International Journal of Innovative Research and Advanced Studies (IJIRAS)
Volume 5 Issue 1, January 2018

ISSN: 2394-4404

Energy Conservation For Water Management In India

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***Abstract:** The rise in population and growth in industry especially in dry climatic regions has led to significant increase in water and energy demands. Energy is consumed during every stage of the cycle of water supply, treatment, use and disposal. The intensity of energy consumption depends upon the specific technologies applied at each stage of the water cycle. For some technologies, the intensity may be relatively low, whereas the intensity of other technologies is substantially greater. Eventually advanced technology would require less energy as compared to conventional one for the same purpose. Because water affects many economic, social and environmental aspects, an interdisciplinary approach is needed to solve current and future water scarcity problems, and to minimize energy requirements in water production. This report surveys the available literature on energy intensity for water use in the municipal and agricultural sectors and separates the process into several stages. Water supply, water treatment, residential end use, wastewater treatment, and agricultural end use are considered. Representative values of the energy consumed per unit water are given for a broad range of processes. Water extraction and pumping from ground and surface sources is considered. The energy intensity of treatment required for different types of water source is found to vary widely between the extremes of relatively fresh surface waters, which use energy mainly in pumping, and seawater, which requires desalination. Energy usage for different methods of irrigation including pressurized as well as surface irrigation is studied. Processes such as heating water, washing clothes and dishes, and cooking are briefly studied within the water end-use stage. Hot water use in different buildings is briefly reviewed. Wastewater treated with various processes is considered, and it is concluded that the energy intensity is found to be highest when advanced wastewater treatment methods are applied. Energy consumption in the agricultural sector, which is principally related to irrigation pumping, is generally of lower energy intensity than for the municipal treatment or end use. In arid regions, energy could be supplied by solar energy, thus addressing water shortage problems through integrated water resource management combined with new technologies of water production driven by renewable energy sources.*

***Keywords:** Energy, Water, Water Supply, Water Treatment, Desalination, End Use*

I. INTRODUCTION

India is one of the developing countries. Due to faster industrialization and urbanization and increase in population, water demand is increasing day by day. Extrapolating this urban growth, there would be a 40 per cent rise in the demand for municipal water and wastewater services by 2030. At present, only 73 per cent of urban households in developing countries have access to piped water and 68 per cent have access to improved sanitation, compared with virtually universal coverage of such services in developed countries. The balance of water supply and demand is affected regionally by a broad range of factors including population growth, increasing urbanization, intergovernmental relations, political and policy choices, social factors, technological growth, and uncertainties of climate. In addition to these issues, water consumption directly affects energy consumption. This energy consumption is the focus of the present paper. The infrastructure that provides water for agriculture, domestic consumption and sanitation requires extensive treatment and distribution systems that consume significant amounts of energy for pumping and purification.

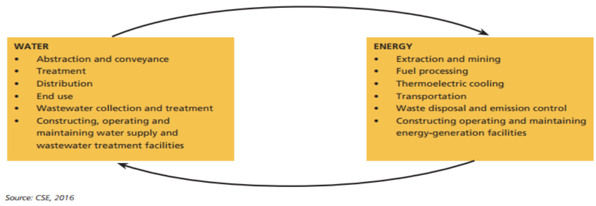

Figure 1: The Water Energy Nexus

Further, various end uses of water, such as water heating, washing clothes and dishes, showering, and food preparation consume substantial amounts of energy. This highlights the need for energy efficiency (EE) in water and wastewater management. Water in India is highly subsidized due to which it is not considered a valuable resource. As per Centre for Science and Environment (CSE), it is estimated that two-thirds of the water supplied by the Delhi Jal Board is never paid for. Water conservation is therefore directly linked to energy conservation. Alternative choices of water supply, treatment, end use and reuse can have very different implications for energy demand.

The ‘‘water–energy nexus’’ has garnered much attention recently. It includes both the energy consumption of water supply mentioned above and the water consumption of energy production processes. In the present article, the consumption of energy for production, treatment, distribution, end-use, reclamation and disposal of wastewater is assessed taking into account processes, appliances and technologies.

A. PRESENT SCENARIO OF WATER USE IN DIFFERENT SECTORS

Table 1 shows the water withdrawals, in cubic kilometers per year, by various sectors of use from various regions of the world. The contrasts are significant. Asia’s water consumption is largely agrarian while North America and Europe withdraw more water for the industrial sector, which includes water withdrawn for thermal power plant cooling. From Table 1, industrial water use including power production accounts for 20% of total world- wide water use while use in the residential sector uses only 10%.

The total utilizable water resource in the country has been estimated to be about 1123 BCM (690 BCM from surface and 433 BCM from ground), which is just 28% of the water derived from precipitation. About 85% (688 BCM) of water usage is being diverted for irrigation (Figure 1), which may increase to 1072 BCM by 2050. Major source for irrigation is groundwater.

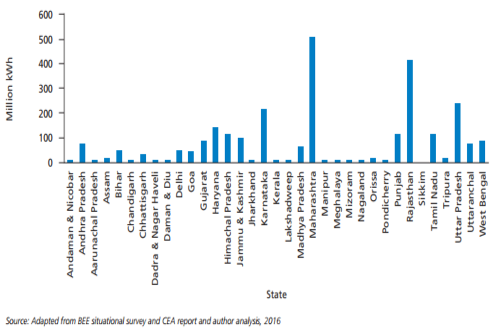

Figure 2: Potential Withdrawal savings across states

Region	Available surface and ground water resources	Total water with drawn	Volume of water withdrawals (Gm^3/year)					Withdrawal as percent of renewable resource
			Agriculture		Industry		Domestic	
			Volume	Percent	Volume	Percent	Volume	
Africa	3,936	217	186	86	9	4	22	5.5
Asia	11,594	2378	1936	81	270	11	172	20.5
Latin America	13,477	252	178	71	26	10	47	1.9
Caribbean	93	13	9	69	1	8	3	14
North America	6,253	525	203	39	252	48	70	8.4
Oceania	1,703	26	18	73	3	12	5	1.5
Europe	6,603	418	132	32	223	53	63	6.3
World	43,659	3829	2663	70	784	20	382	8.8

Table 1: Water Withdrawals in different sectors

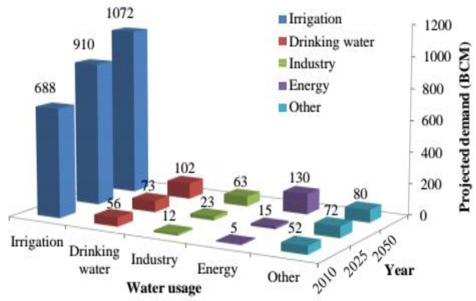

Figure 3: Projected water demand by different sectors (CWC, 2010)

The quantum of non-revenue water (NRW) has been going up from about 53 percent in 2002–03 to 56 percent in 2006–07. Municipal water supply and sewage treatment infrastructure in India is often outdated and its inefficient operation places a hefty burden on municipal budgets. As per various energy audit studies, about 40–60 percent of a water utilities’ operating cost is spent on energy. If energy use for water delivery remains at the current level, the energy cost of providing water supply to this growing population will be huge.

Another study, Report on Seventh Electric Power Survey, indicates that the public water works in India consume more than 12,000 MUs of electricity. Energy costs account for approximately 40–60 percent of the operating expense of supplying water. By becoming energy efficient, each urban local body can reap minimum energy savings of 25–40 per cent. The graph given in Figure 2 illustrates this:

B. BACKGROUND ON WATER–ENERGY LIFE CYCLE

The water life cycle starts with production or extraction of water from natural sources such as groundwater aquifers, lakes, rivers, and oceans. Fresh water from lakes and rivers normally requires treatment for the removal of microorganisms and suspended solids such as sand or silt. In some cases, advanced treatment is needed to remove organic compounds, dissolved ions, or, in the case of ground water, absorbed gases. Seawater, being more saline needs more stringent treatment measures to remove the very high concentrations of dissolved ions than other less saline waters. Desalination is performed using thermal processes such as multi-stage flash (MSF) and multi-effect distillation (MED) or electrically driven processes such as reverse osmosis (RO).

Treated water is used in different ways by various customers in the residential, commercial, industrial and agricultural sectors. For example, residential customers usually pump, heat, wash and cook, while agricultural consumers pump water to irrigate fields. These processes consume widely varying amounts of energy per unit water.

this used water becomes polluted and may require treatment before it is discharged or reused. The level of water pollution differs with sector and type of application, as do the treatment requirements. The importance of each stage in the water cycle is distinct and is also significantly

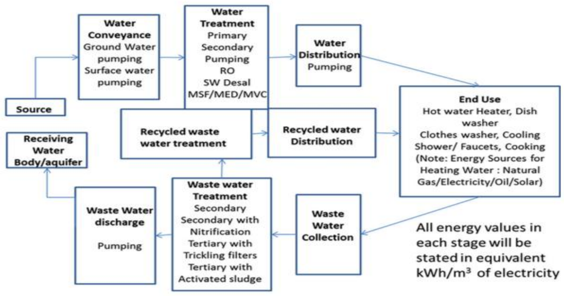

Figure 4: Different stages of water life cycle

affected by variations in the geographical location being served, water availability there, the local climate, the culture and customs of the area, and the economic status of the location. The present authors aim to provide a collective analysis of the major independent energy consuming processes within each stage in the cycle using datasets for separate locations. The stages enumerated in Fig. 1 have been disaggregated to illustrate some of the energy consuming processes possible within each stage in water life cycle. The energy consumed by each process is expressed in terms of kWh of electricity per cubic meter of water applied or served. Caution is to be exercised while dealing with different sources of energy and their application in water use processes. Several processes within Figure 4 may consume energy from thermal sources under differing conditions of temperature and primary energy supply. This is particularly true of natural gas heating of water and of some steam driven desalination processes. In order to express energy in uniform units the authors have chosen equivalent electricity units of kWh. Therefore, a unit of thermal energy expressed in kWh may converted to equivalent electrical energy by assuming an appropriate efficiency of electrical generation from thermal power, e.g., assuming that 0.33 kWh of electrical energy is produced from 1 kWh of primary thermal energy under given conditions. Contextually appropriate conversion efficiencies are applied in what follows.

II. ENERGY FOR WATER PRODUCTION

One major reason for rise in pumping energy cost (KWh/ MLD) is the depletion of water table across India and scarcity of surface water in rivers and canals. Optimizing pumping operations can result in energy savings in energy-efficient water delivery systems.

Stage	Operation	Energy-using systems
Extraction	Deep well extraction	Submersible or shaft turbine deep well pumping systems
	Extraction from a surface source	Horizontal or vertical centrifugal pumping systems
Water treatment	Chemical (disinfection and clarification)	Piston-type dosing pumps
	Physical (e.g., filtration and sedimentation)	Pumping systems, fans, agitators and centrifugal blowers
Piping between source and distribution network	Sending the drinking water to the distribution grid	Submersible or shaft turbine deep well pumping systems, and horizontal or vertical centrifugal pumping systems
	Booster pumping	Horizontal or vertical centrifugal pumping systems used to increase pressure of water going into the distribution system or to pump water to a higher elevation
Distribution	Distribution to end users	Horizontal or vertical centrifugal pumping systems
Storm and sanitary sewer system	Sewerage and drainage	
Wastewater treatment	Physical (e.g., screening and sedimentation)	Pumping systems, fans, centrifugal blowers
	Chemical (e.g. clarification, disinfection)	Piston-type dosing pumps
	Biological	Pumping systems, agitators, aerators, centrifugal blowers
Support systems	Support functions associated with the utility building(s)	Lighting systems, heating, ventilation and air conditioning (HVAC)

Source: WATERGY: Energy and Water Efficiency in Municipal Water Supply and Wastewater Treatment, 2007

Table 2: Water and Wastewater utility systems that uses energy

A. GROUNDWATER PUMPING

Deep well water (generally less than 300 m) is considered to be microbial free, but it can contain inorganic minerals such as iron, manganese, arsenic radionuclides as well as other chemicals originating from natural geological formations. Further, interactions with surface water can introduce agricultural run-off or microbial contamination. Extraction of water from underground aquifers primarily requires energy for pumping. Electrical energy (kWh) is expended when a unit volume (m3) of water passes through a pump during its operation. An essentially linear relationship exists between the energy intensity value for groundwater pumping and the depth from which it is pumped at a specific pressure.

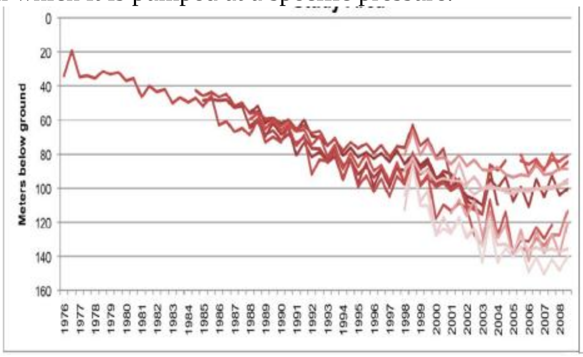

Figure 5: Depth to water observed by 16 monitoring wells in the study area

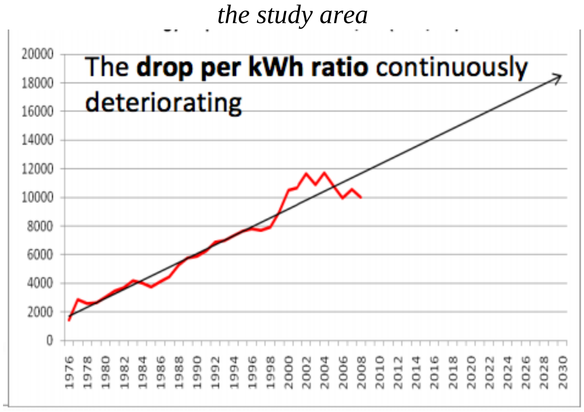

Figure 6: Energy required to lift 600mm/Ha(kwh/Ha)

B. SURFACE WATER PUMPING

Tunnels, aqueducts or pipelines, siphons, valves, and booster pumping stations are a part of most water supply systems. There are many large water supply systems around the world for which documentation is available. The energy consumption of these systems varies considerably depending upon the length of the system and the elevation changes involved.

In the production stage, groundwater pumping is usually found to be more energy intensive than surface water pumping, with the exception of situations in which water is hauled extremely long distances to the point of use.

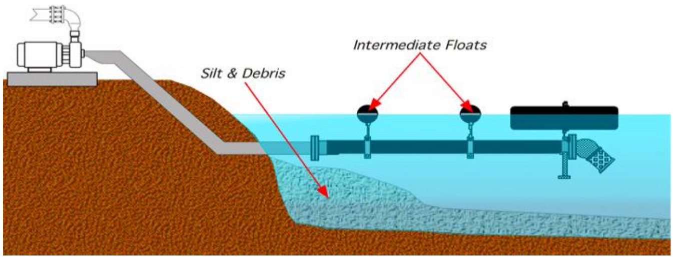

Figure 7: Schematic illustration of surface water pumping

Electrical systems and motors	Pumping Systems	Operational and Other Aspects
Fine tuning of contract demand	Suitable sizing of pumps	Leakage reduction
Penalties paid in lieu of maintaining low power factor	Replacing of pumps due to poor efficiency	Operating schedules / Practices of pumps
Segregation of Lighting and Fan loads	Replacing of the impellers	Parallel operation Vs individual operation of pumps
Switching “OFF” of transformers	Rectification of pumps	Changes in filling practices
Power factor improvement	Header and piping systems	
Clubbing of facilities		

Table 3: Energy Saving Options - Water Pumping

III. ENERGY FOR WATER TREATMENT

A. TREATMENT OF RAW WATER FROM GROUND AND SURFACE SOURCES

A raw water treatment system is a system made up of several individual technologies that address your specific raw water treatment needs.

Before supplying water to consumers, it must be treated to appropriate physical and chemical quality and must be free of protozoan, bacterial, and viral pathogens. So, an efficient and well-designed raw water treatment system should be able to handle seasonal variations in turbidity and flow, variations in water chemistry needs and required chemical volumes adjustments and changes in water quality requirements (such as the quality of feed water required for a new boiler)

a. STAGES OF GROUND AND SURFACE WATER TREATMENT

Specific treatment processes vary, but a typical raw water treatment facility process will usually include the following steps:

Raw Water Intake

Raw water (untreated water found naturally in the environment) can come from many sources, including rivers, lakes, oceans, or groundwater. Usually, when an industrial plant draws in the water from their surface water source, they pull it in (with pipes or by gravity) through a mesh screen or grate to eliminate the larger objects, such as twigs, leaves, and fish. The water is then pumped to the main facility where treatment begins.

Coagulation

After all the large objects are removed from the raw water source, various chemicals are added to a reaction tank to remove the bulk suspended solids and other various contaminants. This process starts off with an assortment of mixing reactors, typically one or two reactors that add specific chemicals to take out all the finer particles in the water by combining them into heavier particles that settle out. The most widely used coagulate are aluminum-based such as alum and polyaluminum chloride.

Sometimes a slight pH adjustment will help coagulate the particles, as well.

Flocculation

When coagulation is complete, the water enters a flocculation chamber where the coagulated particles are slowly stirred together with long-chain polymers (charged molecules that grab all the colloidal and coagulated particles and pull them together), creating visible, settleable particles that resemble snowflakes.

Sedimentation

The gravity settler (or sedimentation part of the raw water treatment process) is typically a large circular device where flocculated material and water flow into the chamber and circulate from the center out. In a very slow settling process, the water rises to the top and overflows at the perimeter of the clarifier, allowing the solids to settle down to the bottom of the clarifier into a sludge blanket. The solids are then raked to the center of the clarifier into a cylindrical tube where a slow mixing takes place and the sludge is pumped out of the bottom into a sludge-handling or dewatering operation.

The dewatering process takes all the water out of the sludge with filter or belt presses, yielding a solid cake. The sludge water is put onto the press and runs between two belts that squeeze the water out, and the sludge is then put into a big

 ISSN: 2394-4404

hopper that goes to either a landfill or a place that reuses the sludge. The water from this process is typically reused and added to the front end of the clarifier.

Filtration

The next step is generally running the water overflow into gravity sand filters. These filters are big areas where they put two to four feet of sand, which is a finely crushed silica sand with jagged edges. The sand is typically installed in the filter at a depth of two to four feet, where it packs tightly. The feed water is then passed through, trapping the particles.

On smaller industrial systems, you might go with a packed-bed pressure multimedia filter versus gravity sand filtration.

Ultrafiltration (UF) can also be used after the clarifiers instead of the gravity sand filter, or it can replace entire clarification process altogether. Membranes have become the newest technology for treatment, pumping water directly from the raw water source through the UF (post-chlorination) and eliminating the entire clarifier/filtration train.

Disinfection

After the water flows through the gravity sand filter, the next step is typically disinfection or chlorination to kill the bacteria in the water.

Sometimes this step is done upstream before filtration so the filters are disinfected and kept clean. If your system utilizes this step prior to filtration, you will need to use more disinfectant . When you add the chlorine upfront you're killing the bacteria and have less fouling. If bacteria sits in the bed, you might grow slime and have to backwash the filters more often. So it all depends upon how your system operates, whether your system is set up to chlorinate upstream (prior to filtration) or downstream (after filtration).

Distribution

If the raw water treatment is being used in an industrial process, it's typically pumped into a holding tank where it can be used based on the demands of the facility. If for municipal use, the treated water is usually pumped into a distribution system of water towers and various collection and distribution devices in a loop throughout the city.

After the removal of most of the solid impurities, even if the physical and chemical characteristics of water are acceptable, it is still not fit for drinking until it is free from bacteria and other microbial pathogens.

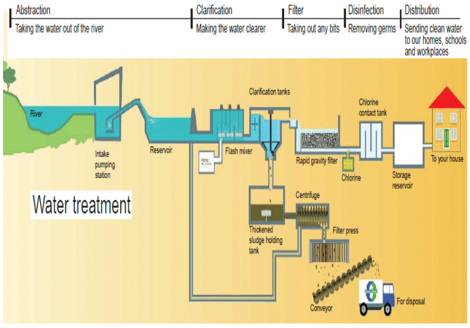

Figure 8: Different Stages of Raw water Treatment

B. WATER TREATMENT FOR HIGHER PURITY REQUIREMENTS AND DESALINATION

In arid and water scarce areas, desalination technologies have become a viable source of water. Desalination is employed to remove high concentrations of minerals and salts from seawater, as well as in treatment or recycling of brackish water. Two major classes of desalting processes are thermal and membrane desalination. Thermal separation processes include multistage flash distillation (MSF), multiple effect distillation (MED) and mechanical vapor compression. Membrane processes rely upon the application of pressure or electric fields to separate ions from water. While the 60% of the world's desalination capacity is reverse osmosis (RO), thermal technologies still represent about 80% of worldwide capacity for seawater desalination

The minimum energy required to desalinate water is proportional to the salinity of the raw water, but the energy required in practice also depends upon the technology employed. The energy consumed in membrane processes such as reverse osmosis, nanofiltration, and electrodialysis varies with the salinity of the water, whereas the energy required in thermal [distillation] processes is independent of the salinity of the source water. The minimum energy consumption in reverse osmosis membrane processes is determined by the need to pressurize the inlet water stream above its corresponding osmotic pressure.

In general, brackish waters (1500–15,000 ppm of total dissolved solids or TDS) require less energy to desalinate than seawater (15,000–50,000 TDS); and reverse osmosis is generally more energy efficient than thermal processes. RO desalination of brackish water with 500 ppm, 1000 ppm, and 4000 ppm TDS consumes roughly 0.66, 0.79 and 1.59 kWh/m^3, respectively, while seawater reverse osmosis consumes energy in the range of 2.5–7 kWh/m^3. Thermal processes are almost universally driven by low temperature steam extracted from an adjacent power plant, rather than electricity as for reverse osmosis; and as a result it is important to carefully distinguish the type of energy being consumed when comparing thermal to electrically driven desalination processes. That electrical energy in turn depends upon the steam pressure and temperature at the location of extraction.

In comparison to the treatment of fresh ground and surface water, desalting is much more energy intensive. But new innovations in desalting technologies aim to reduce this energy gap. Energy recovery devices are now widely used to recover the energy loss in the high pressure brine reject stream. Centrifugal energy conversion devices include turbines, positive displacement devices, rotary pressure exchangers, and have efficiencies that can exceed 95%.

Desalination is energy intensive but when overall costs, life- cycle energy expenditures, and environmental impacts are taken into account, it may remain advantageous relative to alternatives such as long distance water transfers.

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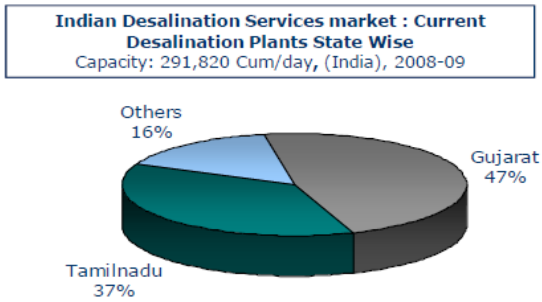

Figure 9: Current Desalination Plants(State Wise)

Process	Total Energy (kW-h/m3)	Capital Cost ($/m3/d)	Unit Water ($/m3)
MSF (Without waste heat)	55-57	-	-
MSF (with waste heat)	10 - 16	1000 - 1500	0.8 -1.0
MED (without waste heat)	40-43	-	-
MED (with waste heat)	6 - 9	900 - 1200	0.6-0.8
SWRO	3 - 6	800-1000	0.5-0.8
SWRO (with energy Recovery)	2 - 3	<800	0.45-.6
BWRO	0.5 – 2.5	<800	0.1-0.3
Innovative Technology/Hybridization	< 2.0 *	<800	<0.5

Table 4: Energy Requirement and cost of various desalination processes

IV. ENERGY CONSUMPTION FOR WATER END USE

Water end-use, in buildings, industrial facilities, and farms, often has the highest energy intensity. Heat pumps for energy recovery from hot grey water in residential buildings, and micro-turbines operating from grey water in tall buildings, are being increasingly explored.

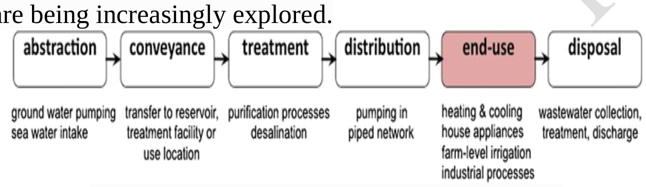

Figure 10: Different stages of water end use

For end-use, energy is required for on-site pumping (e.g. in the case of high-rise buildings) and heating (to obtain a hot water supply in the building). In residential water use applications, energy is used in appliances such as clothes washers and dishwashers. In landscaping applications, some additional pumps and electrical control equipment (motors and valves) may be used that add to the energy consumption. For buildings with on-site wastewater recycling units, energy is consumed in running the units to treat and pump the recycled water. Industrial facilities use water in various operations and have associated energy requirements, typically in terms of pumping, pressurization, heating, cooling, and treatment of water.

A. RESIDENTIAL SECTOR: HUMAN BEHAVIORAL ASPECTS

Energy consumption in residential sector is influenced by the behavior of the occupants and their water demand. It is recognised that human behaviour can have a significant impact on strategies designed to manage water and energy sustainably. Even with adequate knowledge of how to save energy and a professed desire to do so, most of them still fail to take noticeable steps towards energy and water efficiency and their conservation. There is often a sizeable discrepancy between people's self-reported knowledge, values, attitudes and intentions, and their observable behaviour—examples include the well-known 'knowledge-action gap' and 'value-action gap'.

People in India use almost two full bathtubs of water every day — most of which is flushed away. According to a survey, Kolkata consumes the maximum amount of water with an average of 444.5L per household while Madurai consumes the minimum amount with an average of 370.9L per household. According to current estimates, each person consumes approximately 150 litres per day — equating to almost two full bathtubs of water per person per day, or 54,750 litres per person each year. Most of this water is flushed away every day.

Washing clothes are one of the biggest consumers of water in households followed by bathing. The average seven-minute shower uses up to 49 litres of hot water, while power showers can use up to 175 litres in the same period. Water usage for bathing and washing clothes contributes to about 28 per cent and 19 per cent of total consumption respectively.

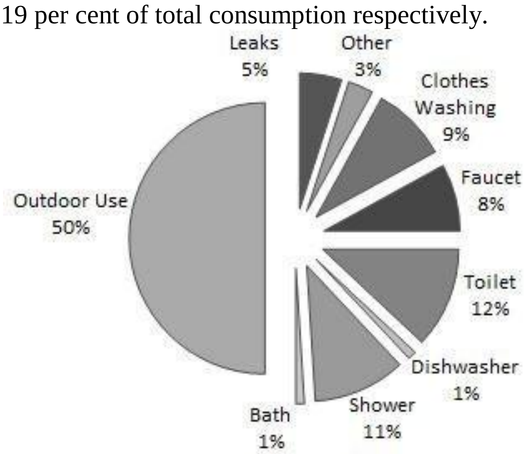

Figure 11: Water usage profile

B. WATER COOLING AND HEATING

Water is usually heated or cooled before consumption at end use. Equivalent electrical energy consumed for cooling water from a room temperature of 20 degree Celsius to around 31 degree Celsius is about 18.2 kWh/m3. In the residential sector, hot water is used in dishwashing and clothes washing. The other uses of hot water are for showering, cooking, and sometimes boiling water to disinfect or to cook. There is a wide diversity in commercial brands of water heating options available and hence it becomes difficult to set any criteria for use when doing life cycle energy analysis in residences worldwide. The energy efficiency of some water heaters are given below.

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Water Heater Type	Efficiency Rating
Conventional Gas Storage	0.60
Condensing Gas Storage	0.86
Conventional Elec Storage	0.90
Elec Heat Pump Storage	2.20
Tankless Gas	0.82

Table 5: Energy efficiency of water heaters

a. ENERGY CONSUMPTION OF BUILDINGS RELATED TO HOT WATER USE

Differences in building types such as homes, apartment buildings, offices, and hospitals, and the external temperature (local weather conditions) influence how much energy is used. Furthermore, individual appliances vary significantly. Electric water heaters have higher end-use efficiencies than natural gas water heaters, but significant electrical losses make the primary energy use greater

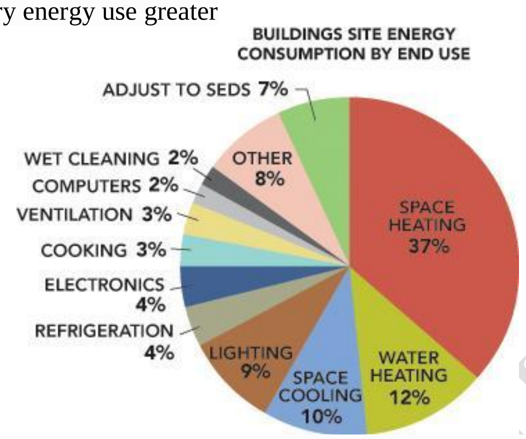

Figure 12: Buildings site energy consumption by end use

C. DISH WASHING

Dish washing is another major water and energy consuming process at home. There are two scenarios of interest: manual washing and machine washing.

a. MANUAL DISH WASHING

In manual washing, energy for heating wash water is the primary factor, so wash temperature and volume are of importance. They also found that people concentrated on decreasing their energy and water usage when asked to act as subjects in water-use experiments. This was related to the fact that participation in an experiment has a psychological effect, which led people to limit water consumption. The mean energy consumed for manually washing a load of 12 different tableware (soiled with seven standard types of food) was about 1.7 kWh (electric heating) with an average use of 49.2 l of water in an hour

b. MECHANIZED DISH WASHING

Within the last two decades, the machine dish washing has contributed to electricity savings of 6–40% and water savings of 50–80% as compared to manual dishwashing lower temperature, as for showers, energy intensity of showering is significantly lower than that for hot water heating.

Caution is exercised when primary energy such as natural gas is compared with transformed form of energy such as electricity. Power plant conversion of primary [thermal] energy to electricity is assumed to be 33.2% efficient. The energy expended during end use in a geographic location is dependent on the climate specific to the location.

D. CLOTHES WASHING

Any clothes washing method uses energy for various tasks including mechanized work or manual labor, and hot water heating and pumping. The end users of a specific community can be characterized by the regional perception of cleanliness and convenience. In India, 14% of urban households and 7% of rural households own a washing machine, however they are expected to see rises of up to 19% by 2015. Indian consumers also generally associates heat with hygiene rather than cleanliness and thus only washed clothes in hot water when someone was ill.

Washing on hot and rinsing in warm water consumes an average of 4.5 kWh per load, which at a cost of $0.15 per kWh costs $0.68. On the other hand, the same activity on cold water uses an average of 0.3 kWh per load, which at a cost of $0.15 per kWh costs you $0.04.

The chief argument for using hot water is that hot water is the best route for getting your clothes as clean as possible. The high temperature of the water is most likely to kill bacteria and also to cause more movement of the water, causing more soiling and germs to be removed from the clothes. Taking another aspect, mechanized cloth washing consumes energy saving water whereas manual labor consumes a large amount of water but saves energy. Thus deciding between the two is a major concern.

E. COOKING

Cooking consumes a major fraction of the overall energy expended in a household. Many common diets water are intensive and include foods that require boiling in water to make them consumable. Substantial amounts of energy are involved in both bringing water from room temperature to the boiling point (on the order of 0.1 kWh/L) and then in holding it near the boiling point temperature during the cooking process. The energy consumption per unit food mass for boiling cooking water decreases with an increase in volume of water .The source of energy also plays a very decisive role in energy consumption for cooking. Rice is a very common dietary staple around the world. Energy consumption for cooking rice using natural gas is less energy intensive compared to the use of electricity.

V. ENERGY CONSUMPTION FOR WASTEWATER TREATMENT

The water used in residential, commercial, and industrial end use gets polluted with liquid and solid wastes. Domestic wastewater is treated with primary, secondary, and sometimes tertiary treatment stages. The energy consumed by these processes depends on size of the plant, the location of the treatment plant, the population served, the type of impurity, the type of treatment process, the end users of water in the area, quality of water the treatment plants receive, quality of treatment required for water discharge, economic status of the wastewater treatment plant, and the experience of the plant managers. In a wastewater treatment plant (WWTP), energy is used in the form of electrical, manual, chemical and petroleum. However, for exploring opportunities for energy efficiency and energy substitution, a detailed analysis of various forms of energy consumption is required. Such analysis should include share of various energy forms and energy intensity at various stages of treatment process. More importantly, it demonstrates a methodological framework by which such studies can be replicated to generate data with respect to various scales of treatment and choice of treatment technology. This information will provide a sound basis for planning tools and answers to the growing debate of water-energy nexus, developing energy efficiency benchmarks for urban water sector and finding possibilities for the application of renewable energy to substitute conventional forms of energy.The type of impurity to be removed is the major parameter that drives energy consumption in wastewater or water treatment.

PARAMETERS	INLET	OUTLET
pH	4-9	7.5-9
COD(mg/l)	840-890	<200
SS(mg/l)	550-680	<30
BOD(mg/l)	770-755	<20
P(mg/l)	2-1.5	<.63
S(mg/l)	3-2	<.8
NH4(mg/l)	45-30	<19

Table 6: Characteristics of wastewater

A. PRIMARY TREATMENT

Primary treatment includes screening, size reduction and inorganic suspended solids removal process. These are low energy intensity processes. Primary sludge pumping is the most intensive primary treatment process. Primary treatment processes include waste collection, screening, chemical treatment, grit removal and sedimentation.

B. SECONDARY TREATMENT

At this stage, wastewater with remaining colloidal organic impurities such as proteins and dissolved organic matter, such as carbohydrates, enters secondary treatment. Biological treatment is predominant in this stage of wastewater treatment. This induces the need for enough oxygen to run the processes. Mechanical or surface (used in continuously stirred tank) and diffused (used in plug flow) aeration systems are used for this purpose. Aerators also help proper mixing of the waste sludge apart from providing more oxygen. Secondary treatment processes include aeration, stabilization, suspended growth or fixed film processes, clarification, and membrane bioreactor processes. Secondary processes only remove 20–30% of nitrogen from the wastewaters. These systems have a distribution arm which helps the wastewater to be distributed evenly over this media. Microbes would break down the flocculating biomass. The biomass after its breakdown is sent to the sludge treatment tanks while the effluent is recycled to provide kinetic energy to the distributor arm. Recirculation pumping in trickling filters was reported to consume an average of 0.021 kWh/m^3 of energy.

C. TERTIARY TREATMENT

The energy consumed by waste treatment plants varies depending on the final, high level treatment applied to the effluents, and rises if the effluents are treated to potable water standards.Higher nitrogen and phosphorus removal can be met by use of tertiary processes such as nitrification–denitrification. These processes can consume substantial amounts of energy.

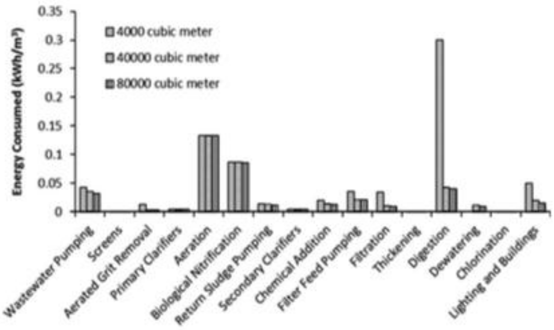

Figure 13: Energy use in advanced wastewater treatment plants

THE TREATMENT PLANT HAS THE FOLLOWING UNITS

- ✓ Sump tank: reinforced cement concrete, rectangular shape underground tank, size (39292) m, having two submerged sludge pumps (one as standby) each of 0.75 kW motor for feeding raw wastewater.
- ✓ PST: rectangular shaped MS tank, size (3919225)m, fitted with one SS turbine plate stirrer with 0.19 kW motor.
- ✓ Chemical dosing tanks: three tanks each of 100 ltr. capacity with total 3 dosing pumps (1 pump as standby) having 0.19 kW motor.
- ✓ RBC: tank of size (2908908) m; discs fitted with a worm gear motor of 0.19 kW.
- ✓ Disinfectant tanks: two tanks each of 100 ltr. capacity with total 3 dosing pumps (1 pump as standby) having 0.19 kW motor.
- ✓ SST: tank of size (3919225) m, fitted with SS turbine plate stirrer 0.19 kW motor and single stage monoblock recirculation pump of 0.38 kW.
- ✓ Sand filter and carbon filter: 200 l capacity, fiberglass reinforced plastics (FRP) vessel with manual multiport valve.
- ✓ Treated water tank: RCC rectangular, (39292) m, having one centrifugal regenerating pump of 0.75 kW.

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Unit	Electrical Energy (kWh/m3)	Manual energy (kWh/m3)	Chemical Energy (kWh/m3)	Total Energy (kWh/ m3)
Sump	.20	.003	.00	.203
PST	.09	.019	.096	.205
Dosing tank	.04	.046	.00	.086
RBC	.09	.002	.00	0.092
SST	.17	.008	0.00	.178
Disinfecta nt tank	.03	.006	0.00	.036
Sand filter	0.00	0.010	0.00	0.010
Carbon filter	0.00	0.010	0.00	0.010
Treated Water tank	0.18	0.00	0.003	0.183
Sludge storage tank	0.00	0.027	0.00	0.027
Total	0.8	0.131	0.099	1.030

Table 7: Energy consumption due to various wastewater treatment processes

This Table gives the assessment of energy consumption pattern in each treatment operation. In addition, the fuel energy (diesel) for entire treatment process is estimated at 0.036 kWh/m3. Therefore, the total energy consumption is 1.07 kWh/m3 of wastewater treated. It is much less as compared to the value obtained in a WWTP in California, which was reported to be 1.69 kWh/m3 excluding manual energy (Stokes and Horvath 2010).

VI. ENERGY CONSUMPTION OF WASTEWATER REUSE AND RECOVERY

Water reuse is an option to decrease the energy demand needed for water supply. Poor wastewater treatment is one of the biggest enemies of a safe and sustainable water supply all over the world. Next to frugal handling of existing water resources, the treatment of wastewater towards future reuse is important. Unfortunately, the allusive effect of improving water supply through groundwater recharge or surface water improvement must be weighed off against the capital cost, the cost of energy demand, and other variable costs of wastewater treatment facilities. With the costs per unit energy constantly rising, it is of utmost importance that future wastewater treatment preparing wastewater for reuse is energy-efficient. Especially in developing countries important points to consider are reliability and simplicity of a wastewater treatment process.

Insufficient capacity of wastewater treatment and increasing sewage generation pose big question of disposal of waste water. As a result, at present, significant portion of wastewater being bypassed in STPs and sold to the nearby farmers on charge basis by the Water and Sewerage Board or most of the untreated waste water end up into river basins and indirectly used for irrigation. In areas like Vadodara, Gujarat, which lack alternative sources of water, one of the most lucrative income-generating activities for the lower social strata is the sale of wastewater and renting pumps to lift it (Bhamoriya, 2004). It has been reported that irrigation with sewage or sewage mixed with industrial effluents results in saving of 25 to 50 per cent of N and P fertilizer and leads to 15-27 % higher crop productivity, over the normal waters (Anonymous, 2004). It is estimated that in India about 73,000 ha of (Strauss and Blumenthal, 1990) per-urban agriculture is subject to wastewater irrigation. In peri-urban areas, farmers usually adopt year round, intensive vegetable production systems (300-400% cropping intensity) or other perishable commodity like fodder and earn up to 4 times more from a unit land area compared to freshwater (Minhas and Samra, 2004). Major crops being irrigated with wastewater are:

- ✓ Cereals: Along 10 km stretch of the Musi River (Hyderabad, Andhra Pradesh) where wastewater from Hyderabad is disposed-off, 2100 ha land is irrigated with wastewater to cultivate paddy. Wheat is irrigated with wastewater in Ahmedabad and Kanpur.
- ✓ Vegetables: In New Delhi, various vegetables are cultivated on 1700 ha land irrigated with wastewater in area around Keshopur and Okhla STPs. Vegetables like Cucurbits, eggplant, okra, and coriander in the summers; Spinach, mustard, cauliflower, and cabbage in the winters are grown at these place. In Hyderabad, vegetables are grown in Musi river basin all year round which includes spinach, amaranths, mint, coriander, etc.
- ✓ Flowers: Farmers in Kanpur grow roses and marigold with wastewater. In Hyderabad, the farmers cultivating Jasmine through wastewater.
- ✓ Avenue trees and parks: In Hyderabad, secondary treated wastewater is used to irrigate public parks and avenue trees.
- ✓ Fodder crops: In Hyderabad, along the Musi River about 10,000 ha of land is irrigated with wastewater to cultivate paragrass, a kind of fodder grass.
- ✓ Aquaculture: The East Kolkata sewage fisheries are the largest single wastewater use system in aquaculture in the world.
- ✓ Agroforestry: In the villages near Hubli-Dharwad in Karnataka, plantation trees viz., sapota, guava, coconut, mango, arecanut, teak, neem, banana, ramphal, curry leaf, pomegranate, lemon, galimara, mulberry, etc. are irrigated with wastewater.

VII. ENERGY INTENSITY FOR IRRIGATION IN AGRICULTURE

Agriculture is a major consumer of water worldwide, as seen clearly from the data in Table 1. Energy consumption and irrigation in agrarian economies are intertwined with each other. The energy expended to irrigate a field is dependent on the amount of water pumped, area of the field, soil characteristics of the location, geology, slope, crop varieties or cropping patterns, precipitation or climate at the location, temperature, type of irrigation, irrigation scheduling, application effectiveness, pumping system type, pressure requirement at the point of use and energy cost.

Human behavior also plays its part in influencing energy consumption. Farmers' desire to obtain higher yields in water scarce regions influences the use of fertilizers. In water abundant areas, farmers increase labor to intensify irrigation in order to get higher yields. This can lead to overexploitation of groundwater resources in water abundant regions, and thus lead to pumping from increasing well depth. Therefore, farmers' behavior clearly influences energy use in irrigation. This behavior can be related to the phenomenon that irrespective of crops, agriculture was more productive under irrigated than rainfed (no irrigation) conditions.

It is observed in the last few decades, the underground water levels have been falling down drastically and cultivated area has been increasing by cutting the forests. Hence, there is growing demand for electrical energy for irrigation. The generation is not growing proportionately to the growing demand. On the other side, the available energy is also not properly utilized for agricultural purposes. Although the agricultural sector accounts for the consumption of around one-fourth of total electricity in India, the revenue from this sector is very low. While agricultural consumption at national level is around 23 per cent, the revenue leverage from this sector is just six per cent of the total revenue of all Indian electricity utilities. This has resulted in deteriorating financial status of electricity utilities.

Activity	Energy	Firewood, Charcoal	Substitutes
Planting and Cultivating	Shaft power	With gasifier	Commercial liquid and gas fuels, biogas
Pumping	Shaft power	With gasifier and/or electricity	Commercial liquid and gas fuels, biogas, solar, hydro-wind, central grid, compressed air
Harvesting	Shaft power	With gasifier	Commercial liquid and gas fuels
Drying	Process heat	Direct combustion, process steam	Solar, biogas, agricultural wastes, commercial fuels
Killing	Shaft power	With gasifier engine or electricity	Agricultural residues, commercial liquid and gas fuels, wind central grid, hydro-electric, biogas, water wheels
Cooking, Baking	Process heat	Direct combustion, process steam	Commercial fuels, solar, biogas, agricultural residues, geothermal, cogeneration
Woodworking	Shaft power	Electrification, process steam	Commercial fuels, wood wastes, central grid, biogas
Metalworking	Shaft power	Gasification, process steam, electrification	Commercial fuels, hydro-electric, central grid, biogas, water wheels, wind
Forging, Smelting	Process heat	Charcoal by direct combustion	Oil, gas, coke
Bricks, Cement	Process heat	Direct combustion	Agricultural residues, commercial liquid and gas fuels, geothermal, cogeneration
Mineral processing	Process heat	Direct combustion	Commercial fuels, agricultural residues
	Shaft power	Gasification, electrification, central steam	Commercial fuels, hydro-electric, central grid, hydro, biogas

Table 8: Industrial and agricultural energy usage

Location	Crop	Activity	Requirement* (Hp-hr/ha)	Notes	Source
Up India	HYV Rice	Land prep Irrigation Threshing	576 458 1.4	Tractor	Singh & Singh
	HYV Wheat	Land prep Irrigation Threshing	1069 217 550		
We Bengal, India	Rice	Field Prep** Field Prep** Irrigation Threshing Transport	216+ 200+ 394-440 49-51 12-13	8HP/Tiller 35HP/Tractor	Indian Institute of Technology (IIT)
	Wheat	Field prep Field prep Irrigation Threshing Transport	200 176 189-234 115-120 4-8	8HP/Tiller 35HP/Tractor	IIT
Asia	Rice	Cultivation Irrigation	6 125 320 310 310 310	Traditional Transition Modern Traditional Transition Modern	Kuether, et al.

Table 9: Energy Requirements for Agriculture

A. ENERGY EXPENSE FOR SURFACE IRRIGATION

Surface irrigation is mainly divided in basin, border, and furrow systems.

The tailwater deep percolation trade-off can also be solved by collecting and recycling the runoff to improve surface irrigation performance. It is often more economical to regulate the inflow rather than to collect and pump the runoff back to the head of the field or to another field; tailwater reuse systems are more cost-effective when the water can be added to the flow serving lower fields and thereby saving the cost of pumping.

B. ENERGY REQUIREMENTS FOR IRRIGATION

Energy consumption for irrigation in agriculture can also be characterized according to the crop grown. Each plant has distinct regimes of pollination and related growth or seed production. Productivity of crops is dependent on timely irrigation and judicious application of energy in direct (human labor, water etc.) and indirect (manure, chemicals, machinery etc.) forms. Recently, the need to study the energy consumption and energy output of different fruit and vegetable crops across the world has been stressed, particularly in order to understand the energy used to irrigate crops for efficient production. The following sections will review the energy expenditure in irrigating some of these crops.

a. FRUITS AND VEGETABLES

Drip irrigation has been practiced in India since 1980. Crops have been gradually shifted from conventional surface irrigation to drip irrigation. This shift has been mostly related to water scarcity, the low energy consumption characteristics of drip irrigation, and crop change. From Table 21, it is clear that a large amount of electricity can be saved by installing a drip irrigation instead of a surface irrigation system.

Recently sugarcane has emerged as a biofuels crop, and so its energy and water requirements are of interest. Data from Iran include sugarcane and several fruit crops: orange, apple, mandarin, and kiwi fruit. Table 22 provides the equivalent energy consumption to (surface) irrigate these fruit crops. From Table 22 sugarcane is observed to consume comparatively more water among the fruits crops, but the least energy for irrigation.

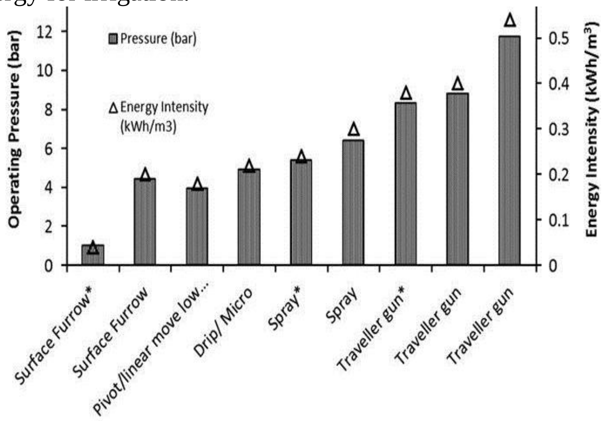

Figure 14: Different types of irrigation systems with their operating pressure

b. GRAIN CROPS

In the production of a crop, irrigation, seed-bed preparation, harvesting and threshing were found to be energy-intensive operations. Further, it was found that irrigation consumed up to 60% of the total energy requirements for crop production under different methods of irrigation. Paddy, wheat, sugarcane crops are more energy intensive as compared with other principal crops. A study basically focused on Gurgaon and Rohtak districts of Haryana which comprise the main zone of bajra-wheat cultivation revealed that cultivation of high-yielding varieties of wheat consumed energy three times more than the growing of hybrid bajra. In both the crops nearly 82 percent of the total power used was observed before harvesting. The specific energy requirements for the production of crops did not differ significantly with irrigation methods.

C. AGRICULTURAL WATER TREATMENT

About 85% (688 BCM) of water usage in India is being diverted for irrigation, which may increase to 1072 BCM by 2050. Major source for irrigation is groundwater. Annual groundwater recharge is about 433 BCM of which 212.5 BCM used for irrigation and 18.1 BCM for domestic and industrial use (CGWB, 2011). In India, there are 234-Sewage Water Treatment plants (STPs). Most of these were developed under various river action plans (from 1978-79 onwards) and are located in (just 5% of) cities/ towns along the banks of major rivers. Apart from domestic sewage, about 13468 MLD of wastewater is generated by industries of which only 60% is treated. In areas like Vadodara, Gujarat, which lack alternative sources of water, one of the most lucrative income-generating activities for the lower social strata is the sale of wastewater and renting pumps to lift it (Bhamoriya, 2004). It has been reported that irrigation with sewage or sewage mixed with industrial effluents results in saving of 25 to 50 per cent of N and P fertilizer and leads to 15-27 % higher crop productivity, over the normal waters (Anonymous, 2004).

Use of municipal wastewater for farming, whether treated or not, is widespread in peri-urban areas in India. Although there are no comprehensive estimates of the total agricultural area using wastewater irrigation, several isolated studies indicate that this area is considerable. An IWMI study of five selected urban areas came up with a figure of about 50,000 hectares, while another study on Gujarat state alone came up with a figure of 38,000 hectares. In most per-urban areas of India, untreated rather than treated sewage is used for irrigation because either adequate sewage treatment capacity is non-existent, or the farms in question are not located close to the outflow of the sewage treatment plant. In a few cases where treated sewage is used, it is used by farmers close to the sewage treatment plant, as in the case of famers close to the Keshopur and Okhla Sewage Treatment Plants (STPs) in Delhi. Wastewater irrigation in peri-urban farms can be direct or indirect: direct when sewage is used from a sewage channel close to/adjacent to the field, and indirect when the sewage flows into a water body (lake/river) and water is taken from this polluted water body.

VIII. CONCLUSIONS

Energy consumption for water production, treatment, supply, use and recycling has been reviewed in this article. In the production stage, groundwater pumping is usually found to be more energy intensive than surface water pumping, with the exception of situations in which water is hauled extremely long distances to the point of use. Desalination processes are the most energy intensive options in the water treatment stage, and they will only yield energy efficiencies as an alternative to long distance hauling of water. In conventional water treatment systems, pumping processes consume the largest fraction of total energy. Membrane filtration processes are the most energy intensive water disinfection processes. The energy consumption in conveyance and treatment is location specific. Site specific factors are very important in determining the processes used, and thus the energy consumption in each stage of the water cycle differs by location.

From this study, as in previous studies, it is found that end use is the most energy intensive stage in the water–energy cycle. In the residential sector, the energy consumption of heating water increases with demand; hot water energy consumption patterns in the residential sector also vary with climate. Human behavior influences energy consumption as well. Mechanized clothes washers have varied energy performance, and the local cultural practices affect the machine washing technology in the local market. Manual dishwashing was found to be more water and energy intensive than mechanized dish washing machines. Boiling water for cooking was a major consumer of energy in the residential sector. Cooking large quantities of food is by mass less energy intensive than cooking small quantities. The greatest potential for energy savings associated with water consumption lie at the end use component of the water life cycle.

In wastewater treatment plants, digestion is the process that consumes most of the energy in small capacity plants (o' 4000 m^3). With advanced wastewater treatment, which is in growing demand, energy consumption increases. Energy consumption in wastewater treatment is linearly related to the size of the population served. In agriculture, surface as well as groundwater is extracted for irrigation. Pressure based pumping systems are found to have high energy intensity. With an increase in pressure requirements at point of use, energy consumption increases. With area, the amount of water used for irrigation increases, and this in turn increases the energy consumed per unit volume of water. The energy intensities in irrigation also change with the type of crops planted, for example, fruits are more energy intensive than vegetables. The direct and the indirect input energies for crop production are interdependent on each other. Relatively little data is available on energy analysis of wastewater treatment systems associated with agricultural water reuse.

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