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Assessment of Groundwater Quality Due to Dumping of Municipal Solid Waste and Its Remediation through Energy Recovery in Nashik

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Abstract - *The menace of environmental pollution due to improper Municipal Solid Waste Management (MSWM) has been enduring the human world since early times and is still growing due to the enormous growth of industries in the developing countries. Current global Municipal Solid Waste (MSW) generation level is approximately 1.3 billion tones per year and is expected to increase to approximately 2.2 billion tones per year by 2025. The challenge in MSWM is not just handling the volume, but also its composition and our ability to design and accomplish its management in an efficient and sustainable manner. Waste should be disposed of during a safe way which takes into cognizance the health of environment which of the general public, while ensuring non detrimental effects on generations to come. In developing countries, open dumpsites are common, due to the low budget for waste disposal and non-availability of trained manpower. Open dumping of MSW is a common practice in many countries and it poses serious threat to groundwater resources. Increased environmental pollution from industrial, agricultural and municipal sources has deteriorated the groundwater quality over the past years. On the other hand, availability of energy is insufficient and poses a serious threat to the economic and social development. By considering the necessity for sustainable practices in disposing the solid waste, this scientific study was initiated in terms of research for the Assessment of groundwater quality due to dumping of MSW and its remediation through energy recovery in Nashik, Maharashtra, India. The main objectives of this research are: (a) To assess the suitability of groundwater for domestic and irrigation purposes. (b) Anaerobic digestion studies on individual components such as food waste, organic fraction of MSW, vegetable waste, fruit waste with water hyacinth and cow dung. (c) To develop a model for anaerobic co-digestion of food waste, organic Fraction of MSW, vegetable waste and fruit waste with water hyacinth & cow dung.*

Groundwater samples from 6 wells from Gaulane Ghat Prakalp were collected for a period of four months (December to March of 2018 - 2019) and analyzed for 13 selected water quality parameters Potenz Hydrogen ion concentration, Electrical conductivity, Total hardness, Total dissolved solids, Calcium, Magnesium, Sodium, Potassium, Chloride, Bicarbonate, Sulphate, Nitrate and Fluoride. Sampling methods and water analysis were carried out. The hydro-chemistry and assessment of groundwater for irrigation were discussed for the period of 2018-2019.

To evaluate co-digestion of water hyacinth with food waste, organic fraction of MSW, vegetable waste and fruit waste along with cow dung as seeding agent, the materials for anaerobic digestion was collected from various locations in and around Nashik. A set of 5 batch digesters of 2 litres capacity were used for different proportions of wastes and 1 digester was kept as control waste. Each digester consisted of fixed quantity of cow dung and water hyacinth, but an increasing amount of food waste, organic fraction of municipal solid waste, vegetable waste and fruit waste. Control waste digester consisted of 250 gm cow dung and 250gm water hyacinth along with 750 ml of water. The volume of biogas produced in each digesters was measured daily by water displacement method.

Key Words**:** *Municipal Solid Waste Management (MSWM),*
Solid Waste Management (SWM), Water Hyacinth, Ground Water, Detailed Project Report (DPR), Biogas Production.

1. INTRODUCTION

Solid waste is inevitable because by nature every human activity generates a certain amount of solid waste. The rate of solid waste generated tends to increase with the increase in population. Numerous debates are still going on about population growth in urban areas in developing countries. A large number of researchers agreed that the major factor that leads to an increased number of people in the cities is, seeking a better life, among others. Rapid development of cities has come with various environmental challenges concerning solid waste management (SWM) in developing countries. Solid waste arising from domestic, social and industrial activities is increasing in quantity and variety as a result of growing population, rising standards of living in most African countries and the development of technology. SWM is a well-known term that includes a wide range of activities and practices that depict unwanted residues of any given society. All forms of human activities result in the generation of waste which leads to an assortment of changes in the environment and harm to animals, plants and ecosystems. Therefore, proper implementation of a careful SWM will limit the harm done to the environment.

1.1 Muncipal Solid Waste Management in India

India is an agricultural based country with a present population of approximately 1286 millions. There are 29 states and 7 union territories in the country. Due to the rapid industrial growth, the urban population is increasing rapidly and this has resulted in an increase in the number of Class I cities from 394 in 2001 to more than 468 by 2011. The problem of SWM in India, in combination with rapid urbanization, population growth and unplanned development is on the rise day by day. Municipal solid waste includes 2 degradable (paper, textiles, food waste, straw and yard waste), partially degradable (wood, disposable napkins, sludge and sanitary residues) and non-degradable materials (plastics, leather, glass, rubbers, metals, ash from fuel burning like coal, briquettes or woods, dust and electronic waste). During the last 3 decades, the National Environmental Engineering Research Institute (NEERI) has carried out studies in more than 50 city and towns in India. Characterization of Municipal solid waste indicated that the waste consists of 30–45 % organic matter, 6–10 % recyclables, and the rest as inert matter. The per capita of solid waste generated daily in India ranges from about 100 gm in Class II towns to 500 gm in Class I cities. The organic matter in solid waste in developing countries is much higher than the waste in developed countries. According to a study conducted by Central Pollution Control Board (CPCB), 366 cities in India had been generating 31.6 million tons of waste in 2001 and are currently generating 47.3 million tons, a 50% increase in 1 decade. It is estimated that these 366 cities will generate 161 million tons of MSW in 2041, a five - fold increase in four decades. At this rate the total urban MSW generated in 2041 would is 230 million tones / year (630,000 tones per day) (TPD).

1.2 Muncipal Solid Waste in Nashik

Nasik city located in north-west of Maharashtra State in India, is 180 km away from Mumbai and 202 km from Pune. Nashik is the administrative headquarters of Nashik District and Nashik Division. Nashik, which has been referred to as the "Wine Capital of India", is located in the Western Ghats, on the western edge of the Deccan peninsula on the banks of the Godavari River. According to the Census of India (2011), Nashik had a population of 1,486,973 and present population is estimated to be 2,000,006 (projected in year 2018) with a total area of 259 km^2 which makes it the 4th largest urban area in Maharashtra in terms of population. Nashik is the 3rd most industrialized city in Maharashtra after Mumbai and Pune. Nashik has been on the tourist map of India, especially Hindu religious tourism, because of the legend that Lord Rama lived here during his exile.

The Nashik Municipal Corporation is collecting 300-350 MSW Tons/day. According to Detailed Project Report (DPR) for SWM, 2007 the average waste generation is only 218 gm/capita per day. This situation is either due to collection inefficiencies or due to high proportion of agriculture/horticulture farming, which helps in utilization of green waste for in-situ 3 composting. With better collection and transportation measures, the collection efficiency should increase.

The city is registering almost 20% extra growth rate compared to similar other cities in India. This is leading to rapid development of real estates, complexes, housing, shopping malls etc. Consequently the per capita MSW quantity has been estimated to reach 400 gm/day by 2011 as per Detailed Project Report (DPR) (2007). The population growth rate of the city during the last decade has been 63.98%. This type of growth-rate may be witnessed in the current decade also. Keeping above factors in view the projected quantity of MSW is 750 TPD by year 2015 and 1628 TPD by year 2031.

Analysis of city waste carried out recently, reveals 37.8% easily compostable (short-term biodegradable) materials, 19.50% hard lignite and long term (future) biodegradable and 16.20% textiles, rubber, plastic etc. These last 2 components having 35.70 % content in MSW have become a major cause of concern. Mounting heaps of high volumes of low density waste is a common scene around each compost plant. This has necessitated re-thinking of the integrated technological approach to solve MSW disposal problem towards a total solution in a sustainable manner. Looking to the recent trend of changing waste characteristics, increasing quantities of combustible materials and infrastructural bottlenecks, it became essential to upgrade overall MSW collection, storage, transportation and processing through integrated technological facility at Khat Prakalp site. This plant came into operation in 2000. However, this plant was small and could not deal with the entire 350 TPD waste reaching the plant and a backlog of >2.50 lakh MT waste was generated, which was piled put in two heaps close to the plant. Under JNNURM, NMC sought more funds and upgraded the plant to a capacity of 500 to 600 TPD.

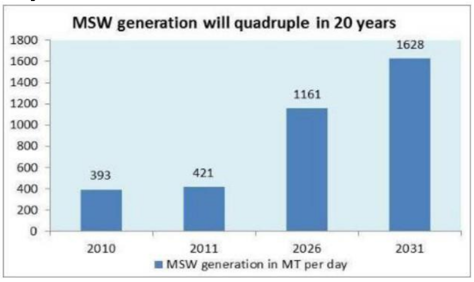

Fig.1: Projected Solid Waste Generation in Nashik

Table 1: Generation of Municipal Solid Waste (projections) (Source: Detailed Project Report (DPR) for SWM, 2007)

Sr No	Year	MSW MT/ day	Quantity MT / year	Remnants @ 15 % MT for Sanitary Land Fill
1	2006	300	109500	16425
2	2011	421	153665	23050
3	2021	827	301855	45278
4	2031	1628	594220	89133
Total			7520095	1128015
Volume in SLF at compaction density of 0.8=1410018				

1.3 Disposal Methods of Solid Waste

Disposal-in-lands is one of the most widely recognized strategies utilized in India for the disposal of

MSW. The current treatment strategies being followed are channelized towards the reduction in the amount of solid wastes that need to be land filled. It also reduces the recovery and utilization of materials in the discarded waste that forms a large part of the resources.

a) Landfill
b) Incineration
c) Pyrolysis
d) Composting
e) Anaerobic digestion

2. LITERATURE REVIEW

2.1 General

In order to understand the subject research, appropriate information within in the international and national scientific field was collected through studies of diverse literature from journals, books, environmental progress reports from different agencies, websites, reports by governmental agencies were gathered and reviews of other researchers on issues concurring with the research topic were included. A detailed literature review was then undertaken to gather information on the research in the field of impact of solid waste on the quality of groundwater and soil in different areas various parameters pertaining to anaerobic digestion are discussed. The characteristics and composition of the urban waste was studied by various workers in the world. Literature shows evidences of the work carried out on health risk assessment due to urban waste. The impact of urbanization on the water quality as well as soil quality was also studied by various researchers in different parts of the world. Various International and National organizations including private and government are working in the field of environment and are engaged in research and development in the field of waste management. International agencies like World Health Organization (WHO), Environmental Protection Agency (EPA) and United Nations Environment Programme (UNEP), as well as National agencies like Central Pollution Control Board (CPCB), Centre for Science and Environment (CSE) and National Environmental Engineering Research Institute (NEERI) are engaged in developing new technologies for waste management and its disposal including its characterization. A clear and detailed literature review at national and international level is given below. Waste management has become an issue of growing global concern as urban population continue to increase and consumption patterns keep changing. The health and environmental implications related to garbage disposal are mounting in urgency, particularly in developing countries. However, the growth of solid-waste market, increasing amount of resource scarcity and availability of new technologies are offering opportunities for turning waste into a resource. Cities in the developing world have undergone rapid urbanization during the past fifty years. Between 1987 and 2015, the number of urban dwellers is expected to double. Nearly 90 per cent of this increase will take place in the developing world, where growth rates exceed 3 % a year, 3 times that of the developed countries (UN-HABITAT 2003). There is a correlation exists between a community‟s income and the amount of solid waste generated. Wealthier individuals, who consume more than people on lower income, generate a higher rate of wastes. The processes of accelerated population growth and urbanization translate into greater volume of wastes generated. Globalization can promote economic growth, a desirable outcome however this economic growth in addition to the increase in the population and urbanization will seriously strain the municipal resources in order to deal with a booming amount of waste. According to United Nations Environment Programme (UNEP) report 2011 on Green Economy, every year an estimated 11.2 billion tonnes of solid waste are collected worldwide and decay of the organic proportion of solid waste is contributing to about 5 % of Global Greenhouse Gas (GHG) emissions. The increasing volume and complexity of waste related to economic growth are posing serious risks to ecosystems and human health.

2.2 Waste Generation, composition and characteristics

According to NEERI 2010 report the estimated waste generation rates in kg/capita/day for various population ranges are categorized as follows:

Cities with a population < 0.1 million (8 cities): waste generation 0.17–0.54 kg/capita/day.

Cities with a population of 0.1–0.5 million (11 cities) waste generation 0.22–0.59 kg/capita/day.

Cities with a population of 1–2 million (16 cities): waste generation 0.19–0.53 kg/capita/day.

Cities with a population > 2 million (13 cities): waste generation 0.22–0.62 kg/capita/day.

Das & Bhattacharyya estimated that MSW generated in Kolkata per year was approximately 17.6 lakh metric tones, with per capita values ranging from 0.2 to 6 kg /person/day and an average of 0.35 kg/capita/day. It was concluded that the per capita waste generation rate is changing decade to decade (0.2kg/capita in 1981 and 0.47 kg/capita will be in 2035) due to the change in economic growth. Late & Mule concluded that the average degradable material present in solid waste collected from representative houses was 83.50 %, whereas the average non - degradable material present in cumulative solid waste collected from selected houses was 16.50 %. However, the physico- chemical parameters of the solid waste collected from disposal sites were found in moderate range in Aurangabad city. Kumar & Gaikwad reported that MSW contains large organic fraction (30 - 40 %), ash and fine earth (30-40 %), paper (3–6 %) along with glass, plastic and metal (each less than 1%), calorific value of refuse ranges between 800- 1000 kcal/kg and C/N ratio ranges between 20 and 30. Keisham & Paul reported that between 2000 and 2025, the waste composition of Indian garbage will be in the following proportion: a. Organic Waste will go up from 40 % to 60 %. b. Plastic will rise from 4% to 6%. c. Metal will escalate from 1 % to 4 %. d. Glass will increase from 2% to 3%. e.

Paper will climb from 5 % to 15 %. f. Others (sand, ash, grit) will decrease from 47 % to 12 %. Lingan & Poyyamoli reported that the organic fraction of waste occupies 58.50 % of the total waste, followed by inert materials with 11.50 %, cloths 2.54 %, fine earth 8.6 %, plastic 3.57 %, glass 2.80 %, paper 9.14 % and others 0.61%. These major organic fractions of waste include food, market waste, garden waste that are from daily market and residence of the Cuddalore city. Parvathamma reported that the composition of urban MSW in India is 51% organics, 17.5% recyclables (paper, plastic, metal, and glass) and 31 % of inert. The moisture content of urban MSW is 47% and the average calorific value is 7.3 MJ/kg (1745 kcal/kg). The composition of MSW in the East, North, West and South regions of the country varied between 50 - 57 % of organics, 16 - 19 % of recyclables, 28 - 31 % of inert and 45 - 51 % of moisture. The calorific value (CV) of the waste varied between 6.8 - 9.8 MJ/kg (1,620-2,340 kcal/kg). Bhide & Sundaresan carried out a study to identify the fertilizer value of nitrogen, phosphorus and potassium in MSW and confirmed their ranges between 0.5 - 0.7, 0.5 - 0.8 and 0.5 - 0.8 % respectively. Pynthamil & Amarnath reported that composition of MSW in Kanchipuram district mainly consisted of biodegradable 56%, plastic 11%, paper 10%, glass 2%, cloth 1%, footwear 1%, metal 0.5% and miscellaneous 18.5%. Understanding the quality of ground water is as important as that of its quantity, since it is the main factor that determines its suitability for drinking, domestic use, agricultural use and industrial purposes, reported by Rajkumar et al.. Kamboj & Choudhary observed that pH of water in different areas around dumping sites in Delhi ranged between 6.42 - 7.76, conductivity between 1220 µmhos/cm - 2945µmhos/cm and Total Dissolved Solids (TDS) from 840 mg/l to 2061 mg/l. The very high Electrical Conductivity (EC) and Total Dissolved Solids (TDS) observed in the groundwater suggests a downward transfer of leachate into groundwater as reported earlier by Mor et al. and Longe & Enekwechi. Alewunmi et al. recorded the TDS value of 2000 mg /l in surface water near dumping area in Ondo state, in the western part of Nigeria. Shanthi et al. observed that the EC ranged between 512 µs/cm to 951 µs/cm, TDS was found between 545 mg/l to 996 mg/l, the value of chlorides was found to be in the range of 114 mg/l to 287 mg/l and the concentration of fluoride in the studied water samples ranged from 0.1mg/l to 1.2 mg/l in the groundwater samples taken near municipal solid waste dump sites in Coimbatore city. A study on groundwater quality in Perur block, Coimbatore district reveals that the value of potential of hydrogen (pH), Total Dissolved Solids (TDS), Electrical Conductivity (EC) and total hardness (TH) ranges between 6.6 to 7.9, 968 - 2010 mg/L, 1020 - 2910 µ mho/cm and 855 - 2432 ppm respectively Jothivenkatachalam et al.. Niloufer et al. observed that pH levels varied between 7.1 to 7.8, TDS between 200-1700 mg/l, sodium 446.9 – 1000 mg/l, potassium17-127.9 mg/l, nitrates between 0.25 - 45.2 mg/l and chlorides from 270 to 804.79 mg/l near the MSW dump yard in Vijayawada city, Andhra Pradesh. The leachate generated from solid waste dumps may have the potential to pollute the surrounding water sources but the most serious problem is groundwater contamination. It is proved that this polluted groundwater is unfit for drinking and causes health complaints like nausea, jaundice, asthma, miscarriage and infertility. The environmental impacts of leachate pollution on ground water supplies in Nigeria have also been reported by Akinbile& Yusuf. Rajkumar et al. studied groundwater contamination due to open dump of municipal solid waste in Erode, Tamilnadu. It was observed that the abundance of major ions were in the following order $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$ = $HCO_3>Cl>SO_4^{2-}>NO^{-}>CO_3^{2-}$. The concentrations of cations such as Na and Mg^{2+} exceeded the 3 maximum allowable limits for drinking water at some locations are near to the MSW dumping yards in the study area. However, Ca^{+} concentrations in the groundwater were within the permissible limits in February 2009. The anions such as SO_4^{2}, NO_3 and F were also within the permissible limits for drinking except at one location which is near to the area of location of tanneries. The chloride concentrations are found to exceed the permissible limits during February 2009, in 4 locations, out of which, three are very near to the MSW dump yards in the study region. Mahadevaswamy et al. published a report on Groundwater quality of Nanjangudu Taluk, Mysore. In Nanjangudu area, the aquifers are mostly open geochemical system, in which the chemical composition is controlled by the rock water interaction during the time of residence and it was identified by using Gibbs diagram. Groundwater samples were collected from 41 wells and analysed as per IS methods for various Physico-chemical parameters such as EC, pH, TDS, Ca, Mg, Na, K, HCO_3, CO_3, Cl, NO_3 and SO_4. Thematic maps were prepared to illustrate the spatial distribution of groundwater in the Taluk. Ramesh et al. observed that the groundwater type was Cl, HCO_3 and mixed Ca, Mg. Percentage of sodium showed that most of the samples fell under the good to permissible level and few samples fell under doubtful to unsuitable category, indicating the dominance of ion exchange and Weathering. Residual Sodium Carbonate were < 1.25meq/l and fell within the safe category for irrigation purpose in Periyakulam Taluk of Theni District. The groundwater quality in Coimbatore south Taluk was evaluated for its hydro-chemical composition and suitability for irrigation by researchers Murali & Elangovan. Higher concentration of EC was observed during pre-monsoon season when compared to post-monsoon season and majority of sample fell within the permissible limit for irrigation use during both the seasons. It is observed that majority of the samples fell within the low sodium water and can be used for irrigation purposes without any hazard from the Percentage of sodium and sodium adsorption ratio. Based on residual sodium carbonate, 40.77% the groundwater samples during Pre-monsoon and 22.29% during Post-monsoon was not suitable for irrigation purposes. Water quality Index is a useful method to understand the quality of water in order to determine the suitability for various uses. Murali et al. carried out a study on groundwater quality in Coimbatore South Taluk and it was observed that Water Quality Index (WQI) in all the sampling location was reported to be less than 100 indicating that the water is suitable for human use. Mangukiya et al. computed WQI in Surat city and observed that the values ranged from 22.55 to 247.17. It was categorized into 5 types "excellent water" to "water unsuitable for drinking" i.e. if WQI is less than 50 then it's excellent water, 50- 100 good water, 100-200 poor water, 200-300 very poor water and greater than 300, water is considered unsuitable for drinking. Desai & Tank Studied ground water quality in Gandhi Nagar Taluk in Gujarat, it shows that water quality of bore wells in Gandhi Nagar Taluk is poor for drinking purpose as per Water Quality Index (WQI) So, this water can be used for drinking purpose after purification treatment. The results of WQI of Post monsoon (POM) and Premonsoon (PRM) were compared. The PRM samples exhibited poor quality in greater percentage (60%) when compared with POM. This may be due to effective leaching of ions, over exploitation of groundwater, direct discharge of effluents and agricultural impacts studied by Vasanthavigar et al.. Anaerobic digestion it has been known for several centuries that combustible gas is generated when organic waste is allowed to rot in huge piles. Anecdotal evidence indicates that biogas was used for heating bath water in Assyria during l0th century BC and in Persia during 16th century. In 17th century, Van Helmond recorded that decaying organic material produced flammable gases. Tietjen established in their independent researches that this combustible gas ismethane. Abbasi et al. reported that the formation of methane during the decomposition of organic matter was through a microbiological process. He also reported that methane perhaps formed due to micro- organism-mediated reaction between hydrogen and carbon dioxide. Abbasi et al. also detailed that fermentation of complex materials occurs through oxidation- reduction reactions to form hydrogen, carbon dioxide, and acetic acid. He also demonstrated that hydrogen then reacts with carbon dioxide to form methane. He also assumed that acetic acid through decarboxylation forms methane. Anaerobic digestion is often considered to be a complex process the digestion itself is based on a reduction process consisting of a number of biochemical reactions taking place under anoxic conditions. Methane formation in anaerobic digestion involves four different steps: hydrolysis, acido-genesis, aceto-genesis, and methano-genesis. Generally, in an anaerobic digestion process, the rate limiting step can be defined because the step that causes process failure under imposed kinetic stress studied by Aslanzadeh. In other words, during a context of a continuous culture, kinetic stress is defined because the imposition of a constantly reducing value of the solids retention time until it is lower than the limiting value; hence it will result in a washout of the microorganism studied by Paslotathis & Girardo- Gomez. Ma et al., Lu et al. And Skiadas et al. reported that the rate-limiting for complex organic substrate is the hydrolysis step due to the formation of toxic by- products (complex heterocyclic compounds) or non-desirable Volatile Fatty Acids (VFA) formed during hydrolysis step , whereas methano-genesis is the rate limiting step for easy bio-degradable substrates. The different phases during the hydrolysis stage depend greatly on the nature of the substrate. The transformation of cellulose and hemicellulose generally takes place more slowly than the decomposition of proteins. In general, during acido-genesis phase, simple sugars, fatty acids and amino acids are converted into organic acids and alcohols. Products which cannot be directly converted to methane by methano-genic bacteria are converted into methano-genic substrates. Volatile Fatty Acids and alcohols are oxidized into methano- genic substrates like acetate, hydrogen and carbon dioxide, VFA, with carbon chains longer than one unit are oxidized into acetate and hydrogen during aceto- genesis phase. In the methano-genic phase, the production of methane and carbon dioxide from intermediate products is carried out by methano-genic bacterial under strict anaerobic conditions studied by Gerardi. Agulanna et al. studied laboratory scale experiment in anaerobic process at 37^{o}C using organic substrate materials sorted from MSW obtained from the central market Owerri Imo State Nigeria. The total volumetric load of the reactor was 62.8 nliters of substrate slurry. Evaluation of process dynamics of the reactor was limited to the use parameters such as Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Operating temperature, biogas yield, methane content and hydraulic retention time. The bioreactor operated in nine days hydraulic retention time at mesophilic temperature. COD and TOC reduction efficiency were quite appreciable at 95.5% and 87.6% respectively. Experimental maximum biogas yield of the bioreactor was 17.94l per kilogram of raw feedstock material. This value was consistent with the theoretical maximum biogas yield of 18.55l/kg based on a modified Gompertz equation. The first order kinetic constant for COD reduction based on Fenton‟s 1st order reaction was 0.312 day. Furthermore, the estimated biogas energy yield per unit nominal operational power input was 31292J/w. Anaerobic co-digestion of grass silage, sugar beet tops and oat straw with cow manure was evaluated by Lehtomaki et al. (2007) in semi- continuously fed laboratory continuous stirred tank reactors (CSTRs). It showed that it is feasible with up to 40% of crops in the feedstock. The highest specific methane (CH_4) yields of 268, 229 and 213 CH_4 kg^{-1} added in co- digestion of cow manure with grass, sugar beet tops and straw, respectively, were obtained when fed with 30% of crop in the feedstock. Compared with that in reactors fed with manure alone at a similar loading rate, volumetric methane production increased by 65, 58 and 16% in reactors fed with 30% of sugar beet tops, grass and straw, respectively, along with manure. Patil et al. studied on anaerobic co-digestion of water hyacinth with poultry litter and water hyacinth with cow dung in different ratios in 250 ml batch digesters for a 60 days retention period. Co-digestion was carried out in mesophilic temperature range of 30 to 37°C with a total solid concentration of 8% in each sample (fermentation slurry). The biogas was collected by the downward displacement of water, and was subsequently measured. The cumulative biogas produced was maximum at 0.39 l/g for co-digestion of water hyacinth with poultry litter. But it was observed that maximum biogas production for co-digestion of water hyacinth with cow dung was 0.26 l/g. Zhang et al. evaluated anaerobic digestibility and biogas and methane yields of the food waste. This test was performed at 50^0C using batch anaerobic digestion mode. The daily average moisture content (MC) and the ratio of volatile solids to total solids after week sampling determined were 70% and 83%, respectively, while the weekly average MC and were 74% and 87%, respectively. The food waste contained well balanced nutrients for anaerobic microorganisms as per nutrient content analysis. The methane yield after 10 days of digestion was 348 ml/g and 435 mL/g after 28 days of digestion. The average methane content of biogas was 73% and the average destruction at the end of the 28-days digestion test was 81%. The methano-genic evaluation for the production of methane gas using lingo-cellosic weeds such as water hyacinth along with cow dung were quantified by Pachaiyappan et al.. In their study, maximum methane production was observed in 100% cow dung sample A (control) on 2nd day of incubation period followed by 50% WH+ 50% CD which showed methane production at 2.8% on 7thday followed by 25% WH + 75% CD (1.25%). However, there was no methane (CH_4) production observed from 100% water (H_2O) hyacinth (control) containing vials, but 55% of carbon dioxide (CO_2) was observed over a period of 30 days of incubation. This wide difference suggested that there was no contribution of biogas production from water hyacinth alone when incubated under anaerobic condition. Hence from the 3 different ratios, the final result indicates maximum methane $(CH_4)_{max}$ (24 %) was observed in the ratio of 50 % WH + 50 % CD followed by 25 % WH + 75 % CD (21.42 %) on 30th day and 75 % WH + 25% CD combination showed very low level of methane (8.25%). The different combinations using cow dung and water hyacinth were tried and encouraging results were obtained at 50% Water hyacinth and 50% cow dung combination.

3. OBJECTIVES

The main objective of the study is to find an effective method of disposing enormous quantity of solid wastes and methods of recovering materials and energy from wastes, in a most cost effective and environmental friendly manner. In this regard, this study examines the prospects of disposing MSW in Nashik city. On the other hand, energy crisis plays a vital role in finding alternate source of energy. The objectives of this research were formulated by considering the above points. This research mainly focuses on the groundwater quality of around the MSW open dumping areas and energy recovery studies on food waste, organic fraction of MSW, vegetable waste and fruit waste.

The main objectives of this study are:

A) To assess ground water quality in Nashik Corporation and selected town Panchayats where MSW is indiscriminately dumped without any segregation or treatment.

B) To compare groundwater quality with Bureau of Indian Standards (BIS) (IS:10500-1991), World Health Organization (WHO) standards and evaluation of Water Quality Index(WQI).

C) To assess the groundwater quality parameters to identify the suitability for irrigation purpose through analytical and graphical methods.

D) To utilize the water plant (water hyacinth) in the anaerobic co-digestion of food waste, organic fraction of MSW, vegetable waste and fruit waste that poses a serious disposal problem.

E) Anaerobic digestion studies on individual components such as food waste, organic fraction of municipal solid waste, vegetable waste, fruit waste with water hyacinth and cowdung.

F) To develop a model for anaerobic co-digestion of food waste, organic fraction of municipal solid waste, vegetable waste, fruit waste with water hyacinth and cowdung.

4. PROBLEM STATEMENT

4.1 Problems due to open dumping of MSW

India is now facing a major contrast between its increasing urban population and available services and resources. SWM is one such service where India has a huge gap to fill. Appropriate MSW disposal systems to deal with the mushrooming amount of wastes are absent. The current SWM services are inefficient, expensive and pose a threat to the public health and environmental quality. Inappropriate solid waste management deteriorates public health, causes environmental pollution, pick up the pace of natural resources degradation, causes climate change and greatly impacts the citizens quality of life. The entire quantity of MSW generated in 108 wards of Nashik city is dumped near to Gaulane in dumping yard located at the out skirt of the City. The open dumping of solid waste practiced in dump yards in Nashik city and town Panchayats of Gaulane poses a major problem in these areas.

The key issues due to open dumping of solid wastes were classified into two categories namely:

A) Environmental impacts- Surface and groundwater contamination- Contamination of water may occur when leachate from the dumpsite, flow on or under the surface and reaches groundwater or surface water. Wastes sometimes deposited directly into water at dumpsites, results in the direct chemical and physical contamination of surface water.

B) Impact on public health and safety- Impact on public health and safety- The resultant smoke had affected the

10,000 residents living in various colonies near the dump yard surrounding Pandavleni and Gaulane. The smoke from solid wastes results in respiratory complaints, dizziness, and headaches in the short-term as well as potentially more serious diseases such as cancers and heart disease in the long term.

Fig.2: Nashik Open Dumpyard

One of the primary health risks of dumps is that the spreading of diseases (diarrhoea, hepatitis etc.). The ways in which such infection spreads are numerous but are often related to direct contact with the waste (e.g., clinical waste, faecal matter) by scavengers and other unauthorized persons being on the site. Another way is through vectors such as foraging animals, rats, birds, flies and mosquitoes etc. Additionally the recovered lands are subsequently cultivated (for urban dwellers) which may lead to bio accumulation of metals which can constitute a health risk.

The present citizens of India are living in times of exceptional economic growth, rising hopes and rapidly changing lifestyles, which will raise the expectations on public health and quality of life. Remediation and recovery of misused resources will also be expected but these expectations, if not met, might result in a low quality of life for the citizens. Pollution of air, water or land results in long-term reduction of productivity, leading to a deterioration of the economic condition of a country. Therefore, controlling pollution to reduce the risk of poor health, to protect the natural environment and to contribute to our quality of life is a key component of sustainable development.

4.2 Energy crisis

India is marching towards achieving a desirable status of a developed country with rapid strides. Ensuring uninterrupted supply of energy to support economic and commercial activities is important for sustainable economic growth. In a true sense, sustainable development should be widely spread in all three dimensions (3D) - social, economic, and environmental. For all these areas, energy is perhaps the most important aspect. The production and the consumption patterns at the local and the global scale, determine not only all the other activities in society, but also some major environmental issues like pollution, greenhouse effect, and desertification.

Global depletion of energy supply due to over utilization is turning into a major problem of the present and future community. It is estimated that the fossil fuels will be running out by next few decades, so government and industries are constantly looking out for more efficient and cost effective technologies. Another major crisis is the generation and usage of Power and the Energy consumption in India which is shown below Although electricity is a cheap commodity, it is very scarce since India has an energy deficit of 200,000 MW (Source: Ministry of power of India).

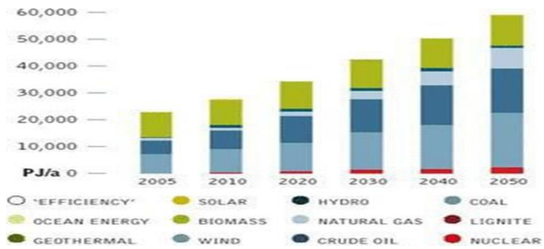

Fig.3: Energy consumption in India
(Source: Energy Statistics 2012, Ministry of power of India Govt. Of India)

The MSW generated from urban and rural population can be effectively transformed into valuable energy resource by making use of modern energy conversion technologies. One technology that can treat the organic fraction of wastes successfully is anaerobic digestion, in which digestion of wastes produces methane gas which is of calorific value.

There are 10 lakes in Nashik district and they are often posed with the problem of removal of water hyacinth. These problems in lakes and streams are due to the enormous growth of Water hyacinth, biologically known as "Eichorniacrassipes", a plant which grows in shallow temporary ponds, large lakes and rivers. This water hyacinth has attracted much attention due to its quick and congested growth, leading to serious problems for biodiversity, alteration of water characteristics, blockage of drainages and rivers and its enormous contribution to environmental pollution. Although there are many methods for eradication of hyacinth, there has been an increasing potential for utilization of water hyacinth for biogas production and the reason being that the water hyacinth is rich in hydrocarbon. The attention of researchers in disposal of Eichorniacrassipeshas increased in recent years.

5. METHODOLOGY

The methodology consists of groundwater collection during December 2018 to March 2019. These samples were collected around Khat Prakalp dump yard and was analysed for physicochemical parameters. The methodology adopted in this study is presented below. Solution to the MSW disposal through AD was sought. Nashik district is situated in the northwest part of Maharashtra holding many advantages of its own. Nashik, which has been referred to as the "Wine Capital of India", is located in the Western Ghats, on the western edge of the Deccan peninsula on the banks of the River Godavari. Nashik was elevated as a municipal corporation in 1991.

Agriculture is the main source of living for the people in and around Nashik Corporation. Solid wastes generated from 108 wards in Nashik Corporation is dumped in Khat Prakalp dump yard, 12 km away from the city. Although land filling and composting methods of solid waste disposal are practiced, it's not properly organized by the agents. Huge portion of solid waste is dumped in this site which is close to the irrigation land. During the rainy season, the surface water percolating through the garbage dissolves or leaches harmful chemicals that are carried away from dumpsites to the surface or sub-surface and reaches the nearby land or groundwater respectively and this causes groundwater pollution.

5.1 Description of Khat Prakalp dump yard

The domestic wastes are being brought to the Khat Prakalp dump yard by Ghantagadi, lorries& tractors and these wastes are then processed through various processing units of Khat Prakalp dump yard such as closure, composting yard, lagoons, landfill and segregation area.

A) The new processing plant includes the Following:
B) Pre- sorting unit with a capacity of 500 TPD
C) Aerobic composting unit
D) Inert processing unit with capacity of 50 TPD
E) Leachate treatment plant with a capacity of 0.4 mld leachate
F) Refuse derived fuel pant with capacity of 150 TPD
G) Animal Carcass Incinerator with a capacity of 250 kg per hour
H) Sanitary landfill in an area of 2 hector The map of Nashik City are shown in below fig. 4 .

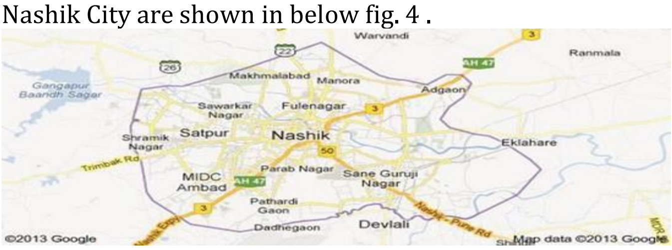

Fig.4: Nashik City Map (Source : Google Map)

5.2 Location of Groundwater Sampling Stations

The groundwater sampling locations in and around Location of dump yard are designated as (W_1 to W_6) are presented in Table 2. The ground water samples were collected for a period of four months (December to March of 2018-2019).

Table 2: Groundwater sampling stations in and around dump yard (Sampling stations distance were measured from the disposal site)

Stations	Latitude	Longitude	Distance (m)	Use of water
W1	19093.15N	73073.72E	600	Domestic
W2	19093.05N	73073.71E	650	Domestic
W3	19093.18N	73074.08E	136	Irrigation
W4	19093.22N	73074.16E	265	Irrigation
W5	19093.30N	73074.16E	148	Irrigation
W6	19092.81N	73074.30E	125	Irrigation

Fig. 5: Locations of selected wells around Gaulane dump yard

5.3 Methods used for collection of groundwater samples

Groundwater Sampling can be collected by any of the following techniques such as Composite sampling which is a method of collection of numerous individual discrete samples taken at regular intervals over a period of time and Grab sampling which is a technique where samples are collected at one time at the point in time. For this study, groundwater samples were collected around MSW disposal site by Grab sampling method. Groundwater samples were collected from all the sampling points locations. Ground water samples were collected for a period of 4 months (December 2018 to March 2019), which includes winter and summer seasons of Nashik. Two litre plastic bottles were used to collect groundwater samples and before collecting the test samples, the containers were rinsed thoroughly with the water being sampled. After collection of samples, these bottles were instantly sealed and capped with wax and transported to Environmental Engineering laboratory of Brahmavalley College of Engineering and Research Institute (BVCOE & RI) in Nashik for physico-chemical analysis. Ground water samples collection and preservation were done as per standard methods.

5.4 Assessment of Groundwater quality for drinking

It is needless to emphasize the importance of water in our life. Without water, there is no life on our planet. The types of analysis could vary from simple field testing for a single analysis to laboratory based multi-component instrumental analysis. The measurement of water quality is a very exhaustive and time consuming process and a large number of quantitative analytical methods are used in this study. The selected water quality parameters were Potenz Hydrogen ion concentration, Electrical conductivity (EC), Total hardness (TH), Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium(Na), Potassium (K), Chloride (Cl^-), Bicarbonate (HCO_3), Sulphate (SO_4), Nitrate (NO_3) and Fluoride (F) for assessing the accuracy of results, the groundwater quality data are plotted on an anion- cation balance control chart. The sum of milli equivalents of cation should be equal to the sum of milli equivalents of cation perlitre. Sampling methods and water analysis were carried out as per the standard procedure of American Public Health Association

(APHA 1995). All the instruments were calibrated appropriately for analysis according to the calibration standards prior to the measurements. Various methods according to APHA 1985, WHO 1984, 1992, IS:10500-1991, 1993 adopted for the analysis are listed in Table 3.2. Water quality is examined through detailed chemical analysis of a wide range of parameters. Chemical analysis forms the basis of interpretation of quality of water inrelation to source, geology, climate and use. The units of measurement are most important in chemical analysis of water quality.

Table 3: Methods adopted for analyzing parameters of groundwater

Parameters	Units	Methods used
Hydrogen ion concentration	-	pH analyzer
Electrical Conductivity	(μmohs/cm)	EC analyzer
Total Hardness	(mg/l)	EDTA titration
Total Dissolved Solids	(mg/l)	TDS analyzer
Calcium	(mg/l)	Titration
Magnesium	(mg/l)	Titration
Sodium	(mg/l)	Flame photometer
Potassium	(mg/l)	
Chloride	(mg/l)	AgNO3 titration
Bicarbonate	(mg/l)	Acid titration
Sulphate	(mg/l)	Spectrophotometer
Nitrate	(mg/l)	Colorimeter
Fluoride	(mg/l)	Spectrophotometer

5.5 Water Quality Index (WQI)

Water quality index is an important parameter for the assessment and management of groundwater. WQI indicates a single number (like a grade) that expresses the overall water quality at a certain location and time, based on several water quality parameters. WQI is an indicator, which reflects the composite influence of a number of water quality parameters which are significant for a specific beneficial use. Water quality index based on chemical and physical measurements by assessing rating scales and weighing of various parameters such as pH, TDS, TH, and Alkalinity. The weightage of each parameter are assigned according to its relative importance in overall stream water quality.

WQI calculation- WQI was carried out through Horton‟s method. A set of constituents that collectively represent water quality was chosen and they were combined in several ways to give real index value. For calculation of WQI, selections of parameters are of great importance. The importance of the parameters depends on the intended use and 9 physico-chemical parameters such as hydrogen ion chemistry (pH), TDS, TH, Ca, Mg, HCO_3^-, Cl^-, SO_4 and NO_3. The water quality index can be obtained by Brown‟s equation (Tyagi et al. 2013) as given below,

$$WQI = \sum (i = 1ton) W_i \times Q_i \quad \text{................(1)}$$

$$W_i = \frac{k}{s_i} \quad \text{................(2)}$$

$$Q_i = \frac{C_i - C_{id}}{C_s - C_{id}} \times 100 \quad \text{..................(3)}$$

$$k = \frac{1}{\sum_{i=1ton} \frac{1}{S_i}} \quad \text{..................(4)}$$

Where,
Parameter k = Constant of proportionality
W_i=Unit weight of i_{th}
S_i= Standard value for the i_{th}
Q_i= Quality rating for i_{th} parameter,
C_i= measured concentration for i_{th} parameter which is estimated value
C_{id}= ideal concentration value for i_{th} parameter
C_s= standard concentration for i_{th} parameter recommended by standard (S_i)
The water quality parameters, ideal value and standard value are presented in Table 4.

Table 4: Values of S_i and C_{id} for WQI

Sr.no.	Parameters	Si	Cid
1	Hydrogen ion concentration	8.5	7
2	Total Dissolved Solids	500	0
3	Total Hardness	300	0
4	Calcium	75	0
5	Magnesium	30	0
6	Bicarbonate	200	0
7	Chloride	250	0
8	Sulphate	200	0
9	Nitrate	45	0

Different ranges of WQI and their status of water quality on the basis of increasing scale indices are given in Table 5 (Tiwari and Mishra 1985, Murali et al. 2011).

Table5: Water quality index values and water quality

Sr.no.	Range	Water class
1	< 25	Excellent
2	26-50	Good
3	51-75	Poor
4	76-100	Very Poor
5	>100	Unsuitable

5.6 Assessment of groundwater quality for irrigation

Groundwater plays an important role in agriculture, for both watering of crops and for irrigation of dry season crops. The quality of ground water varies from place to place along with the depth of water table. It also varies with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it. Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water (H_2O) determine its quality for irrigation use. Quality of water is an most important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine the suitability of groundwater for irrigation purpose are (1) Salinity Hazard, (2) Sodium Adsorption Ratio (SAR), (3) Percentage Sodium (% Na), (4) Residual Sodium Carbonate (RSC), (5) Kelley"s Ratio (KR), and (6) United States of Salinity Laboratory (USSL) classification.

A) Salinity hazard- Salinity is a measure of the content of salt in water. Salt is highly soluble in surface and groundwater and can be transported with water movement. Salinity can be measured in terms of Electrical Conductivity. EC is the ability of an electric current to pass through water and is proportional to the amount of dissolved salt in the water, especially, the amount of charged (ionic) particles. EC is a measure of the concentration of dissolved ions in water and is reported in μmhos/cm (micromhos per centimeter) or μS/cm (microsiemens per centimeter). "Salinity" can include hundreds of different ion showever, relatively few make up most of the dissolved material in water Such as Cl, Na, NO_3, Ca , Mg, HCO, and SO_4. High concentration of EC in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salt present in the water not only affects the growth of the plants directly, but also affects the soil structure, permeability and aeration.

Therefore, irrigation water with high EC reduces yield potential. Quality of groundwater based on salinity hazard is given in Table 6.

Table 6: Groundwater quality based on salinity hazard

Symbol	EC range (μmohs/cm)	Water class
C1	< 250	Low
C2	251 – 750	Medium
C3	751 – 2250	Medium-High
C4	2250 – 3000	High
C5	> 3000	Very High

B) Sodium Adsorption Ratio (SAR)- A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of alkali soil. Na or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of sodium adsorption ratio SAR. If the proportion of sodium is high, the alkali hazard is high and conversely, if calcium and magnesium predominate the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which Na is absorbed by the soil (Mass 1990). If water used for irrigation is high in sodium and low in Ca, the CEC complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the SAR (Richards 1955).

$$SAR = \frac{Na^{++}}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}} \quad \text{…………….(5)}$$

Where, Na^{++}, Ca^{++} and Mg^{++}, all the ions concentrations are expressed in meq/l. General classification of irrigation water based on SAR values are given in Table 7 (Ragunath 1987).

Table 7: Classification of water based on SAR

Range	Type of water
Below 10	Low Sodium water
10-18	Medium Sodium water
18-26	High Sodium water
Above 26	Very High Sodium water

C) Percentage Sodium (%Na)- Percentage sodium is another important factor to study sodium hazard. It is calculated as the percentage of sodium and potassium against all cationic concentration. Its also used for adjusting the quality of water for the use of agricultural purpose. The use of high percentage sodium water for irrigation purpose shunts the plant growth. Sodium reacts with soil to reduce its permeability (Todd 1980). Sodium percentage in water is a parameter computed to evaluate the suitability for irrigation. Doneen (1964) & Dhirendra et al. (2009) method is used to calculate the % Na as given in equation 6 and groundwater quality based on % Na is given in table 8.

$$Na\% = \frac{Na^{2+}+K^{+}}{CA^{2+}+Mg^{2+}+K^{+}} \times 100 \quad \text{…………(6)}$$

Where, Na^{++}- sodium ions, Ca^{++} - calcium ions and Mg^{++} - magnesium Ions and K^{+} - potassium are expressed in meq/l.

Table 8: Groundwater quality based on sodium percentage

Sodium percentage	Water class
Below 20	Excellent
21-40	Good
41-60	Permissible
61-80	Doubtful
Above 81	Unsuitable

D) Residual Sodium Carbonate (RSC)- In addition to sodium adsorption ratio and percentage sodium, the excess sum of carbonate and bicarbonate in groundwater over the sum of calcium and magnesium also influences the unsuitability of groundwater for irrigation (Richard LA 1955). The RSC is calculated using the equation 7 and classification of irrigation water are given in Table 9 (Ragunath 1987).

$$RSC = (HCO_3^-) - (Ca^{2+} + Mg^{2+}) \quad ....(7)$$

Where all the concentrations like HCO_3- - carbonate ions, Ca^{++} - calcium ions and Mg^{++} - magnesium ions are expressed in meq/l.

Table 9: Classification of water based on RSC

Range	Water class
Below 1.25	Excellent
1.25-2.50	Good
Above 2.50	Unsuitable

E) Kelley's Ratio (KR)- Kelley et al. (1940) have suggested that the sodium problem in irrigational water could be very conveniently worked out on the values of KR. KR more than 1 indicates an excess level of sodium in water. Hence, water with KR less than 1 is suitable for irrigation, while those with a ratio more than 1 are unsuitable for irrigation. The formula used to estimate this ratio is shown in equation 8. Classification of irrigation water based on KR values is given in Table 10 (Ragunath 1987).

$$KR = \frac{Na^{2+}}{Ca^{2+} + Mg^{2+}} \quad ....(8)$$

Where all the concentrations such as Na^{++} sodium ions, Ca^{++} - calcium ions and Mg^{++} - magnesium ions are expressed in meq/l.

Table 10: Groundwater quality based on KR

Range	Water class
Below 1	Suitable
Above 1	Unsuitable

F) United States Salinity Laboratory (USSL) Classification- In order to assess the suitability of groundwater for irrigational purpose, the values of EC and SAR are compared and plotted on USSL diagram, which gives direct indication of salinity and alkali hazards. Classifications of irrigation water based on USSL are presented in Table 11 (U.S. Salinity Laboratory Staff 1954).

Table11: Groundwater quality according to USSL classification

Sr.no	USSL Classification	Water class
1.	C1 – S1 (Low Salinity – Low Sodium) C2 – S1 (Medium Salinity – Low Sodium) C3 – S1 (High Salinity- LowSodium) C4 – S1(Very High Salinity- Low Sodium)	Good
2.	C1 – S2 (Low Salinity – Medium Sodium) C2 – S2 (Medium Salinity-Medium Sodium) C3 – S2 (High Salinity – Medium Sodium) C4 – S2 (Very High Salinity – Medium Sodium)	Moderate
3.	C1 – S3 (Low Salinity – High Sodium) C2 – S3 (Medium Salinity – High Sodium) C3 – S3 (High Salinity – High Sodium) C4 – S3 (Very high Salinity – High Sodium)	Poor
4.	C1 – S4 (Low Salinity – Very High Sodium) C2 – S4 (Medium Salinity – Very High Sodium) C3 – S4 (High Salinity – Very High Sodium) C4 – S4 (Very High Salinity – Very High Sodium)	Very poor

5.7 Anaerobic Digestion

The management of municipal solid waste (MSW) underwent major developments during the past 20 years. At the end of the 80's, land filling and mass burn incineration was still the major methods by which MSW was disposed. Composting made up a small percentage of the disposal and was on the decline because of major quality challenges due to heavy metals and inert materials in the end - product. Recycling was limited to paper, glass and easily recoverable materials. Major progress was made in all the areas of waste management but the introduction of anaerobic digestion into the treatment of MSW was one of the most successful and innovative technology developments observed during the last 20 years in the waste management field. Anaerobic digestion has become fully accepted as a proven and even preferred method for the intensive bio-degradation phase of organic fractions derived from MSW.

Anaerobic digestion can be performed as a batch process or a endless process. In a batch system, biomass is added to the reactor at the start of the process and the reactor is then sealed for the rest of the process. In its simplest form, batch processing needs inoculation with already processed materials to start the anaerobic digestion. In a typical scenario, biogas production will be formed with a normal distribution pattern over time. Operators can use this fact to determine when the process of digestion of the organic matter has completed. There can be severe odour issues if a batch reactor is opened and emptied before the process is well completed. In continuous digestion processes, organic matter is constantly added (continuous complete mixed) or added in stages to the reactor (continuous plug flow; first in – first out). Here, the end products are constantly or periodically removed and result in constant production of biogas. A single or multiple digesters in sequence may be used and examples of this form of anaerobic digestion include continuous stirred-tank reactors, up flow anaerobic sludge blankets, expanded granular sludge beds and internal circulation reactors. Mshandete & Parawira 2009 reported on Co-digestion is the simultaneous digestion of more than one type of waste in the same unit. Advantages include better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing . Ilori et al. (2007), Adeyanju (2008) and Babel et al. (2009) studies have shown that co-digestion of several substrates, for example, banana and plantain peels, spent grains and rice husk, pig waste and cassava peels, sewage and brewery sludge, among many others, have resulted in improved methane yield by as much as 60% compared to that which was obtained from single substrates . In this study, co-digestion batch study is adopted using Water hyacinth and cow dung with different types of wastes such as food waste, OFMSW, vegetable waste and fruit Waste.

A) Operating Parameters- Degradation of unwanted components/contaminants in the anaerobic treatment depends on several parameters. The important parameters are related to reactor operating conditions (temperature, pH, organic loading rate (OLR), HRT and Carbon and Nutrient availability) and influent characteristics such as particle size distribution.

B) Temperature- Adrien (2008) and Gao et al. (2011) studies have shown that the temperature is an important physical characteristic that affects the acceptability of water as well as water chemistry and water treatment. Anaerobic bacteria are classified into "temperature classes" on the basis of the optimum temperature; the mesophiles survive in mesophilic temperature around 30°C to 40°C, while thermophiles are considered the first microorganism existing at thermophilic temperature around 50°C to 65°C . The rates of reaction proceed much faster at higher temperatures, thus producing more efficient operation and smaller tank sizes.

C) pH- Fang and Jia (1998) studies have shown that the pH is an expression of the intensity of the basic or acid condition of a liquid and a measure of the acidity of a solution. The biomass inhibited at pH 9 was able to regain activities after adjusting the pH to neutrality, but that which inhibited at pH 5 was not as acidic conditions produced can become quite toxic to the methane bacteria. For this reason, it is important that the pH is not allowed to drop below 6.2 for a significant period of time. Because this parameter is very important, thus the system needs to control the pH. When methane gas production stabilizes, the pH ranges between 7.2 and 8.2. Abbasi et al. (2012) and Mc Carty (1982) reported that an optimum pH range of anaerobic treatment is about 7.0 to 7.2, but it can proceed quite well with a pH varying from about 6.6 to 7.6.

D) Hydraulic retention time (HRT)- HRT, also known as hydraulic residence time is a measure of the average length of time that a soluble compound remains in a constructed bioreactor. Hydraulic retention time is the volume of the aeration tank divided by the influent flow rate (HRT = V / Q), where HRT is hydraulic retention time (d) and usually expressed in hours (or sometimes days), (V) is the volume of aeration tank or reactor volume (m^3), and (Q) is influent flow rate (m^3/d). Generally HRT is a good operational parameter which is easy to control and also a macro-conceptual time for the organic material to stay in the reactor. In bio-reaction engineering studies, the reverse of HRT is defined as dilution rate, for which if it is bigger than the growth rate of microbial cells in the reactor, the microbe will be washed out, and otherwise the microbe will be accumulated in the reactor. Either of these situations may result in the breakdown of the biological process happening in the reactor.

E) Organic loading rate (OLR)- Metcalf et al. (2003) and AI Seadi (2008) studies have shown that the Organic Loading Rate (OLR) is defined as the amount of organic dry matter that can be fed into the digester per unit volume of its capacity per day. It is usually calculated based on the mass of volatile solids added per day per unit volume of digester capacity. Another way of calculating it is, the amount of volatile solids added to the digester each day per mass of volatile solids in the digester; although both the approaches are good, the first approach is favourable. Loading rate is an important operational factor for digester because if it is too high, valuable methane former can washout from the system and in addition to this, toxic materials like ammonia can accumulate and upset the process. On the other hand, if the lading rate is too low, it can result in lower organic solids destruction and lower biogas production. Moreover, larger uneconomical digester will require higher heats. For these reasons, the optimum loading rate should be a compromise between the highest possible biogas generation and a justifiable plant economy .

F) Carbon and nutrient availability- AI Seadi (2008) and Metcalf et al. (2003) studies have shown that the Nutrients like carbon, nitrogen, phosphorus and sulphur are very important for the survival and growth of anaerobic digestion process organism. Different micronutrients / microelements (trace elements) like iron, nickel, cobalt, selenium, molybdenum or tungsten are also essential for the anaerobic process microorganisms. Insufficient amount of these nutrients and trace elements can cause inhibition and instability in anaerobic digestion process. The ideal carbon to nitrogen (C:N) ratio for anaerobic digestion ranges from approximately 20:1 to 30:1 (EPA 2012). The optimal nutrient ratio for the carbon, nitrogen (C: N) is considered to be 600:15 .It is also reported that to maintain optimum methano-genic activity, desirable liquid phase concentration of nitrogen, phosphorus and sulphur should be in the order of 50, 10 and 5 mg/l. In addition to the above, it is suggested that level for iron, cobalt, nickel and zinc should be 0.02, 0.004, 0.003 and 0.02 mg/g acetate produced respectively .

G) Co-digestion of MSW- Haider (2015), Riggo (2015), Zarkadas (2015), Razaviarani and Buchanan (2015) studies have shown that the Co-digestion is the synchronized digestion of more than one type of waste in the same unit. Co -digestion tests with two or more substrate are focused in current research . The present study was undertaken to evaluate co-digestion of water hyacinth with food waste, vegetable waste, fruit waste and organic fraction of municipal solid waste along with cow dung as seeding agent. The materials for anaerobic digestion was collected from various locations in and around Nashik as presented in Table 12.

Table12: Collection of samples for co-digestion process

Sr.no	Samples	Location
1	Water hyacinth	Gangapurgaon lake, Nashik.
2	Cow dung	Dairy farm, Belgaondhaga, Nashik.
3	Vegetable waste	Ashoknagar Market, Nashik.

4	Fruit waste	Satpur Market, Nashik.
5	Food waste	BVCOE Hostel, Nashik.
6	OFMSW	KhatPrakalpdumpyard.

5.8 Preparation of Slurry

For the anaerobic digestion study, Water hyacinth was shredded to a particle size of 2-4 mm all the samples collected were dried in sunlight for one week and oven dried for 6 hours after which it was grinded by using grind mill (Momoh et al. 2008 and Patil et al. 2011 a & b). Food waste, OFMSW, vegetable waste and fruit waste were dried in sunlight for 5 days and oven dried for 6 hours at 75˚C after which it was grinded by using grind mill. Different composition of the waste were mixed and used for further analysis.

5.9 Analytical Methods

The following parameters such as (1) Hydrogen ion concentration (pH), (2) Total Solids (TS), (3) Volatile Solids (VS), (4) Total carbon content (TOC), (5) Nitrogen (N) and (6) Carbon nitrogen ratio (C/N) for individual components and different mixtures were analysed before and after digestion as per standards procedure (IS 10158-1982, Patil 2011 a & b, Momoh 2008 & Yusuf 2011), is given in Table 13.

Table13: Methods adopted for analyzing wastes

Sr.No	Parameters	Methods
1	pH	pH Meter
2	Total Solids	were determined at 104 ˚c to constant weight
3	Volatile Solids	measured by the loss on ignition of the dried sample at 550˚
4	Total Carbon content	Oven dried and Ash method
5	Nitrogen Content	Kjeldahl Method

5.10 Biogas Production

Bio-methanation unit was set up for experimentation. The biogas produced were measured by water displacement method and further kinetic modelling were done.

6. HYDROCHEMISTRY OF GROUNDWATER

Water quality analysis is one of the most significant aspects in groundwater studies. The hydro chemical analysis reveals quality of water that is suitable for drinking, agriculture and industrial purposes. Hydrochemistry of groundwater helps to identify the change in quality due to rock water interaction or any type of anthropogenic influence. The chemical composition of groundwater varies because of many complex factors that change with depths and over geographic distances. This chapter presents quantitative findings with regards to water quality parameters in terms of water quality index for human consumption and Total Dissolved Solids (TDS), Total Hardness (TH), Electrical conductivity (EC), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Kelley‟s Ratio (KR), Percentage Sodium (%Na) and United States Salinity Laboratory (USSL) diagram for irrigation purposes in the sampled wells. The selected parameters for analysis were (1) Potenz Hydrogen ion concentration, (2) Electrical conductivity, (3) Total hardness, (4) Total Dissolved Solids, (5) Calcium, (6) Magnesium, (7) Sodium, (8) Potassium, (9) Chloride, (10) Bicarbonate, (11) Sulphate, (12) Nitrate and (13) Fluoride. The findings are compared with World Health Organization (WHO) drinking water standards and Bureau of Indian standards (IS: 10500 1991). The drinking water specifications are tabulated in Table 14 given by BIS (1991) and WHO (1993).

Table14: Drinking water specifications given by IS 10500 (1991) and WHO (1993)

Sr. No.	Water Quality Parameters	Units	Bureau of Indian Standards (1991)		WHO (1993)	
			Highest Desirable	Maximum Permissible	Highest Desirable	Maximum Permissible
1	pH		6.5-8.5	No Relaxation	7-8.5	6.5-9.5
2	EC	µS/cm	-		-	-
3	TH	mg/l	300	-	100	500
4	TDS	mg/l	500	2000	500	1500
5	Ca2+	mg/l	75	200	75	200
6	Mg	mg/l	30	100	50	150
7	Na	mg/l	-	-	-	200
8	K	mg/l	-	-	-	12
9	Cl-	mg/l	250	1000	200	600
10	HCO3-	mg/l	-	300	-	-
11	SO4	mg/l	200	400	200	400
12	NO3	mg/l	45	100	45	-
13	F-	mg/l	1	1.5	-	1.5

The classical use of water analyses in groundwater hydrology is to produce information concerning the water quality. The groundwater quality may yield information about the environment through which water has circulated. The hydro-chemical assessment was carried out to determine the use of groundwater suitability based on different chemical indices. Ground water samples collected from 6 locations in Gaulane were analysed for its Physico-chemical characteristics during December 2018 to March 2019 are presented in Table 15 respectively.

Table15: Physico-chemical parameters of groundwater samples at Gaulane during December - March of 2018 – 2019

Water Quality Parameters	December	January	February	March	Water Quality Parameters	December	January	February	March	Water Quality Parameter	December	January

										s		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
pH	7.68	8.15	7.92	7.78	8.2	7.97	7.6	8.1	7.91	7.45	7.9	7.69
EC (µS/cm)	176	340	255.67	184	370	275.83	201	376	282.67	204	364	272.33
TDS (mg/l)	858	1100	952.17	886	1135	970.5	794	862	831	658	852	763.5
TH (mg/l)	250	308	277.33	262	322	285.67	248	308	280.33	252	287	270.33
Ca(mg/l)	10	20	15.4	14.8	25	18.8	9	19	14.83	9	18	13.5
Mg(mg/l)	16.67	26.72	22.17	19.67	29.51	25.17	15.3	25.7	20.57	9.1	23	17.37
Na(mg/l)	17.9	19.9	18.7	17.1	19	18.08	16.8	17.9	17.3	16.1	17	16.75
K(mg/l)	11	17	14.33	10	14	11.33	9	11	9.83	9	10	9.33
Cl(mg/l)	234.98	284.99	258.15	238	288	259.33	238.1	280.8	252.62	210	257	231.16
HCO3(mg/l)	135	425	248.33	145	455	266.66	131	409	241	115	395	216.67
SO4(mg/l)	128.9	178.3	165.3	138	179	165.66	125.6	175.3	161.42	110.1	172.18	152.91
NO3 (mg/l)	19	22.1	20.76	18	22	19.92	15	20	17.58	14	19	16.67
F(mg/l)	0.55	0.82	0.71	0.45	0.79	0.64	0.25	0.59	0.41	0.1	0.29	0.18

A) Potenz Hydrogen ion concentration (pH)- From Table 15, it was observed that in and around Gaulane disposal site, the pH concentration ranged from 7.6 to 8.1 with a mean value of 7.91 during February and during March it varied from 7.45 to 7.9 with a mean value of 7.69 which indicated the normal ground water was present as shown in table 15.

Table16: Percentage of pH in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of Samples	Range
		Feb	March
7.5 to 9	Highest Desirable Limit	100	100
>7.5 to 9	Permissible limit	0	0

Table 16 showed the percentage of samples falling within the highest desirable and maximum permissible limits in the study area. It was observed that 100 % of samples are within the desirable limit during February and March of 2019 respectively in and around Gaulane disposal site. From the study around locations it is proven that the pH value of groundwater is found normal and all of the samples are within the desirable limit.

B) Electrical Conductivity(EC)- In and around Gaulane disposal site the EC values ranged from 201 to 376 µmohs/cm and 204 to 364 µmohs/cm with a mean value of 282.67 and 272.33 during February and March respectively as presented in Table 15.

Table17: Percentage of EC in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	Range
		February	March
<250	Excellent	50	50
250-750	Good	50	50
750-2000	Permissible	0	0
2000-3000	Doubtful	0	0
>3000	Unsuitable	0	0

Table 17 shows the percentage of samples falling within the good and maximum permissible limits in the study area. The classification of ground water on the basis of irrigation around was observed that 50% of the samples in around Gaulane disposal site fell in Excellent and 50 % of the samples fell in good category during February & March respectively.

C) Total Hardness (TH)- Around Gaulane disposal site, TH concentration of groundwater samples ranged between 248 mg/l to 308 mg/l with a mean value of 280.33 mg/l, it varied from 252 mg/l to 287 mg/l with a mean value of 270.33 mg/l during February & March respectively and it is given in Table 15.

Table 18: Percentage of TH in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
<75	Soft	0	0
75-150	Moderately hard	0	0
150-300	Hard	100	100
>300	Very hard	0	0

From the study, it was observed that 100% of samples around Gaulane disposal sites were hard during February & March respectively and it is given in Table 18.

D) Total Dissolved Solids (TDS)- TDS concentration of groundwater samples around Gaulane disposal site, ranged from 794 mg/l to 862 mg/l , 658 mg/l to 852 mg/l with a mean value of 831 mg/l, 763.5 mg/l during February & March respectively and it is given in Table 15.

Table 19: Percentage of TDS in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March

<500	Desirable for drinking	0	0
500-1000	Permissible for drinking	100	100
>1000	Unfit for drinking	0	0

Table 19 shows that in Gaulane, 100 % of samples were within permissible limit were fit for drinking during February & March respectively. From this result it was observed that most of samples around location were found within the permissible limit. TDS is the main factor which determines the use of groundwater for any purpose. All of the samples showed values greater than the desired limit of 500 mg/L.

E) Calcium (Ca)- From the study Ca concentration of groundwater samples around Gaulane disposal site were ranged between 9 mg/l to 19 mg/l with a mean value of 13.5 mg/l and 9 mg/l to 18 mg/l with a mean value of 14.83 mg/l during February & March respectively as given in Table 15.

Table20: Percentage of Ca in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
75	Highest Desirable Limit	100	100
> 75	Permissible limit	0	0

Table 20 shows the percentage of calcium in the samples that fell within Permissible limit and highest desirable limits from the study areas. It was observed that 100% of the samples fell within the Highest desirable limit during February and March respectively in and around Gaulane disposal sites.

F) Magnesium (Mg)- Mg ion concentration in the ground water samples around Gaulane disposal site varied from 15.3 mg/l to 25.7 mg/l with a mean value of 20.56 mg/l during February and it ranged from 9.1 mg/l to 23 mg/l with a mean value of 17.36 mg/l which is given in Table 21.

Table21: Percentage of Mg in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
30	Highest Desirable Limit	100	100
> 30	Permissible limit	0	0

It was also observed that 100% samples were within the permissible limit during February & March around Gaulane disposal sites which is given in Table 21.

G) Sodium (Na)- Around Gaulane disposal site Na ranged from 16.8 mg/l to 17.9 mg/l with a mean value of 17.3 mg/l during February and during March,it was 16.1 mg/l to 17 mg/l with a mean value of 16.75 mg/l as given in Table 22.

Table22: Percentage of Na ground water MSW disposal sites within standards during February and March of 2019

Range	Class	Percentage of Samples	
		February	March
200	Highest Desirable Limit	100	100
> 200	Permissible limit	0	0

It was observed that 100% of samples around Gaulane were within the highest desirable limit during February and March. Most of the samples fall above the limit as shown in Table 22. Sodium toxicity was recorded as the result of high Na in water.

H) Potassium (K)- Around Gaulane disposal site, the amount of K varied from 9 mg/l to 11 mg/l with a mean value of 9.83 mg/l during February and in March it ranged from 9 to 10 mg/l with a mean value of 9.33 mg/l, was given in Table 23. It was observed that K in all the samples of disposal sites was within the desirable limit.

Table23: Percentage of K in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
12	Highest Desirable Limit	100	100
> 12	Permissible limit	0	0

Table 23 shows the percentage of potassium around location. From the study it was observed that 100% of samples were within permissible limit in February and March in Gaulane disposal site.

I) Chloride (Cl)- Sodium Cl may impart a salty taste at 250 mg/L and the amount of chloride ranged from238.1 mg/l to 280.8 mg/l with a mean value of 252.62 mg/l around Gaulane disposal site. 33.33% of the samples were within the desirable limit and 66.67% samples were within the permissible limit during February. During March it ranged from 210 mg/l to 257 mg/l with a mean value of 231.16 mg/l and 83.33 % of the samples were within the desirable limit and 16.67 % of the samples were within the permissible limit, as given in Table 24. From this study it was observed that the presence of Cl around disposal sites were within the permissible limit.

Table24: Percentage of Cl in ground water samples of MSW disposal sites within standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
250	Highest Desirable Limit	33.33	83.33
> 250	Permissible limit	66.67	16.67

J) Bicarbonates (HCO_3)- Concentration of HCO_3 in and around Gaulane ranged between 131 mg/l to 409 mg/l with a mean value of 241 mg/l during February and it varied from 115 mg/l to 395 mg/l with a mean value of 216.67 mg/l during March as given in Table 25.

Table25: Percentage of HCO_3 in ground water samples of MSW disposal sites within standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
300	Highest Desirable Limit	83.34	100
> 300	Permissible limit	16.66	0

Around Gaulane 100 % of the samples were within the desirable limit during March & 83.34% were within the desirable limit and 16.66% were within the permissible limit February. Bicarbonates in all the samples around the disposal sites were found within the desirable limit.

K) Sulphate (SO_4)- Around Gaulane disposal site, the SO_4 concentration varied from 125.6 mg/l to 175.3 mg/l with a mean value of 161.42 mg/l during February and 110.1 mg/l to 172.18 mg/l with a mean value of 152.91 mg/l during March as given in Table 26.

Table26: Percentage of SO_4 in ground water samples of MSW disposal sites within standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
400	Highest Desirable Limit	100	100
> 400	Permissible limit	0	0

100% of the samples were within the highest desirable limit during February and March around Gaulane disposal site. Concentration of SO_4 were found that disposal sites were within desirable limit.

L) Nitrate (NO_3)- Around Gaulane disposal site the presence of NO_3 concentration ranged from 15 mg/l to 20 mg/l with a mean value of 17.58 mg/l during February and 14 mg/l to 19 mg/l with a mean value of 16.67 mg/l during March as given in Table 27.

Table27: Percentage of NO_3 in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
45	Highest Desirable Limit	100	100
> 45	Permissible limit	0	0

100% percentage of the samples fell within the highest desirable limit as shown in Table 27. NO_3 in the samples around the disposal sites were found within the desirable limit.

M) Fluoride (F)- The Fluoride concentration around Gaulane disposal site samples ranged from 0.25 mg/l to 0.59 mg/l with a mean value of 0.41 mg/l during February and 0.1 mg/l to 0.29 mg/l with a mean value of 0.18 mg/l in March as given in Table 15.

Table28: Percentage of F in ground water samples of MSW disposal sites within the standards during February and March of 2019

Range	Class	Percentage of samples	
		February	March
1	Highest Desirable Limit	100	100
1.5	Permissible limit	0	0

100 % of samples were within the desirable limit limit during February & March around Gaulane disposal site.

6.1 Water Quality Index (WQI)

For calculation of water quality index, nine parameters namely hydrogen ion concentration (pH), total dissolved solids, calcium, magnesium, bicarbonate, chloride, sulphate, nitrate and total hardness were used. WQI during December, January, February and March were determined based on the equation 3. The results obtained are presented in Table 29.

Table29: Summary of WQI in Gaulane during December to March 2018 - 2019

Samples Id	Years				Mean
	December	January	February	March	
W1	46.81	48.03	44.57	40.56	44.9925
W2	50.71	52.55	46.99	45.12	48.8425
W3	48.88	49.76	45.64	41.76	46.51
W4	52.99	53.55	49.77	45.16	50.3675
W5	55.22	56.18	49.47	46.41	51.82
W6	47.27	48.21	49.29	43.91	47.17

The status of water quality in the study areas were compared with the WQI range by taking the mean values of WQI calculated during December, January, February and March and presented in Table 30. In Gaulane, WQI analysis showed that 66.67 % of samples fall under good and 33.33 % under poor category. The percentage of suitability of water quality changes in different areas, are due to characteristics of solid waste seasonal effects and diluted waste. The overall quality of the groundwater within the study areas was fit for domestic purposes and agricultural purposes.

Table30: Status of groundwater quality based on WQI (Mean of Feb-Mar 2019)

Range	Class	Percentage of samples
< 25	Excellent	0
26-50	Good	66.67
51-75	Poor	33.33
76-100	Very Poor	0
>100	Unsuitable	0

6.2 Suitability of Groundwater for Irrigation

Suitability of groundwater for irrigational purpose depends upon the salinity, electrical conductivity and hardness of water. These parameters are on the increasing trend due to the poor sanitation, dumping of solid waste and release of sewage. In the recent years, the concern for groundwater quality in irrigation water supplies gained more importance and with that a need for sound planning to ensure that the quality of water available is put to the best use. Groundwater contains a varying amount of different kinds of ions such as carbonate,bicarbonate,calcium,magnesium, sulphate, hardness and so on. Among them, the major cations are Ca, Mg and Na that influence the suitability of groundwater for irrigation purpose. Some of these cations are beneficial to crop production at expected concentration which otherwise would cause toxicity to plant and affect the properties of soil. The suitability assessment of groundwater for irrigation in the study areas were determined using (1) Salinity Hazard, (2) Sodium Adsorption Ratio (SAR), (3) Percentage Sodium (% Na), (4) Residual Sodium Carbonate (RSC), (5) Kelley‟s Ratio (KR), and (6) United States Salinity Laboratory(USSL) Classification.

A) Salinity hazard- Groundwater quality based on salinity hazard is given in Table 31. In Gaulane the groundwater samples fell within excellent to permissible range for irrigation.

Table31: Groundwater quality based on salinity hazard (Mean of Feb-Mar 2019)

Range	Type of water	Classification	Percentage of Samples
< 250	Low Saline	Excellent	50
251 – 750	Medium Saline	Good	50
751 – 2250	Saline	Permissible	0
2250 – 3000	High Saline	Doubtful	0
> 3000	Very High Saline	Unsuitable	0

B) Sodium Adsorption Ratio (SAR)- According to this classification, it was observed that Sodium concentration is very high in Gaulane. This may be due to the percolation of leachate into groundwater. The details are illustrated in Table 32.

Table32: Groundwater quality based on SAR (Mean of Feb-Mar 2019)

Range	Type of water	Classification
< 250	Low Saline	Excellent
251 – 750	Medium Saline	Good
751 – 2250	Saline	Permissible
2250 – 3000	High Saline	Doubtful

SAR and EC could be used reciprocally to evaluate irrigation water quality formulated by US Salinity Laboratory Staff (1954). Salinity and Alkalinity hazard based on US Salinity diagram for the mean of December to March in the study areas are illustrated in Figure 6 respectively. The classification of water based on US salinity diagram is presented in Table 33. It was observed that 100% of sample in come under good category. The overall quality of groundwater in the study area was fit for irrigation.

Table33: Distribution of groundwater samples according to USSL diagram

Sr. No	USSL Classification	Water Class	Gaulane
1	C1 - S1 (Low Salinity - Low Sodium)	Good	50
	C2 - S1 (Medium Salinity - Low Sodium)		50
	C3 - S1 (High Salinity - Low Sodium)		---
	C4 - S1(Very High Salinity - Low Sodium)		---
2	C1 - S2 (Low Salinity - Medium Sodium)	Moderate	---
	C2 - S2 (Medium Salinity - Medium Sodium)		---
	C3 - S2 (High Salinity - Medium Sodium)		---
	C4 - S2 (Very High Salinity - Medium Sodium)		---
3	C1 - S3 (Low Salinity - High Sodium)	Poor	---
	C2 - S3 (Medium Salinity - High Sodium)		---
	C3 - S3 (High Salinity - High Sodium)		---
	C4 - S3 (Very high Salinity - High Sodium)		---
4	C1 - S4 (Low Salinity - Very High Sodium)	Very poor	---
	C2 - S4 (Medium Salinity - Very High Sodium)		---
	C3 - S4 (High Salinity - Very High Sodium)		---
	C4 - S4 (Very High Salinity - Very High Sodium)		---

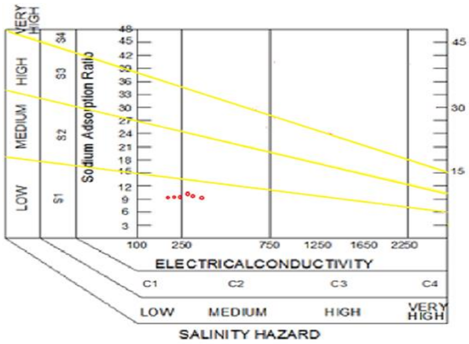

Fig.6: Salinity and alkalinity hazard based on US Salinity diagram for Gaulane

C) Percentage of Sodium (% Na)- From Wilcox diagram, it was observed that in Gaulane 33.33% of samples fell within excellent to good to permissible, 66.67 % in the range of good to permissible. The overall quality of the groundwater in the Gaulane areas it was suitable for irrigation purpose. The Wilcox plot for the locations are presented in Figure 7 respectively.

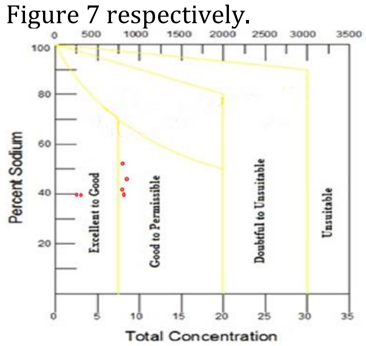

Fig.7: Wilcox diagram for Gaulane

D) Residual Sodium Carbonate (RSC)- Based on RSC value, it was observed that 49.83% of groundwater samples were excellent in Gaulane. Nearly 29.17% of groundwater samples were unsuitable for irrigation in the study areas Gaulane.

Table34: Groundwater quality based on RSC(Mean of February-March)

Range	Type of water	Percentage of samples
Below 1.25	Excellent	49.83
1.25-2.50	Good	25
Above 2.50	Unsuitable	29.17

E) Kelley's Ratio (KR)- According to KR, the ground waters in all the study areas are suitable for irrigation purposes as illustrated in Table 35.

Table35: Groundwater quality based on KR (Mean of February-March)

Range	Type of water	Percentage of samples
< 1	Suitable	100
> 1	Unsuitable	0

7. CO-DIGESTION OF WASTES WITH WATER HYACINTH

Water hyacinths (Eichhorniacrassipes), known as an aquatic weed has become a persistent and expensive aquatic problem to propagate rapidly , impeding navigation and fishing activities, clogging and irrigation system. It causes shortage of dissolved oxygen which is crucial for flora and flora in the aquatic ecosystems. Since water hyacinth has abundant nitrogen content, it has been used a substrate for biogas production and it is used in combination with other wastes to increase biogas content. addition of cow dung to water hyacinth enhanced the biogas yield. The effect of waste paper on the production of biogas from fixed amount of cow dung and water hyacinth was found to increase in a parabolic manner. Hence in this research work we have fixed the amount of cow dung and water hyacinth and varied the concentration of food waste, organic fraction of MSW, vegetable waste and fruit waste.

7.1 Biomethanation Unit

A) Digester: A 2 liters reagent glass bottle, serves as digesters

B) Water tank: A 10 liters transparent plastic can, used as water tank

C) Water collector: A 2 liters transparent plastic measuring jar, used as water collector

D) Rubber hoses: The length of the hose is about 1 meter and the inner diameter is about 7 mm. It was used to convey gas from the digesters to the water tank and to the water collector. The bio digester set up is shown in Figure 8.

Fig.8: Composition of bio digesters

7.2 Experimental procedure

A set of five batch digesters of 2 litre capacity were used for different proportions of wastes and one digester was kept for control. Each digester consisted of fixed quantity of cow dung and water hyacinth, but varying amount of Food waste (FOW), Organic fraction of municipal solid waste (OFMSW), Vegetable waste (VW) and Fruit waste (FW). The volumes of biogas produced in each digesters was measured daily by water displacement method.

The physic- chemical characteristics of water hyacinth, cow dung and FOW, OFMSW,VW, FW and Control waste (CW) digester and the initial characteristics such as pH, Total solids (TS), Volatile solids (VS), and Total organic carbon (TOC) and Nitrogen (N), for different mixtures and control mix were determined before starting up the digesters. Optimum mix ratio was calculated based on maximum biogas production. The control mix digester consisted of 250 g cow dung and 250 g water hyacinth along with 750 ml of water. The chemical compositions of CD, WH and CW are presented in Table 36 to 38 respectively. cumulative biogas calculated, was given in Table 39.

Table36: Chemical compositions of CD

Sr. No.	Parameter	Units	Values
1	pH		6.7
2	Total solids	%	8
3	Volatile solids	%	35
4	Total organic carbon	%	53.3
5	Nitrogen	%	1.2
6	C/N ratio		46

Table37: Chemical compositions of WH

Sr. No.	Parameter	Units	Values
2	Total solids	%	15
3	Volatile solids	%	82
4	Total organic carbon	%	26.4
5	Nitrogen	%	0.68
6	C/N ratio		20.63

Table38: Chemical compositions of CW

Sr. No.	Parameter	Units	Values
1	pH		7.05
2	Total solids	%	7.37
3	Volatile solids	%	85.8
4	Total organic carbon	%	44
5	Nitrogen	%	1.79
6	C/N ratio		24.51

Table39: Cumulative biogas production for the CW

Days	Biogas production (ml)	Cumulative biogas production (ml)

1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	500	500
7	507	1007
8	507	1514
9	507	2021
10	507	2528
11	578	3106
12	650	3756
13	700	4456
14	700	5156
15	700	5856
16	750	6606
17	770	7376
18	740	8116
19	745	8861
20	800	9661
21	850	10511
22	850	11361
23	820	12181
24	830	13011
25	800	13811
26	750	14561

7.3 Food waste (FOW)

The chemical composition of FOW, mix proportion and initial characteristics mixtures in all the 5 batch digesters were analysed and given in Table 40 to 42. Biogas production was measured daily and cumulative biogas calculated, was given in Table 43.

Table40: Chemical compositions of FOW

Sr. No.	Parameter	Units	Values
1	pH		6.7
2	Total solids	%	26.1
3	Volatile solids	%	50.8
4	Total organic carbon	%	27
5	Nitrogen	%	0.75
6	C/N ratio		36

Table41: Mix proportion of FOW

Digesters	Mix ratios	Compositions			
		CD (g)	WH (g)	FOW (g)	Water (ml)
FOW1	1:1:0.2	250	250	50	750
FOW2	1:1:0.4	250	250	100	750
FOW3	1:1:0.6	250	250	150	750
FOW4	1:1:0.8	250	250	200	750
FOW5	1:1:1	250	250	250	750

Table42: Initial characteristics of FOW for different mix

Digester	pH	TS	VS	TOC	N	C/N
		%	%	%	%	
FOW1	7.08	6.55	72.18	40.1	1.32	30.3:1
FOW2	6.53	7.11	73.28	40.7	1.28	31.8:1
FOW3	6.46	6.27	70.38	39	1.2	32.5:1
FOW4	6.57	6.88	71.26	39.5	1.19	33.2:1
FOW5	6.64	7	73.92	41	1.204	34.1:1

Table43: Cumulative biogas production for the FOW_5

Days	Biogas production (ml)	Cumulative biogas production (ml)
1	0	0
2	0	0
3	0	0
4	476	476
5	496	972
6	488	1460
7	484	1944
8	500	2444
9	550	2994
10	600	3594
11	650	4244
12	672	4916
13	704	5620
14	804	6424
15	1000	7424
16	1010	8434
17	1015	9449
18	1020	10469
19	1030	11499
20	1035	12534
21	1044	13578
22	1046	14624
23	1040	15664
24	1040	16704
25	1043	17747
26	1042	18789

27	1060	19849
28	1000	20849
29	1100	21949
30	1150	23099
31	1200	24299
32	1100	25399
33	1150	26549
34	1000	27549
35	1000	28549
36	1000	29549

7.4 Organic fraction of Municipal Solid waste (OFMSW)

It is evident that Nashik City has 65% of biodegradable, 18% of recyclables remaining (toxic, non-toxic and undefined particles).Chemical compositions of OFMSW, mix proportion and their initial characteristics of the mixtures in the 5 batch digesters were analysed and given in Tables 44 to 46. Biogas production was measured daily and cumulative biogas calculated, is given in Table47.

Table44: Chemical compositions OFMSW

Sr. No.	Parameter	Units	Values
1	pH		7.6
2	Total solids	%	89.6
3	Volatile solids	%	70
4	Total organic carbon	%	8
5	Nitrogen	%	0.1
6	C/N ratio		80

Table45: Mix proportion of OFMSW

Digesters	Mix ratios	Compositions			
		CD (g)	WH (g)	OFMSW (g)	Water (ml)
OFMSW1	1:1:0.2	250	250	50	750
OFMSW2	1:1:0.4	250	250	100	750
OFMSW3	1:1:0.6	250	250	150	750
OFMSW4	1:1:0.8	250	250	200	750
OFMSW5	1:1:1	250	250	250	750

Table46: Initial characteristics of OFMSW for different mix

Digesters	pH	TS	VS	TOC	N	C/N
		%	%	%	%	
OFMSW1	6.37	7.43	87.8	47.5	1.67	28.4:1
OFMSW2	6.41	8.11	89.35	48.3	1.63	29.6:1
OFMSW3	6.89	6.99	90.25	49	1.57	31.2:1
OFMSW4	6.93	7.83	93.45	50.5	1.55	32.5:1
OFMSW5	6.87	7.64	96.35	52.08	1.51	34.5:1

Table47: Cumulative biogas production for the $OFMSW_4$

Days	Biogas production (ml)	Cumulative biogas production (ml)
1	0	0
2	0	0
3	0	0
4	580	580
5	595	1175
6	620	1795
7	700	2495
8	850	3345
9	1100	4445
10	1200	5645
11	1250	6895
12	1300	8195
13	1350	9545
14	1400	10945
15	1500	12445
16	1520	13965
17	1550	15515
18	1560	17075
19	1580	18655
20	1600	20255
21	1650	21905
22	1580	23485
23	1550	25035
24	1500	26535

7.5 Vegetable waste (VW)

The chemical compositions of VW used for the feed, mix proportion of VW and their initial characteristics are given in Tables 48 to 50. Biogas production was measured daily and cumulative biogas calculated, is given in Table 51.

Table48: Chemical compositions of VW

Sr. No.	Parameter	Units	Values
1	pH		5.2
2	Total solids	%	28.62
3	Volatile solids	%	83
4	Total organic carbon	%	45.2
5	Nitrogen	%	1.02
6	C/N ratio		44.1

Table49: Mix proportion of VW

Digester	Mix ratios	Composition			
		CD (g)	WH (g)	VW (g)	Water (ml)
VW1	1:1:0.2	250	250	50	750

VW2	1:1:0.4	250	250	100	750
VW3	1:1:0.6	250	250	150	750
VW4	1:1:0.8	250	250	200	750
VW5	1:1:1	250	250	250	750

Table50: Initial characteristics of VW for different mix

Digester	pH	TS	VS	TOC	N	C/N
		%	%	%	%	
VW1	6.83	8.06	82.96	46.08	2	20.2:1
VW2	6.67	7.01	83.5	46.3	2.15	21.5:1
VW3	6.49	7.24	80.5	45	1.96	22.8:1
VW4	6.3	6.49	84.2	46.7	1.9	23.4:1
VW5	6.24	7.81	85.5	47.5	1.93	24.5:1

Table51: Cumulative biogas production for the VW_5

Days	Biogas production (ml)	Cumulative biogas production (ml)
1	0	0
2	0	0
3	0	0
4	370	370
5	550	920
6	615	1535
7	700	2235
8	700	2935
9	750	3685
10	800	4485
11	900	5385
12	950	6335
13	1000	7335
14	1010	8345
15	1100	9445
16	1150	10595
17	1200	11795
18	1210	13005
19	1220	14225
20	1230	15455
21	1240	16695
22	1250	17945
23	1260	19205
24	1290	20495
25	1300	21795
26	1300	23095
27	1325	24420
28	1300	25720
29	1300	27020
30	1200	28220
31	1000	29220

7.6 Fruit waste (FW)

The chemical compositions of FW, mix proportion, compositions of digesters with initial characteristics of each mix are presented in Tables 52 to 54. Biogas production was measured daily and cumulative biogas calculated is given in Table 55.

Table52: Chemical compositions of FW

Sr. No.	Parameter	Units	Values
1	pH		6.4
2	Total solids	%	31.2
3	Volatile solids	%	91
4	Total organic carbon	%	47.23
5	Nitrogen	%	2.09
6	C/N ratio		22.6

Table53: Mix proportion of FW

Digester	Mix ratios	Composition			
		CD (g)	WH (g)	FW (g)	Water (ml)
FW1	1:1:0.2	250	250	50	750
FW2	1:1:0.4	250	250	100	750
FW3	1:1:0.6	250	250	150	750
FW4	1:1:0.8	250	250	200	750
FW5	1:1:1	250	250	250	750

Table54: Initial characteristics of FW for different mix

Digester	pH	TS	VS	TOC	N	C/N
		%	%	%	%	
FW1	6.47	8.2	83.72	44.6	1.68	22.6:1
FW2	5.74	6.34	85.45	45	1.7	22.4:1
FW3	5.85	7.15	87.5	46.05	1.23	21.9:1
FW4	5.69	8.61	88.65	46.65	1.24	21.7:1
FW5	4.99	7.19	92.45	48.65	1.62	21.2:1

Table55: Cumulative biogas production for the FW_4

Days	Biogas production (ml)	Cumulative biogas production (ml)
1	0	0
2	0	0
3	0	0
4	565	565
5	500	1065
6	600	1665
7	650	2315
8	800	3115

9	900	4015
10	1100	5115
11	1150	6265
12	1200	7465
13	1250	8715
14	1300	10015
15	1300	11315
16	1350	12665
17	1400	14065
18	1450	15515
19	1450	16965
20	1480	18445
21	1480	19925
22	1490	21415
23	1500	22915
24	1520	24435
25	1510	25945
26	1500	27445
27	1460	28905
28	1400	30305
29	1350	31655

7.7 Biogas Production

The trend of biogas and cumulative biogas produced with time for all the five digesters were found and optimum mix proportion was computed based on maximum gas production is given in Table 39, 43, 47, 51 and 55. The biogas productions commenced in all the digesters on the 4th day except control mix digester which started on the 6th day. Digesters of CW produced maximum biogas on the 21st day, while digesters, FOW_5 produced maximum biogas on the 31st day, $OFMSW_4$ produced maximum biogas on 21st day, VW_5 and FW_4 produced maximum biogas on 24th and 27th days respectively. In this study, the pH was found to be optimum in all the reactors during the digestion process. The pH value in the digesters ranged from 5.69 to 6.87, the optimum value for effective digestion was 5.5 to 8.5 (reported by Kangle et al. in 2012). The cumulative biogas production in all the digesters starting from CW, FOW_5, $OFMSW_4$, VW_5 and FW_4 are 10511 ml, 24299 ml, 21905 ml 24420 ml, and 24435 ml respectively.

Wastes and its initial characteristics before digestion were presented in Table 56. The volatile solids before & after digestion and reduction VS% was presented in Table 57 and pictorially represented in Figure 9. The biogas yield in terms of m^3/kg of VS is presented in Table 58.

Table56: The Optimum proportions of wastes and its initial characteristics before digestion

Digester	CD	WH	Waste	Water	pH	TS	VS	TOC	N	C/N
	(g)	(g)	(g)	(ml)		%	%	%	%	
FOW5	250	250	250	750	6.87	7.64	96.35	52.08	1.51	34.5:1
OFMSW4	250	250	200	750	6.57	6.88	71.26	39.5	1.19	33.2:1
VW5	250	250	250	750	6.24	7.81	85.5	47.5	1.93	24.5:1
FW4	250	250	200	750	5.69	8.61	88.65	46.65	1.24	21.7:1

Table57: Percentage of VS and reduction in optimum digesters

Digesters	Mix ratio	Before digestion VS %	After digestion VS %	Reduction VS%
FOW5	1:1:1	96.35	39.9	44
OFMSW4	1:1:0.8	71.26	39.5	58
VW5	1:1:1	85.5	44.46	48
FW4	1:1:0.8	88.65	42.55	52

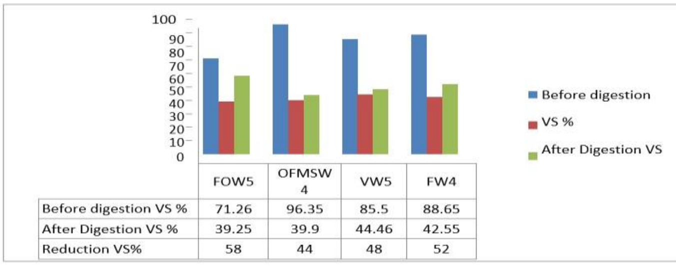

Fig.9: Percentage of VS and reduction in optimum digesters

Table58: Summary of performance of anaerobic digesters

Digester	Time	Biogas yield	Biogas yield
	days	in ml	m3/kg of VS
FOW5	21	24299	0.564
OFMSW4	31	21905	0.257
VW5	27	24420	0.382
FW4	24	24435	0.309

A) Linear and polynomial models- Anaerobic digesters often exhibit significant stability problems that may be avoided only through appropriate control strategies. Such strategies require the development of appropriate mathematical models, which adequately portray the key processes that take place (Lyberatos and Skiadas1999). Biogas production rate of food waste, OFMSW, vegetable waste and fruit waste, co-digested with water hyacinth and cow dung was simulated using linear plot and polynomial plot. It is assumed that biogas production rate will increase linearly with the increase in time and after reaching a maximum point, it would decrease linearly to zero with the increasein time. The linear and polynomial equation with R^2 value, predicted value from equation and experimental value are presented in Table 59. From the two models it was observed that, the polynomial equation model holds good for the anaerobic digestion. The polynomial model can be used to predict the biogas production. The plots corresponding to linear and polynomial models are presented in Figures 10 to 17.

Table59: Linear and polynomial model of co-digestion process

Digester	Linear equation	R^2	Polynomial equation	R^2
FOW_5	y = 73.5x + 143.5	0.839	y = -4.099x² + 140.5x	0.942
$OFMSW_4$	y = 30.12x + 473.8	0.456	y = -1.646x² + 128.0x	0.945
VW_5	y = 51.73x + 149.5	0.87	y = -2.374x² + 102.3x	0.96
FW_4	y = 60.46x + 174.7	0.844	y = -3.085x² + 121.6x	0.958

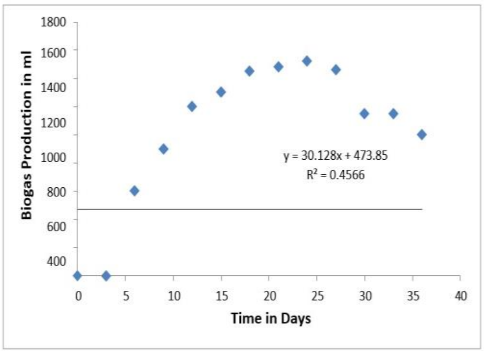

Fig.10: Linear model of FOW_5

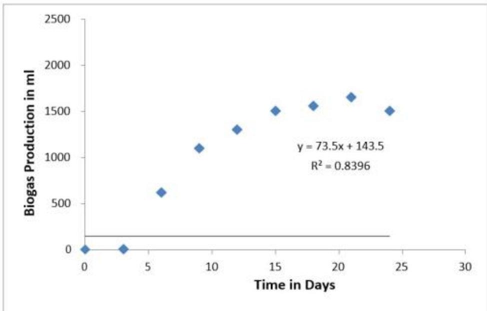

Fig.11: Linear model of $OFMSW_4$

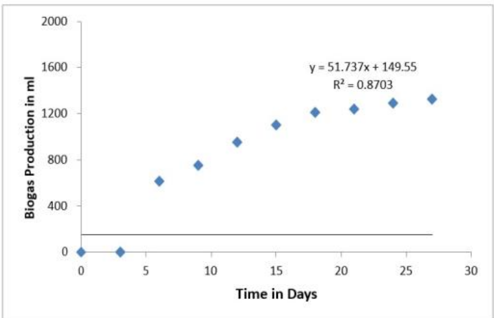

Fig.12: Linear model of VW_5

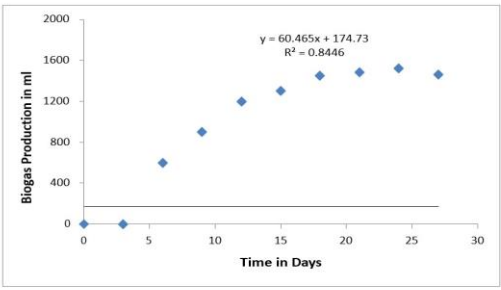

Fig.13: Linear model of FW_4

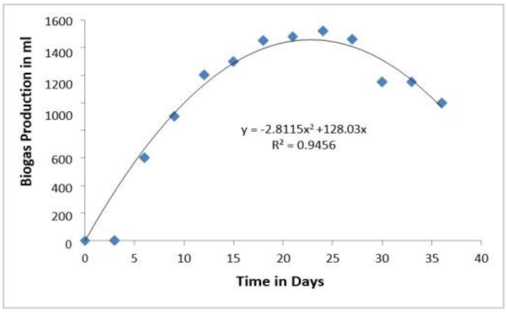

Fig.14: Polynomial model of FOW_5

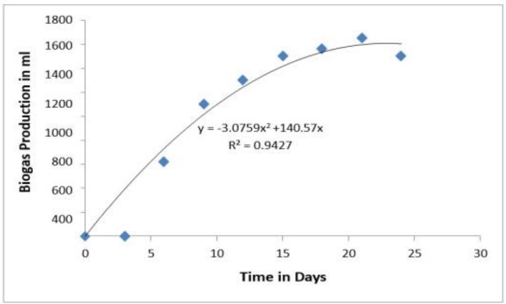

Fig.15: Polynomial model of $OFMSW_4$

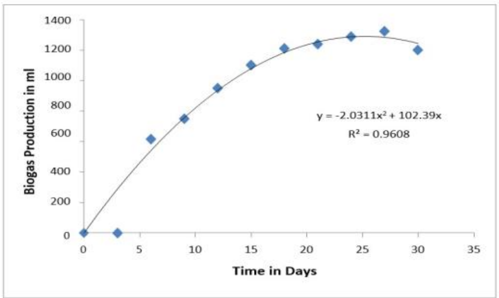

Fig.16: Polynomial model of VW_5

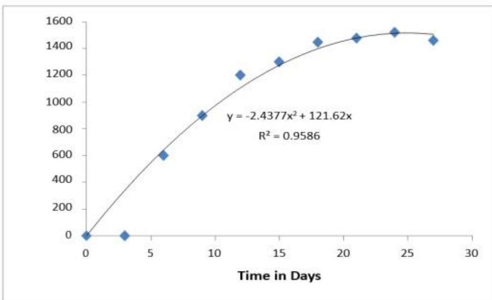

Fig.17: Polynomial model of FW_4

B) Modified Gompertz equation (MGE)- The results of the non linear regression fit are shown in Figure 18 to 22. The parameters predicted by MGE are summarized by the Table 60. When compared with the CW the B_{max} biogas production potential for all the other mixtures was higher. FOW_5 in particular, showed the highest potential among the tested waste materials. The coefficient of determination was found to be greater than 0.99 in all the cases, showing best fit between the experimental data and the predicted values. The MGE was fitted to the experimental values.

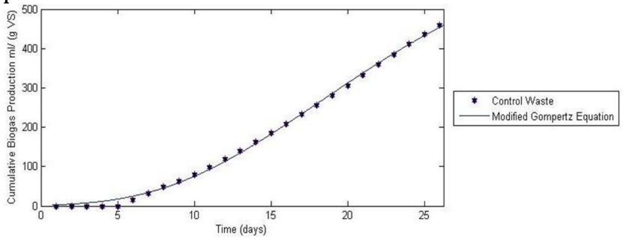

Fig.18: Modeified Gompertz Equation fit for CW

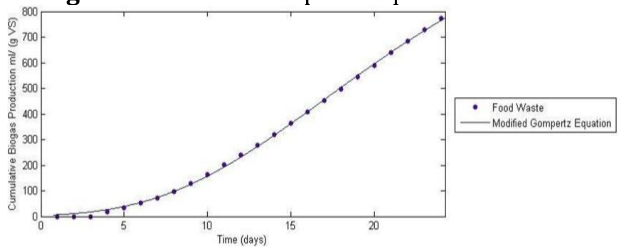

Fig.19: Modified Gompertz equation fit for FOW_5

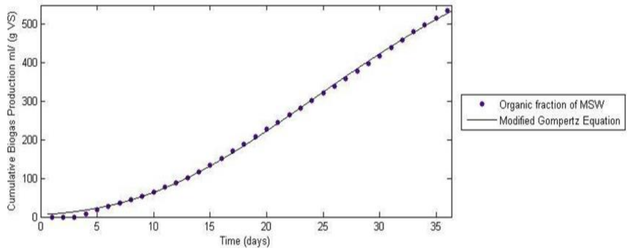

Fig.20: Modified Gompertz equation fit for $OFMSW_4$

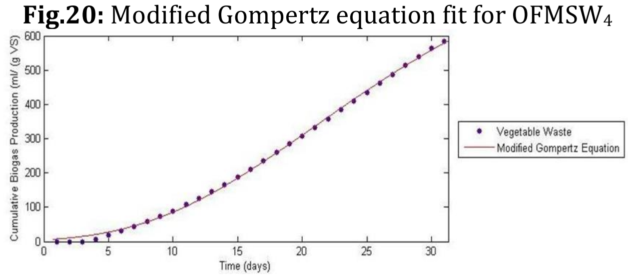

Fig.21: Modified Gompertz equation fit for VW_5

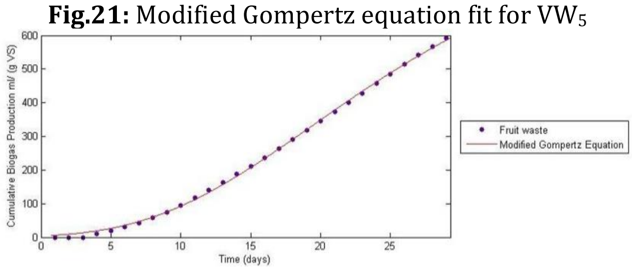

Fig.22: Modified Gompertz equation fit for FW_4

Table60: Summary of estimated kinetic parameters for biogas Production

Mixture	Biogas Yield (ml/(gVS)	Modified Gompertz Equation			R2
		Bmax (ml/(gVS)	Rm, (ml/(gVS*d)	λ (d)	
CW	460.5	715.1	26.32	8.126	0.9983
FOW5	773.16	1247	47.33	7.361	0.9993
OFMSW4	535.21	826.5	20.45	9.142	0.9992
VW5	583.47	912.2	26.37	8.239	0.999
FW4	592.46	904.4	29.03	7.988	0.9992

8. CONCLUSIONS

This research study was carried out to make an attempt to identify the impact disposal of solid waste on groundwater and soil and energy recovery from the solid waste. Groundwater samples were collected for a period of four Months (December, January, February & March of 2018-2019) from 6 locations Near by Gaulane. The sampling locations were selected to cover the entire study areas. The Physico-chemical characteristics of groundwater samples and soil samples were determined according to the standard methods. Quantitative findings with regards to water quality parameters in terms of water quality index for human consumption and Total Dissolved Solids (TDS), Total Hardness (TH), Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), Residual Sodium Carbonate (RSC), Kelley"s Ratio (KR), Percentage Sodium (%Na), Wilcox and United States Salinity Laboratory (USSL) diagram for irrigation purposes in the sampled wells were used to analyse the groundwater quality.

A) Groundwater Quality- An investigation has been made to find the suitability of groundwater for drinking purpose in the study areas. Groundwater samples in the 6 selected locations around Gaulane were analysed for their Physico -chemical characteristics such as hydrogen ion concentration, electrical conductivity, total dissolved solids, total hardness, bicarbonate, sulphate, chlorides, nitrates, sodium, calcium, magnesium, potassium and fluoride during December 2018 to March 2019.

B) Suitability of groundwater for drinking purpose- Groundwater quality parameters were compared with World Health Organization (WHO 1993) drinking water standards and Indian drinking standards (BIS: 10500-1991). From this study, it was observed that most of the physico-chemical characteristics such as Electrical Conductivity (EC), Chloride (Cl^-), Total Hardness (TH), Bicarbonate (HCO_3) and Sodium (Na) in groundwater samples were at their maximum and higher than the highest desirable limit in all the locations. Based on Total Dissolved Solids (TDS), 100% in Gaulane the groundwater samples were fit for drinking purpose. The mean value of Water Quality Index (WQI) calculated for Gaulane exhibited good quality in greater percentage

C) Suitability of groundwater for irrigation purpose- The suitability of groundwater for irrigation was assessed based on the total concentration of salts and relative proportion of sodium. Based on Wilcox diagram, it was observed that 33.33% of samples fell within excellent to good to permissible, 66.67 % in the range of good to permissible respectively in Gaulane area. The overall quality of the groundwater in Gaulane was fit for irrigation purpose. The United States Salinity Laboratory (USSL) classification shows that 100% of the samples in Gaulane area came under good category. The study confirms that the overall quality of groundwater in the study areas are fit for irrigation. Groundwater quality in the study areas are slowly reaching an alarming stage. Hence, an immediate remedial measures and proper planning are essential in this venture to preserve the fragile ecosystem.

D) Co-digestion of solid waste with water hyacinth- An attempt has been made to assess the energy recovery from co- digestion of water hyacinth with Food waste (FOW), Organic fraction of municipal solid waste (OFMSW), Vegetable waste (VW) and Fruit waste (FW) along with CD as seeding agent. The potential of hydrogen (pH) value in the digesters ranged from 5.69 to 6.87 and the optimum value for effective digestion is 5.5 to 8.5 . The cumulative biogas production in all the digesters starting from control mix , FOW_5, $OFMSW_4$, VW_5 ,FW_4 were 10511ml, 24299ml, 21905ml, 24420ml, and 24435ml respectively. The addition of FOW_5, $OFMSW_4$, VW_5, FW_4 to Control waste (CW) has significant increase in biogas production as shown in Fig.23.

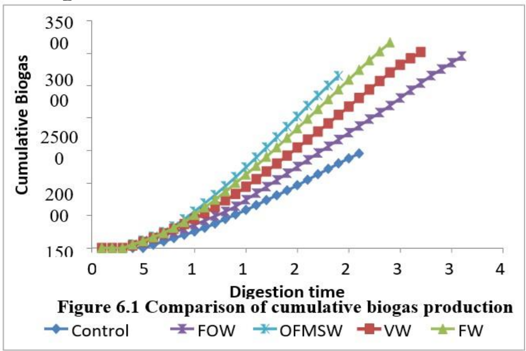

Fig.23: Comparison of cumulative biogas production

Kinetic Model- From the linear and polynomial models it was observed that the polynomial equation model holds good for the anaerobic digestion. The polynomial model could be used to predict the biogas production for FOW_5 0.564 m^3/kg of Volatile solids (VS), $OFMSW_4$ 0.257 m^3/kg of VS, VW_5 0.382 m^3/kg of VS and FW_4 0.309 m^3/kg of VS. The Modified Gompertz equation (MGE) was fitted to the experimental values. The maximum predicted cumulative biogas production B_{max} for CW, FOW_5, $OFMSW_4$, VW_5 and FW_4 was 715.1 ml/(gVS), 1247ml/(gVS), 826.5ml/(gVS), 912ml/(gVS), 904.4ml/(gVS) respectively. The maximum biogas production rate for CW, FOW_5, $OFMSW_4$, VW_5 and FW_4 was 26.32ml/(gVS×d), 47.33ml/(gVS×d), 20.45ml/(gVS×d), 26.37ml/(gVS×d), 29.03ml/(gVS×d) respectively. The coefficient of determination (R^2)reactors lies between 0.9983 and 0.9993 this shows that the predicted values were best fitted with the experimental values

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I feel extraordinary delight to present this paper entitled "Assessment of Groundwater Quality Due to Dumping of Municipal Solid Waste and Its Remediation Through Energy Recovery in Nashik". But it would be unjustifiable on my part if I don't acknowledge efforts of some of the people without the support of whom, this research would not have been a success. First and fore most I am particularly appreciative to my regarded guide Prof. Shailesh P. Gaikwad and Prof. Padmakar J. Salunkhe for their leading guidance in this topic. Additionally they have been persistent source of inspiration to me.

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