Integrated Solid Waste Management for Municipal Solid Waste Generated from Small-Scale Towns and Nearby Villages Located in a Developing Country

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Abstract - According to census 2011, 72% of Indian population lives in small-scale towns and villages. Municipal solid waste (MSW) generation, in terms of kg/capita/day, is showing an increasing trend. MSW management is one of the major problems faced by these local bodies. Due attention is not paid for MSWM due to small quantity of waste generated by individual towns and villages surrounding them. The MSW is collected from the source and disposed off randomly in open dumps. In this paper, we present a systematic study of MSW quantity and characteristics and existing disposal methods for small-scale towns and nearby villages. We also propose an optimization model to identify a comprehensive disposal strategy considering segregation treatment and final disposal of MSW. The model includes fixed cost like land cost, equipment cost and operating cost like transportation cost, labor cost etc. Optimization results revealed that formation of clusters for segregation and treatment of MSW and final disposal at landfill site is more economical than segregation and disposal at each source towns/villages. We have demonstrated the efficacy of the proposed method with the help of case study to identify economical strategy for segregation and disposal of MSW generated form small-scale towns and nearby villages

Keywords - MSW, Small-scale towns, village, quantity, Optimization, Segregation, Economic

INTRODUCTION

Quality and quantity Municipal solid waste depends on various activities carried out in that municipality. Quality of municipal solid waste primarily depends on economical condition, climatic condition and geographical condition. (World Bank 2003), Quantity of solid waste increases with increase in population and modernization in these areas [1]. Ludwig et al. (2003) have observed a quantum jump in quantity of MSW due to increase in consumption pattern.[2]

Studies have shown that waste generated from high economic area has higher calorific value, lower specific density and lower moisture content. This may be largely attributed to more utilization of packed food and disposal material like paper, dishes etc. Waste from lower income group has low calorific value and high moisture content due to more utilization of fresh vegetables [3,4]. Bhide and Shekdar (1998), CPCB(2004) and Garg and Prasad(2003) studied composition of MSW in metro/large cities [5,6,7]. As per these studies MSW sampled at generation source and collection points as wet basis, consists mainly of a large organic fraction (40–60%), ash and earth (30–40%), paper (3–6%) and plastic, glass and metals (each less than 1%). They have also indicated that the C/N ratio ranges between 20 and 30, and caloric value ranges from 800 to 1000 kcal/kg.

As per CPCB (2004)[7] The average waste generated for small towns, medium scale towns/cities and large cities is 0.1 kg per person per day, 0.3 to 0.4 kg per person per day and around 0.5 kg per person per day respectively. Many researchers estimated 1.3% increase in waste generation in these Indian towns (Bhide and Shekdar, 1998; Shekdar, 1992; Pappu et al., 2007).[5,8,9]

Solid waste management with respect to source segregation, storage at various stages, collection, transfer and transport, processing, and disposal has not received due attention in study areas under consideration. Current practices adapted in developing countries for collection, processing and disposing municipal solid waste, is less efficient in comparison with the developed countries. Developing countries face a major problem due to low collection coverage and irregular collection services. Crude open dumping of MSW enhances the breading of flies and vermin. Open burning of MSW without implementing suitable air and water pollution control strategies leads to increase in pollution level. MSWM also need to take care of informal waste picking or scavenging activities [10]. The improper handling and disposal of solid wastes constitutes a serious problem: it contributes to the high morbidity and mortality rates in many Third World cities [11]. Many cities do spend significant portions of their municipal revenues on waste management [12,13,14,15] However, these cities could not cover all aspects of waste management.

Climatic factors play a crucial role in the municipal waste management of the study area. Due to high moisture, content in wet season weight of refuse increases which causes difficulty in transportation of MSW. High humidity due to heat elevates decomposition of organic waste before final disposal of MSW, which makes it more difficult to handle and dispose. Decomposed organic waste also causes health effects on workers and inhabitants (Ludwig et al., (Eds.) 2003).

Hua and Wang (2001) noted that (MSWM) continues to be a major challenge for local governments in both urban and rural areas throughout the world. Poor solid waste management creates a major threat for public health and environment quality in the developing countries it reduces quality of life for poor economic section both in urban and rural area.[16]. Unscientific disposal of MSW affects environment and human health in all aspect. Studies show that there is reduction in field yield due to open dumping of MSW at field sides or open area nearby. [17, 18, 19, 20, 21, 22, 23, 24]

Majority of population lives in rural and semi urban areas in developing countries. As per census of India 2011, with an estimated population of 1028610328, India is the world's second most populated country after the People's Republic of China. India has 593625 inhabited villages and 72.2 % of the total population resides in these rural areas and semi urban centers. Total population of 584069713 resides in 229150 villages having population range of 1000-10,000 & above. While around 26784423 people resides in towns having population less than 20000. Approximately 60% of population resides in these rural and semi urban centers. These centers provide utilizations, services to nearby rural areas, and can play an important role in development of the rural regions.

Lack of necessary data in small-scale towns and villages hampered solid waste management. Moreover, the available data is generally unreliable, scattered and unorganized [25]. Large and medium scale cities have better financial support, trained personnel, public awareness for MSWM compared to small-scale towns/villages. Along with less awareness in public, other necessary infrastructure to handle and dispose solid waste are inadequate in small-scale towns and villages. Hence, low line areas on the outskirts of towns or villages are used for open dumping of MSW. This creates nuisances of flies, mosquitoes and other insects, which can lead to major health hazards in the nearby area. It also causes ground water pollution due to leached water. Due attention is not paid to MSWM of small-scale towns and surrounding villages. As large population, lives in small-scale towns/ villages it becomes important to mange MSW to reduce overall environmental degradation.

Development of mathematical models for prediction of MSW, transportation of MSW, routing etc utilizing ANN, linear programming, life cycle assessment for developed countries attracted considerable attention of the researchers. Quality and quantity of MSW is in general different in developed and developing countries. Daskapoulous et. al. (1998) noted that these municipalities lack infrastructure, human resources and are fast growing [26]. It is necessary to develop suitable model for MSWM in suburban municipalities in developing countries.

For selection of suitable MSWM strategy Optimization models are proposed after considering economic, environmental and management factors [27]. It is necessary to explore the possibility of integrated management of MSW of small-scale towns and their surrounding villages rather than handling them individually.

RESEARCH METHODOLOGY

Selection of study area: For study purpose small-scale town and representative village of Gujarat state, India. The Urban Development and Urban Housing department of Gujarat has classified municipality in following categories based on population: Class A Municipality - Population of 100000 and above, Class B Municipality - Population of 50000 – 99999, Class C Municipality - Population of 25000 – 49999, Class D Municipality - Population of 15000 - 24999. According to census, 2001 data there are 18 class A municipalities, 33 class B municipalities, 45 class C municipalities and 63 class D municipalities exists in the state of Gujarat. Class D municipalities along with small villages around them, have very few facilities for municipal solid waste management. The rate of Infrastructural development in Class D municipalities is little slow.

Amount of solid waste generation is a strong function of population of the area under consideration. Thus, prediction of population is necessary to predict waste generation in the study area. Urban population of Gujarat has grown from 37.4 percent in 2001 to 42.6 percent in 2011. The growth rate in small-scale town has increased by approximately 27 percent 2011. Population projected in the study area for 25 yrs for the study purpose. Quantity of waste generation is estimate based on the projected population data. MSW generation estimated using 1.3% increase solid waste generation per annum per person. Approximately 1 x 106 to 2 x 106MT of MSW has be to be handled by the year 2036.

The study area consists of small towns surrounded by villages having low population. This results in an average generation of solid waste 0.05 to 0.1 Kg/person/day, which is a low per capita generation of MSW. Solid waste generated from small-scale towns and villages around them have high organic matter, as agriculture is major occupation of people. Solid waste presently is disposed in open dumps in low-lying areas at the outskirts of the towns.

Quality and quantity of solid waste: In the present study average solid MSW collected in the community bin over a period of two weeks in each season is determined experimentally. Computerized weighing machine used to weight community bins. To determine the quality of MSW in the present study samples are collected from both dumping site and main collection bins. Recyclable material like metal, paper, bottles are in general segregated at primary level. Further quantity of organic material for composting and inert material for disposal is experimentally determined.

Development of optimization model: To minimize the total disposal cost of MSW generated from small towns and their surrounding villages, within the regulatory framework we propose an optimization model in this paper. The proposed mixed integer non-linear program model solves the minimization problem. Proposed model considers the installation cost of the site, transportation cost, infrastructure cost. Commercial solver GAMS is used to solve MINLP problem. We present indices, sets, parameters, variables, tables and equations used in the program.

Sets: i – source of municipal solid waste j – segregation site

Variable: x(i,j) selection of site z total cost

Parameter: Tw(i) Total solid waste from village p(i) Population of the village Jc(j) Jantri cost Tr(i) Trips from source to segregation site Trp(i,j) cost of each trip Vmc vehicular cost Trc(i,j) total trip cost Ttw(i) total waste collected c(i,j) Cost of segg. Site ls land for composting lm land for movement ln land for shed lf land for finished goods L(j) total land require Mc man power cost d(i,j) distance between villages Sc(j) segregation cost

Scalar: Rp is rate of generation of solid waste S1 is rate of vehicular cost t is rate of transportation S2 no of days of storage S3 density of solid waste S4 height of solid waste S5 remuneration for workers S5 rate of seggregation cost

Total waste generated at source: Total MSW generation depends on the population "P" and average rate of generation of solid waste from study area. Average rate of MSW generation Rp in the study area is experimentally determined as 0.8Kg/person/day. Total MSW generation Tw from village "i" is estimated using equation (1). Where p(i) Population of the village

Tw(i)=Rp * P(i) ……. (1)

TRANSPORTATION COST

Transportation cost is, computed by considering cost of the vehicle and operating cost of vehicle to transport MSW from the source to the segregation site. Operating cost includes fuel and maintenance of vehicle and labor cost. Product of vehicle plying distance "d" and cost of transport per unit distance "Rt" gives cost per trip. In the present study, it is assumed that each vehicle can carry, 2 T of MSW per trip. Minimum cost per trip is (S1).

Tr(i) = Tw(i)/2000 ………….. (2)

Cost per trip Trp(i,j) = Rt * d(i,j) *Tr(i) ………….. (3)

Vehicular cost Vmc(i,j) =Trp(i,j) * S1 ………….. (4)

Total trip cost Trc(i,j) = $\sum_{i=1}^{j} Vmc(i,j) + \sum_{i=1}^{j} Trp(i,j)$ ………….. (5)

Labor cost: We consider storage capacity of 15 days for MSW segregation and storage. Minimum labor cost "S5" is taken as Rs 120/day.

Labor cost to operate segregation plant Mc(i) = Tr(i) trip of vehicle *S2 *S5 (6)

Land Cost: Land require for segregation site depends upon total MSW collected at site "i" from all site factor of x(i,j). Land require for segregation ls(j) considers days for storage (S2), density of waste (S3) and height for which waste can be stored (S4). Total land is considered by summation of land for shed (ln), for composting, for movement (lm) and for management (lf). Land cost depends upon cost of land set by government know as Jantri cost (Jc).

Total waste collected at segregation site Ttw(j) = $\sum_{i=1}^{n} Tw(i)$………….. (7)

Land for storage	ls(j) =(((Ttw(j) *S2)/S3)/S4)	…………..	(8)
Land for movement	lm(j)= ls(j)*1	…………..	(9)
Land for shed	ln(j) = ls(j)*1	…………..	(10)
Land for management	lf(j) = ls(j)*1	…………..	(11)
Total land required	l(j) = Σ(ls(j),lm(j),ln(j),lf(j))	…………..	(12)
Land cost	lc(j) = L(j) * Jc(j)	…………..	(13)

Segregation cost: Segregation cost per ton of MSW (S5) is taken from the existing market price as INR 30 per ton. This includes operating and maintenance cost of the machinery. Total segregation cost is estimated using Equation (14).

Sc(j) = $\sum_{i=1}^{n} Tw(i)$* S5 ………… (14)

Total cost: Segregation site "j" is selected for segregation of waste generated from each source town "i" by minimizing total cost (z). Total cost includes Transportation cost (Trc), Land Cost (L(j)) and segregation cost(Sc(j)) of waste management from collection to disposal.

In the present study, it is assumed that MSW of each source town is segregated at single segregation site. The following constraint realizes this condition. This constraint also ensures that MSW is collected from each one of the source town. However, this constraint can be relaxed depending on the requirements of the study area.

$\sum_{j=1}^{n} x(i,j)$=1 ………… (15)

Segregation cost for each site "j" is taken into consideration only when the site receives MSW from at least one of the source "I", and is estimated using Equation (16)

Segregation cost (j) = $\sum_{i=1}^{n} \mathrm{Sc(j)} * \mathrm{x(i,j)}$ ………… (16)

Transportation cost for segregation site "j" and is estimated based on the total amount of MSW received by the segregation site that is estimated using Equation (17)

Transportation cost (j) = $\sum_{i=1}^{n} Trc(i,j) * x(i,j)$ ………… (17)

Land cost for segregation site "j" is estimated based on the total amount of MSW to be handled by the segregation site using Equation (18)

Land cost (j) = $\sum_{i=1}^{n} L(j) * x(i,j)$ ………… (18)

Total cost of establishing segregation sites for handling MSW generated from all source towns located in the study area is estimated using Equation (19)

Total cost =z = $\sum_{i=1}^{n} \sum_{j=1}^{n} c(i,j) * x(i,j))$ ………… (19)

CASE STUDY

Study area in the present work encompasses small-scale towns and their surrounding villages located in the state of Gujarat, India. We have identified Sojitra and Anklav towns located in Anand district of Gujarat state as representative towns for collection of field/primary data. Gujarat urban planning commission classified these towns as category “D” municipalities. Sojitra town is having 24 villages surrounding it, having population in the range of 1000 to 12000. Anklav town is having 18 villages surrounding it, having population in the range of 1000 to 9000. Primary objective of the study is to suggest optimal waste management strategy. Primary field data collected from these two towns and their surrounding villages. Quality and quantity of MSW generated from these towns are experimentally determined.

Present scenario of MSWM handling at study towns: Analysis of data collected reveals that 20 percentage of population comes under high-income group, 30 percentage of population are middle-income group and 50 percentage of population belongs to low-income group as shown in Table(1). Nearly 80% of population are working in agriculture sector rest are either in service sector or having small business. These towns have hot and humid climate in summer, an average rainfall is 1015 mm/year and climate is dry and cold during winter.

These small-scale towns have separate administrative department for sanitary and solid waste management. They do not have properly trained labor. Labor deficiency is more than 25%. Waste collected from the sources using small hand pulled tricycle containing six small containers. However, presently to segregate waste before transferring it to collection station these containers are not used. To collect waste Large containers are used. These containers are place at collection points. Waste collected from street sweeping s dumped in the container. Vehicles with a capacity to transport 2 tons of waste at a time are available with each town. From containers every alternative day waste is collected. Climatic conditions cause high moisture content in solid waste in the study region. In general, open dumping of solid waste observed in these towns. Open dumping practiced without any segregation or treatment. There is no facility for segregation or proper disposal of waste.

Characteristics of MSW generated from small-scale towns: We have studied composition of MSW for small-scale towns based on socio economic status, of population. Mixed group comprises of areas having residence and commercial area together. Primary segregation at residential source is done for recyclable and resalable items. Rag pickers segregate the remaining recyclable and resalable items at collection centers. MSW is collected from bins/containers to study waste characteristics before segregation. Before weighting, MSW is manually segregated. Digital weighing machine used to determine weight of various components of MSW. Alternative day composite samples are collected. Data collected for two weeks and average weight is considered. Weight of the empty and filled bins, are done to get total volume of waste generating form the area. Computerized weighing machine used for weighing of bins. Figure (I) shows Composition of waste for different economic regions for Sojitra town.

Close observation of the results reveals the followings a) the higher income group generates more inert waste compared to the other groups b) lower income group generated waste that is more organic. This may be attributed to the fact that low income, people bring daily cores of vegetables from fields and leftover of these vegetables as well as leftover of vegetable vendors generates more organic waste. Vermin composting sites are already available at each town. Organic waste can be converted useful fertilizers at these sites. Moreover, recyclable waste can be segregated and send to recycler plants. Inert waste is found more in areas having construction activities, small-scale industries etc. These inert materials are to be disposed in land filling site.

Composition of waste from villages: Four representative villages were, selected around Sojitra to study waste composition. The selected villages are Gada , Piplav, Asodhar and Navakhal. These villages are having population of 3116, 4483, 8811 and 5819 respectively. Piplav is a religious place having higher floating population. Waste composition study done for four weeks. Composite waste from bins placed at different location of village collected to get representative sample. Figure (2) shows composition of waste from villages under consideration.

From Figure (2) it can be observed that more organic waste is generated from villages compared to inert waste. More, recyclable waste collected from village with higher floating population. Figure (3) shows comparison of composition of waste from small-scale town and its surrounding village. Small-scale towns produce more recyclable and inert waste as compared to villages.

Conventionally organic generated from villages are composted along with farm waste. The manure thus generated used as fertilizer. Presence of recyclable material in the waste is less but not negligible. Proximity of these villages to small towns is one possible reason for presence of plastic waste. Incineration and land filling are widely used methods to dispose waste. However, segregation of waste is key step for effective solid waste management in these villages. Segregation of waste at the source is the best possible option. However, with existing literacy to achieve segregation of waste at source requires at least a decade. For proper and scientific method of segregation and disposal of waste, it is advisable to segregate waste at a common place. Two alternative options are a) segregation at the collection point and segregation done at a segregation site. These segregation sites either constructed at each village or constructed at center of cluster of villages.

Quantity of waste from villages: According to census, 2011 population of Sojitra at its surrounding villages are shown in Table(2). Population of Sojitra is 19720 persons. The population of surrounding villages ranges from 1000 to 12000. Quantity of MSW generated from four villages experimentally obtained. For the remaining villages MSW quantity estimated using established methods. The MSW quantity for all the villages surrounding Sojitra town is depicted in Table(2). Quantity of waste generated is less 1 Ton/Day for all the villages under consideration. However, long-term effect of the waste if unattended may cause environmental problems. We propose an economically optimal option for location of segregation site in this present work.

Identification of segregation site for Small-town (Sojitra) and its surrounding villages: The optimization model presented in the previous section used to determine the optimal MSW handling strategy. Distance among villages and small-scale town obtained from road map of Gujarat. The optimization results presented in Figure (4) and Table (3) indicate formation of three clusters. Three segregation sites suggested are located at Sojitra, Deva and Kasor. Figure (4) also shows source villages along with location of segregation site. We have identified segregation sites by minimizing total cost that includes transportation cost, segregation cost and land cost. The mathematical model proposed in the previous section used for optimization. From the results, it is evident that transportation cost is vital for selection of cluster centers.

Detailed cost analyses for two possible options presented in Table (4). The results are indicating that segregation done at collection point of source village is costlier than segregation done at cluster center. Formation of three clusters is more economical compared to formation of single cluster. On the contrary, segregation site at each source village increases total cost by 3.71times sojitra cluster. Similar trend observed for Deva (2.7 times) and Kasor (2.8 times) clusters. Hence, segregation at cluster centers more economical compared to segregation at source village.

Villages around Anklav: Population and quantity of MSW generated by Akalav town and its surrounding villages presented in Table (5). Quality and Quantity of waste obtained for this case also by following same procedure as explained in previous case. Quantity of waste generated is less 1 Ton/Day for all the villages under consideration for this cluster also.

Proposed optimization procedure used to identify optimal solid waste handing strategy. Results show formation of two clusters at Anklav and Bamangam is economical. Cluster centers and their corresponding source villages shown in Table (6) and Figure(5). Results presented in Table (7) shows that formation of two clusters is more economical compared to formation of single cluster. Segregation site at each source village increases total cost by 4 and 3.8 times respectively at Akalav Bamangam clusters.

The results presented for both cases suggest that segregation at cluster centers more economical compared to segregation at source village.

CONCLUSIONS

We found from study that composition of waste for small-scale towns and villages consists of 40 – 70% as organic waste, 20-30% as recyclable waste and 10 – 20% inert waste. The rate of generation of waste ranges from 0.5 to 1.0 Kg /person/Day. An optimization model proposed to determine optimal location of segregation sites. The proposed model suggests formation of cluster for segregation is economical. There is an increase ranging from 2.5 to 4.0 times in total cost if the segregation sites provided at each source town. Efficiency of the proposed method demonstrated with the help of two case studies considering small-scale towns and their surrounding villages located in the state of Gujarat, India.

Table (1) Income group

Sr no	Group	Income per annum (INR/year)
1	High income	> 1,00,000
2	Medium / Mixed group	50000 to 1,00,000
3	Lower income group	< 50000
Source: Gujarat urban planning commission		

Table (2) Population and MSW Generated per day of Different Villages under Sojitra Municipality

Name of village	Population 2011	MSW Quantity (Kg/day)	Name of village	Population 2011	MSW Quantity (Kg/day)
Balinta	3168	253.44	Maghrol	4323	345.84
Bantwa	1177	94.16	Malataj	4666	373.28
Bhadkad	2853	228.24	Medhalpur	1569	125.52
Dali	1078	86.24	Parol	2362	188.96
Devataj	2926	234.08	Petli	3869	309.52
Devavanta	2462	196.96	Piplav	4483	358.64
Devtalpada	6955	556.4	Run	1565	125.2
Dabhou	5570	445.6	Runaj	3182	254.56
Gada	3116	249.28	Trambovad	3891	311.28
Isnav	2774	221.92	Virol (Sojitra).	2384	190.72
Kasor, sojitra	12029	962.32	Kothavi	1155	92.4
Khansol	1008	80.64	Limbali	1508	120.64
Source: census of India 2011					

Table (3) Location of Segregation Site for Different Clusters

Sr No.	Cluster	Name of village
1	Sojitra	Sojitra,Balinta,Dali,Devataj, Gada, Khansol, Kothavi, Madhrol,Runaj, Trambovad, Virol
2	Deva	Bhadkad, Deva, Dhabou, Malataj, Petli, Run
3	Kasor	Kasor,Isnav, Piplav

Table (4) Cost Comparison for Sojitra Site

Detail	Sojitra Site		Deva Site		Kasor Site	
	cluster	Source	cluster	Source	cluster	source
Land cost	2575600	7838700	566500	3360900	663000	2019600
Segregation cost	51410	51410	27375	25437	21900	16896
Construction cost	309000	3672000	309000	1836000	306000	918000
Transportation cost	177472	-	1017484	--	44395	----
Total	3113482	11562110	1920356	5222337	1035295	2954496

Table (5) Population and MSW generated per day of different villages under Anklav municipality

Name of Village	Population 2011	MSW Quantity (Kg/day	Name of Village	Population 2011	MSW Quantity (Kg/day
Ambali	4027	322	Gambhira	7038	563
Ambav	4344	348	Haldari	2249	180
Amrol	5006	400	Hathipura	2546	204
Asarma	3863	309	Jhilod	2078	166
Asodar	8811	705	Kosindra	4006	320
Bamangam	8220	657	Mijkuva	4747	380
Bhanpura	1323	106	Navakhal	5819	469
Bhetasi(Talpad)	1218	97	Umeta	3176	254
Bilpad	2090	167	Kandvadi	5816	465
Source: census of India 2011					

Table (6): Name of villages in Anklav town and villages found

Sr No.	Cluster	Name of village
1	Anklav	Ambali,Ambav,Amrol,Asarma,Asodar,Bhanpura, Bhetasi, Haldari, Hathipura,Joshikuva, Kosindra, Mujkuva, Navakhal
2	Bamangam	Bilpad, Ghambhira,Jhilod,Chamara,Umeta

Table (7) cost comparison for segregation site

Detail	Anklavsite		Bamangam site	
	cluster	source	cluster	source
Land cost	1680000	5661000	306000	1534080
Segregation cost	61465	44117	19799	12598
Construction cost	2320329	3978000	306000	1224000
Transportation cost	307980	-	91966	--
Total	2364446	9683117	723765	2770679

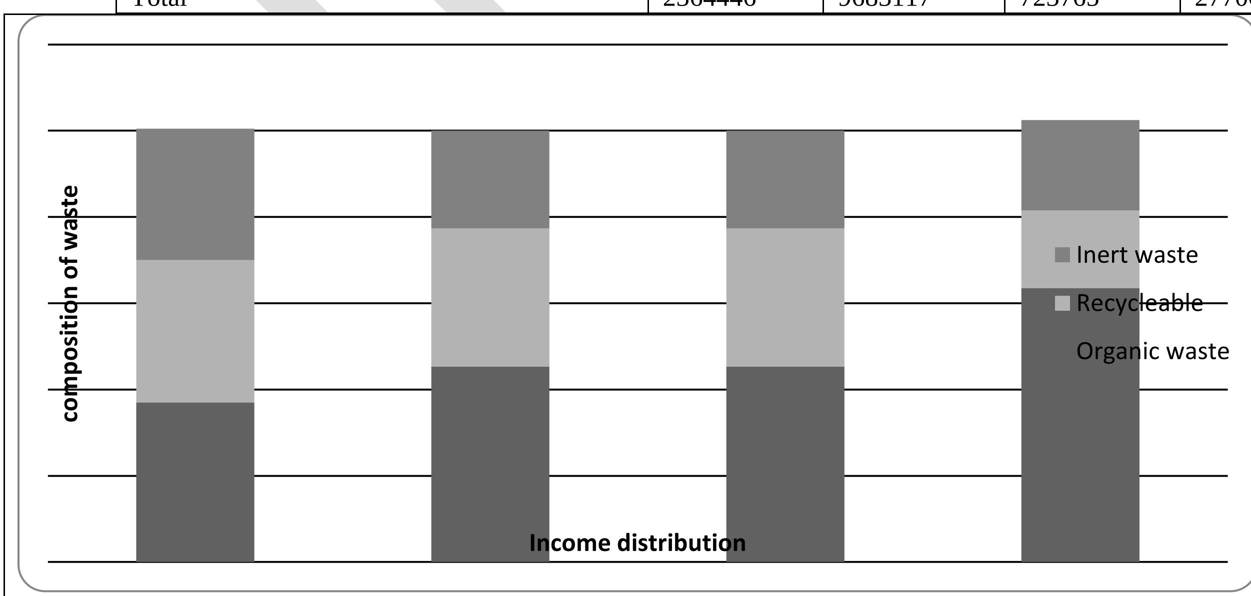

Figure (1) Waste characteristic as per economic status of Sojitra town

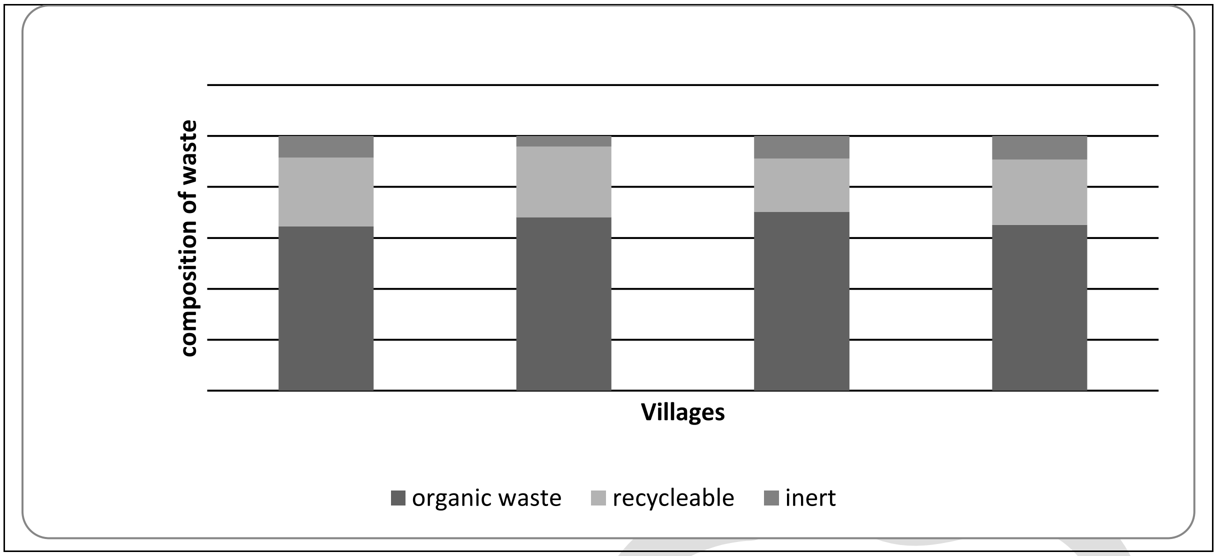

Figure (2) Comparison of MSW composition for villages near Sojitra.

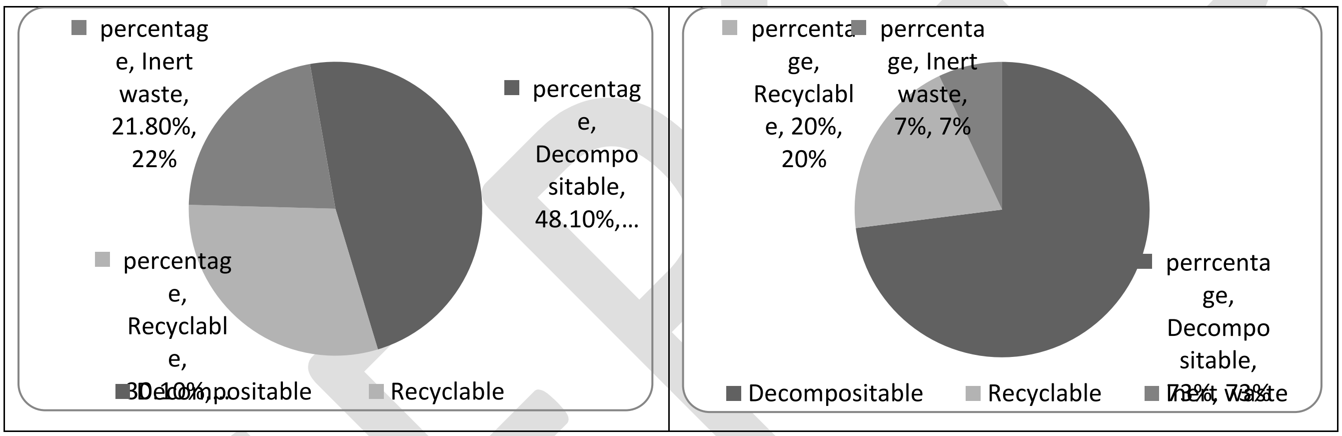

Figure (3) comparison of MSW composition for sojitra (left) and its surrounding villages (right).

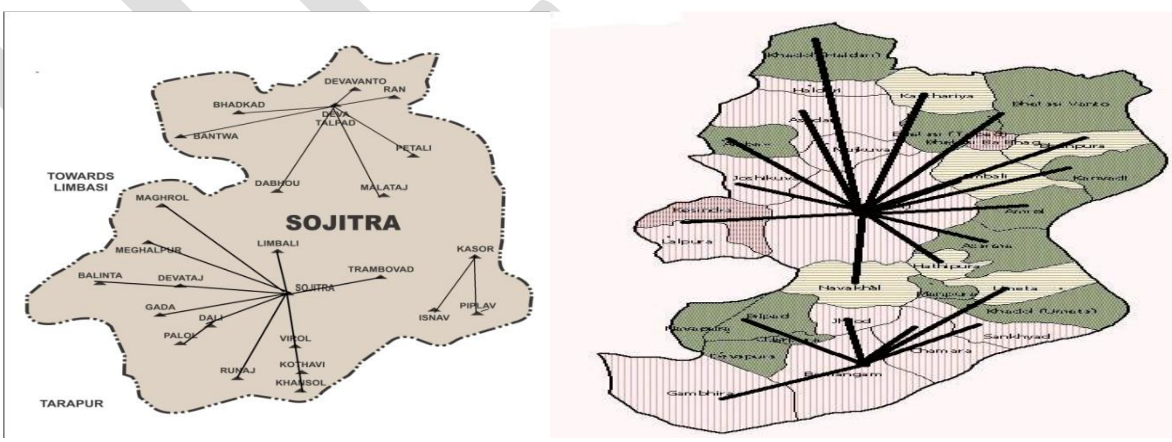

Figure (4): Map showing location of segregation site selected for Sojitra and Anklav municipality

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