSan latrine communities, two featured solar-augmented latrines, and two featured double-vault desiccating latrines without a solar heating component.<sup>89</sup> After a regression for confounding variables including pig ownership, dirt floors, medication and agricultural employment, EcoSan latrine use correlated with certain increased, and decreased, enteric health risks.<sup>90</sup> Compared to traditional latrines, users of double-vault EcoSan toilets had lower rates of hookworm, giardia

and *E. histolytica*, but higher rates of *Ascaris* and *Trichuris* helminth prevalence. In contrast, users of solar latrines had lower rates than controls of *Ascaris*, but higher rates of *E. histolytica* infection.<sup>91</sup> The authors suggested that solar EcoSan toilets may have been more effective than the double-vault EcoSan toilets at heating the *Ascaris* eggs in EcoSan fecal containers to intolerable levels, reducing pathogen risks. The authors also suggested that the primary health risks to users of both types of EcoSan toilets might be from exposure to pathogens during the process of emptying supposedly-neutralized biosolids from the toilets.<sup>92</sup>

Although EcoSan toilets are designed to interrupt disease pathways, this preliminary study indicates that cautious handling of the decomposed feces may be necessary to reduce health risks to users. Firmer conclusions on the health impacts of ecological sanitation are not possible without additional research.

### Indirect Benefits of Sanitation Interventions

Sanitation interventions can be valuable to the public for reasons beyond the straightforward health benefit of reducing the frequency of disease. Providing sanitation can lead to economic benefits stemming from improved health, and may also save time and improve safety for women tasked with collecting household water. Numerous studies detail the potential time savings that could be realized by water supply interventions that provide proximate sources of clean water.<sup>93</sup> Additionally, sanitation interventions that reduce the distance women need to travel to access clean water are hypothesized to increase their safety and reduce the time spent on acquiring safe drinking water.<sup>94</sup> However, we did not find any studies that specifically measured the time savings to women resulting from a sanitation intervention that rendered proximate water sources newly drinkable.

Reducing the frequency of infectious disease will add wealth to a community from fewer days of missed work and reduced costs associated with seeking medical care.<sup>95</sup> Benefits that accrue to adults in time, money or energy savings are in turn expressed in the improved health of children, as parents will have more time to feed and improve the hygiene of their children.<sup>96</sup> A 2006 report to the UNDP from the World Health Organization and the Swiss Tropical Institute estimated that 90% of the total economic benefits to Sub-Saharan Africa from universal sanitation coverage would be due to convenience-time savings associated with defecating and safely disposing of feces.<sup>97</sup> These benefits were illustrated in one sanitation intervention study in rural India by Pattanayak et al. (2007), which estimated a time savings of 17 minutes per family member per day.<sup>98</sup>

Although it is difficult to measure the economic value of many of these indirect benefits, benefit-cost analyses indicate that the time-saving benefits from sanitation interventions are potentially very large. The 2006 report to the UNDP predicted economic gains from sanitation coverage, including both direct health benefits and indirect economic benefits.<sup>99</sup> Economic factors in this model included direct health sector expenditures avoided due to reduced diarrheal illness, direct patient expenditures avoided due to less diarrheal illness, income gained due to avoided lost work, school absenteeism avoided, lost productive parent days avoided, loss of life avoided, and convenience-time savings.<sup>100</sup> Using these criteria, the report estimated that the total economic benefits, including health benefits, of worldwide universal provision of improved sanitation would be U.S. \$163 billion. The report intentionally omitted other sources of potential economic gains from providing sanitation, such as property value increases and leisure opportunities, because it was not feasible to reliably measure them.<sup>101</sup> Modeling the more-modest MDG goal of reducing by 50 percent the worldwide population without sanitation access by 2015 predicted economic benefits of U.S. \$34.7 billion.<sup>102</sup> These estimated benefits were separate and distinct from the also-substantial benefits associated with providing safe drinking water. Expanding on their 2006 report to the UNDP, Hutton et al. (2007) also concluded that the achievement of the MDG for water and sanitation would create a time savings of approximately 40 billion working days worldwide,



whereas achievement of the water goals alone would create a time savings of 4 billion working days.<sup>103</sup> The authors concluded that the biggest sanitation-related time savings gains would be as a result of the closer proximity of toilets, or reduced waiting time for public facilities.<sup>104</sup>

### **3. Evaluation of Partial or Intermediate Sanitation Interventions**

Since sewer infrastructure is frequently prohibitively expensive, sanitation interventions worldwide have employed a variety of feces-disposal facilities to improve upon public defecation. Unfortunately, however, intermediate sanitation solutions that do not involve complete sewer systems have often been incompletely described and detailed in research articles, or are otherwise difficult to compare across multiple studies.<sup>105</sup> The few studies available suggest that partial sanitation interventions only offer public health benefits if they succeed in disrupting exposure pathways. If household-water transmission pathways are not interrupted by the non-sewerage sanitation intervention, or the intervention does not reduce direct household-to-household disease transmission by reducing exposure to public excreta, then full potential public health benefits will not be realized.<sup>106</sup>

Different terminology and definitions of intermediate sanitation interventions complicate generalizing conclusions across studies. For instance, installing flush toilets in houses is often treated as an “intermediate” intervention if not connected to a sewer system. However, many studies do not differentiate such “intermediate” interventions according to the external public receiving environment (where waste from sanitation facilities is disposed of, such as a ditch, street, pit or body of water).<sup>107</sup> This is problematic because the receiving environment is critical to assessing the efficacy of an intervention. The difference between an informal ditch, a concrete-lined stormwater drain and the street itself illustrate the substantial potential disparity in the levels of public exposure to feces.<sup>108</sup> Likewise, other studies consider latrines or septic tanks to constitute “intermediate” interventions, even when the ultimate method of latrine drainage isn’t specified. “No sewerage” or “no sanitation” is often used to describe the category of lowest sanitation, without further description, even though this category could encompass a variety of significantly different feces disposal methods.<sup>109</sup> Although the benefits accruing from non-sewer sanitation interventions are difficult to generalize, several studies discussed below provide evidence for the inefficacy of intermediate and incomplete sanitation systems while another group of studies demonstrate that even these imperfect interventions can have positive benefits and spillover effects beyond the household.

#### Weaknesses of Partial Sanitation Solutions

Several studies found sewer connection to be a critical factor for health benefits. In Salvador, Brazil, Barreto et al. (2007) found that “intermediate” sanitary solutions that don’t safely remove feces from both household and community are insufficient to improve public health. In that study, flush toilets that were not connected to the sewer system were found to increase fecal contamination in the public domain, which counteracted any health improvements due to increased domestic sanitation.<sup>110</sup> Similarly, Checkley et al. (2004) found child height to be positively correlated with sewer connection in Peru. In this study, there were no observed differences in child height between the “no sanitation facility” condition and the “latrine or equivalent” intermediate sanitary condition.<sup>111</sup>

A study in rural Zimbabwe by Dzwauro and colleagues (2006) also provides evidence of minimal public health benefits from incomplete sanitation systems. This study examined soil contamination and water quality in a community living in an area with a high groundwater table. Pit latrines were the community’s primary excreta disposal method, and shallow wells were their primary source of drinking water. The study found that the

absence of a soil infiltration layer between the bottom of the latrine and the groundwater table increased the likelihood of unsafe levels of contaminated drinking water wells located up to 25 meters from the latrine.<sup>112</sup>

#### Successes of Partial Sanitation Solutions

In contrast to the findings above, several studies demonstrate that even intermediate sanitation interventions can have positive spillover effects for communities. In rural Zimbabwe, Root et al. (2003) found that use of a ventilated latrine in a given household provided a “protective effect” for the household’s nearest neighbors. Among a sub-sample of 65 households, the study found that households whose neighbors used a ventilated toilet experienced about half the number of diarrheal episodes as did those whose nearest neighbors did not.<sup>113</sup> The authors suggest that the protective effect was due to the lowered likelihood of neighborhood children coming into contact with feces in the area surrounding the household with the ventilated latrine.<sup>114</sup> Similarly, Bottenheim (2009) provides evidence from urban Bangladesh that the safe disposal of children’s feces is of particular benefit to public health in the surrounding community. In the 153-child study, the author found that latrine usage by a neighboring household with children under four years of age correlated with an individual child’s WHZ score, while latrine usage by neighbors without young children showed no correlation with an individual child’s WHZ.<sup>115</sup> Findings were consistent regardless of whether the child’s own household used a latrine.<sup>116</sup> The size of the WHZ benefit varied according to initial size and weight of study subjects, and the initial neighborhood prevalence of latrines. The suggestion is that non-sewer sanitation interventions have shown at least some success at interrupting disease transmission pathways in a community.

#### **4. Multiple Factor Interventions**

Multiple-factor interventions involve a combination of interventions in at least two of the following areas: drinking water quality, drinking water availability, sanitation facilities or community hygiene. Simultaneously interrupting multiple disease transmission pathways might be expected to have an outcome greater than the sum of the benefits of individual disease pathway interventions.<sup>117</sup> For example, drinking water interventions would be expected to be more effective when complemented by simultaneous hygiene interventions, so as to reduce the likelihood of recontamination between clean water sources and points of water consumption.<sup>118</sup> However, as discussed below, multiple factor interventions are not necessarily more effective at reducing disease risks than single-factor interventions. In addition, single-pathway water interventions can potentially have a counterproductive behavioral effect.

In a paper currently under review for publication, Bennett found that precipitated behavioral changes which reduce hygienic behavior and investment in sanitation may blunt the public health benefits of clean water interventions.<sup>119</sup> Bennett found that when clean water is available, individuals may perceive themselves to better tolerate an unsanitary environment, and thus perceive a decreased marginal benefit from sanitation or hygiene efforts, such as latrine maintenance. In Cebu, Philippines, a city without a centralized sewer system, Bennett found clean water and sanitation to be negatively correlated. Areas serviced by chlorinated piped water were the most likely to feature public defecation.<sup>120</sup> To counterbalance this behavioral phenomenon, a simultaneous intervention in sanitary systems would ensure that gains due to clean water provision are not lost due to discontinued hygienic behavior.

Fewtrell et al. (2005) found that multiple simultaneous interventions resulted in fewer benefits than the sum of each individual component.<sup>121</sup> Similarly, Waddington et al. (2009) identified “inconclusive results” across studies that compared the impact of multiple-factor interventions with single-factor interventions.<sup>122</sup> In the Fewtrell et al. study, multiple simultaneous interventions resulted in a 20% reduction in diarrheal disease in all

examined studies. By contrast, single-factor sanitation interventions showed a 22% reduction, a stronger result than when sanitation interventions were employed in conjunction with water or hygienic improvements. However, solitary water quality interventions showed a smaller reduction in diarrheal disease, at 17% across all studies and 15% in rigorous studies, than did multiple-factor interventions. The authors explained the surprising result that solitary sanitation-interventions were more effective than sanitation interventions combined with water or hygiene interventions by suggesting that multiple-factor interventions might have tended to counterproductively prioritize the water intervention component instead of more-beneficial sanitary or hygienic improvements.<sup>123</sup> The decrease in hygienic behavior observed by Bennett might also partially explain the ineffectiveness of multiple-factor interventions if the water quality component of these interventions had been overemphasized.

## **5. Environmental Influences on Public Health Effects**

The literature examining the public health effects of sanitation interventions under different hydrological conditions is relatively thin. Existing research on the effect of sewage discharges into receiving water bodies tends to focus on environmental effects, and not on human health. In general, larger water bodies, especially oceans and large rivers, seem to be assumed throughout the literature to be the most effective receiving water bodies for sewage because of their potential for dispersion and dilution.<sup>124,125</sup> The literature also tends to assume that sewer outfalls upstream from or in close proximity to water intakes for urban drinking water increase the risk of pathogen contamination.<sup>126</sup>

### Eutrophication

The release of sewage into rivers and lakes poses a public health threat stemming from the nitrogen, phosphorus and other nutrients contained in fecal matter. Municipal sewage discharges are an important cause of eutrophication, the condition that results when water bodies contain excess photosynthesis-stimulating nutrient load, which results in ecosystem-disrupting plant biomass levels. Eutrophication currently impairs 54% of rivers and lakes in Asia, 28% in Africa, and 41% in South America.<sup>127</sup> Though more commonly considered an ecological problem, eutrophication also poses a public health risk: Certain bacteria and toxic metabolites associated with algal blooms, such as clostridium botulinum, can be harmful to humans when imbibed, causing gastroenteritis.<sup>128</sup> Likewise, consuming fish and shellfish contaminated by bacterial and algal byproducts also poses human health risks; for example, consumption of shellfish which accumulate cyanobacteria during nutrient-spurred “red tides” can cause paralytic shellfish poisoning.<sup>129, 130</sup>

### Rivers & Watersheds

Sanitation and drinking water infrastructure tends to be designed around the assumption that sewage discharges will have negative health effects on communities that utilize the river for drinking water or other public purposes. Therefore, waste discharges are often downstream from drinking water intakes or are otherwise designed so that the negative health effects do not directly affect the community generating the waste. For example, Chicago, Illinois famously built its sanitation system to discharge waste down the Illinois and Mississippi Rivers, away from its source of drinking water in Lake Michigan.<sup>131</sup> However, there appears to be relatively little literature which quantitatively measures the impact of sanitation discharges on neighboring or downstream communities.

In a 1999 study of Betim, Brazil, Heller tangentially addresses the impacts of downstream wastewater in looking at the public health effects of sanitation practices in Betim, Brazil. This study included 1,000 households

without connection to the city's sewer system, and 1,000 control households connected to the sewer system. Heller found that the presence of free-flowing wastewater in local streets, gutters, or house plots was positively correlated with the risk of child diarrhea morbidity, with free-flowing wastewater in the streets multiplying by 2.74 the risk of an individual suffering from diarrhea. Free-flowing wastewater was also a more significant predictor of diarrhea morbidity than was the individual household's sanitation disposal practices.<sup>132</sup> Heller concluded that drainage sub-basins should be the unit of implementation in community sanitation interventions in order to incur the public health benefits from completely removing free-flowing wastewater from streets, ditches and exposed drainages.<sup>133</sup>

### Coastal Environments

As the studies discussed below illustrate, a key to safe sewage discharge, in terms of direct public health impacts, in coastal areas is ensuring that discharges are sufficiently far from shore for currents to exchange and dilute the effluent. A benefit-cost simulation by Hernandez-Sancho et al. (2009) of wastewater treatment interventions showed that the initiation of sewage discharge treatment was expected to benefit the environmental health of oceans relatively less than other receiving water bodies, as oceans are less severely impacted by the discharge of untreated sewage to begin with.<sup>134</sup> Coastal sewage disposal does, however, present public health risks if sewage discharge locations are not sufficiently far from areas of probable public exposure. For example, in the Moroccan city of El Jadida, untreated sewage is discharged via surface channels directly into the Atlantic Ocean. In a study of 419 schoolchildren in El Jadida, Moubarrad and Assobhei (2007) found that children who lived in coastal neighborhoods close to the sewage discharge were approximately 18 times likelier to have helminth eggs in their stool.<sup>135</sup>

In contrast, coastal discharges of treated sewage may not pose a significant public health threat if the discharge is far from shore and deep underwater. Laws et al. (1999) studied the water quality effects of treated sewage discharges into an urban Hawaiian bay. They found that discharge points were sufficiently deep underwater, at 63 and 71 meters deep, and far from the shoreline, at approximately 2 kilometers, to dissipate the sewage plumes from the discharge points before the plumes reached the surface.<sup>136</sup> The study found no detectable effect on any parameter of water quality at bay beaches in spite of the large volumes of sewage discharged.<sup>137</sup>

Coastal sewage disposal does pose numerous risks to the local receiving environment which may indirectly impact human health. **Coastal sewage disposal can stimulate eutrophication and depletion of oxygen content in the water, which are both associated with bacterial byproducts toxic to humans and marine organisms.**<sup>138</sup> Wastewater discharges often contain human sewage commingled with nitrogen and phosphorous-rich agricultural wastes which compound eutrophication problems.<sup>139</sup> Certain viruses and bacteria associated with human sewage have been documented in marine mammals, and have been suggested to be directly transmitted to the mammals by sewage effluent.<sup>140</sup> Human sewage effluent is also often commingled with industrial wastes that contain toxic heavy metals which bioaccumulate (increase in concentration up the food chain), resulting in hazardous levels of toxic metal concentrations in marine foodsources.<sup>141</sup> Wastewater discharges may also have deleterious effects on local biodiversity and coral formation in tropical waters. Sewage discharges into Keneohe Bay off the coast of Oahu, Hawaii caused algae to overgrow local coral colonies, a phenomenon which was reversed after sewage discharges into the Bay were diverted.<sup>142</sup>

### **Conclusion**

Complete or improved sanitary systems can offer concrete public health benefits by reducing exposure pathways to a variety of infectious diseases contained in human feces and wastewater. Substantial

complementary economic gains are also predicted to accrue as a result of providing increased sanitation. The prevalence of using untreated wastewater as a source of water and fertilizing nutrients for agricultural products suggests that the successful design and installation of sanitation improvements may need to retain a secondary focus on maintaining water and nutrient access for agriculturalists using wastewater. Ecological Sanitation systems may be a promising means of retaining waste nutrients within a community, but are relatively unstudied and have unclear public health benefits.

Sanitation solutions which separate and contain wastewater sewage and decrease public exposure to feces have been found to be more effective at reducing diarrheal frequency and other negative health outcomes than sanitation systems which do not significantly reduce public exposure to feces-originating pathogens. Similarly, a sanitation solution's ability to interrupt public exposure pathways is more indicative of its effectiveness at reducing health risks than is its direct improvement of sanitary access for a given household. Thus, community-wide sanitation interventions seem to offer the greatest promise for reducing pathogenic health risks from feces.

There is scant literature distinguishing the benefits of sanitation interventions according to a community's hydrological setting. However, as a general principle, larger, faster-moving water bodies with greater volumes of water are better able to dilute and disperse wastewater discharges and reduce the pathogenic health risks than smaller water bodies. Another important hydrological factor in the design of sanitation systems is the proximity of waste discharges into water bodies or groundwater in relation to drinking water intakes or other points of public use of water resources.

**Literature Review Methodology:** This review was conducted using databases and search engines including University of Washington Library, Web of Science, Science Direct, Google Scholar, Google, as well as the WHO, UN, USAID, World Bank, UNICEF and Poverty Action Lab websites. Searches used combinations of the following terms: sanitation, externalities, wastewater, waste, sewer, latrine, public health, health benefits, sewage, downstream, urban, treatment system, urban sanitation, sanitation system, discharge, water body, body of water, river, lake, coast, pollution, ocean, outfall, groundwater, hydrologic, receiving environment, receiving water, ecological sanitation, dry toilet, composting toilet, diarrhea, EcoSan. The methodology also included searching for sources that were identified as central works and examining relevant lists of works cited.

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## Endnotes

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