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Transportation System Planning For Municipal Solid Waste through Gis

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ABSTRACT: *Fast urban development has carried with it an inescapable issue of metropolitan strong waste administration. A significant part of absolute consumption on strong waste administration (SWM) is spent on assortment and transportation of waste. Improvement of course is consistently a difficult undertaking for city organizers. Geological Information System (GIS) is a significant instrument to take care of the issues of waste transportation from assortment to landfill site dependent on least expense. The cost factor is influenced by the work cost, vehicle cost, time, separation and sort of street among others. ArcGIS programming might be utilized for digitization of spatial information in GIS condition. System Extension module is utilized for finding the course with least expense. The proposed strategy can be utilized as an apparatus by urban nearby bodies to make work plan for effective assortment of strong waste. This strategy has been approved for the city of Varanasi (India). It is seen that the current waste stockpiling and assortment framework in Varanasi is deficient and spontaneous. An underlying venture of approx. Rs. 76.45 million is assessed for development of waste stockpiling and transportation framework and roughly Rs. 52.40 million is required per annum for dealing with these two administrations productively.*
Keyword:*Municipalsolidwaste,GIS,wastecollection,transportation,routeplanning,optimization.*

I. INTRODUCTION

Themanagementofmunicipalsolidwaste(MSW)isahighpriorityissueformanycommunitiesthroughouttheworldincludingIndia.Problemsofsolidwastemanagementaregrowingwithrapidurbanizationandchangeinthe lifestyleofthepeople.Thesituationisbecomingcriticalinmanycitieswiththepassageoftime.AWorldBankreportestimatedthatintheyear2000urbanIndiaproducedapproximately100,000metrictonsofMSWdailyorapproximately35million metrictonsofMSWannually(Hanrahanetal.,2006).Variousstudiesrevealthatabout90%ofMSWinIndiaisatpresentdisposedoffunscientificallyinopendumpsandlandfills,creatingproblemstopublichealthandtheenvironment(Kansal,2002;Rathi,2006;Sharholyetal.,2008;OhriandSingh,2011).Mostofthemunicipalitiesarecurrentlyunabletofulfilltheirobligationtoensureenvironmentallysoundandsustainablehandlingofsolidwastesintermsofcollection,storage,transportation,treatment,anddisposal.ToimproveuponthesituationanddevelopaproperinfrastructureforSWM,GovernmentofIndiasanctioned2500Crores(approx.US$500million)exclusivelyforsolidwastemanagementfromthe12thFinanceCommissiongrants.StartingfromDecember2005,ithasalsoearmarkedRs100,000Crores(approximatelyUS$20billion)overaperiodofsevenyearsfordevelopmentofinfrastructurein63citiesunderJawaharlalNehruNationalUrbanRenewalMission(JNNURM).Thus,atleastnowfinancedoesnotappeartobeaconstraintinpropersolidwastemanagement.However,thegrowingcomplexityoftheissuesinvolvedinintegratedsolidwastemanagementdemandsadvancedknowledgebasedtools suchasDecisionSupportSystem(DSS)andGISapplicationtoimprovethecompletesolidwastemanagementsystem. Amongallthecomponentofmunicipalsolidwastemanagement(MSWM),transportationtakesamajorportionofbudgetandunplannedtransportationsystemmaycausehugelossoffunds.Transportationofthewastesatregularintervalsisessentialtoensurethatgarbagebins/containersdonotoverflowandwasteisnotseenlitteredonstreets.Hygienicconditionscanbe maintainedincities/townsonlyifregularclearanceofwastefromtemporarywastestoragedepots(bins)isensured.Transportationsystemhastobesodesignedthatitisefficient,yetcosteffective.Forefficientplanning,transportationsystemmustbesynchronizedwithprimarycollectionandstorageofwaste; otherwiseitisliabletofail.Henceprimarycollection,storageandtransportationmustbeconsideredholisticallytodevelopa wastemanagementplanofacity.

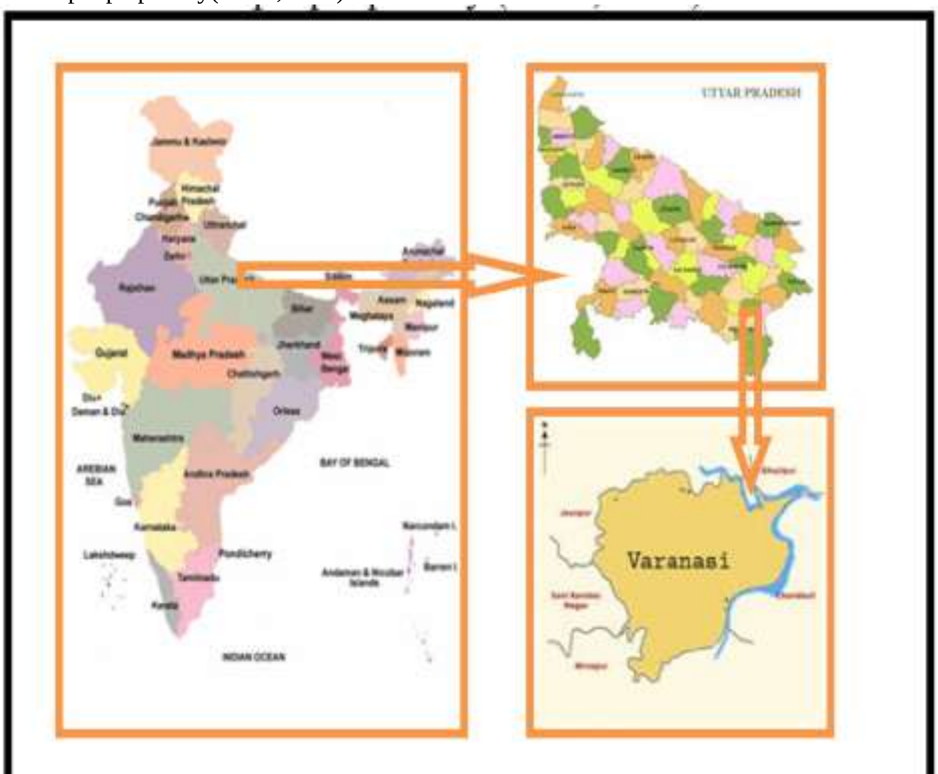
Manyworkshavebeendonealloverthewopldforoptimizingcollectionandtransportationsystemsformunicipal solidwaste.Changetal.(1997)developedamultiobjective,mixed-integerprogrammingmodelforcollectionvehicleroutingandschedulingforsolidwastemanagementsystemssynthesizedwithinaGISenvironment.TungandPinnoi(2000)usedoperationsresearchtechniqueinwastecollectionactivities.AngelelliandSperanza(2002)presentedamodelforestimatingtheoperationalcostsofwastecollection,whicharestrictlyrelatedtothedistancetraveledtocollectthewasteanddeliverittothedisposalpoints.Themodelwasappliedtotraditional,side-loader,sideloaderwithdemountablebodytypesofcollectionsystemstocomparetheperformance.Viottietal.(2003)used GeneticalgorithmsasapromisingtoolforoptimizationoftheMSWcollectionroutes.Theobjectivesofthestudyincludedreductioninfuelconsumption,laborcost,vehiclemaintenanceexpendituresandimprovedtrafficconditionsinurbanareas.

Ghoseetal.(2006)usedGISinplanninganeffectivesolidwastemanagementsystemandanoptimalroutingmodelwasproposedtodeterminetheminimumcost/distanceandefficientcollectionpathsfortransportingthesolidwastestothelandfill.Themodelneedsinformationonpopulationdensity,wastegenerationcapacity,roadnetworkandthetypesofroad,storagebinsandcollectionvehicles,etc.Lakshumietal.(2006)hasdevelopedaGISbasedmodeltocalculateoptimalroutesforsecondarywastecollectionvehiclesbasedondistanceandtimecriteria.Acomparisonismadebetweenthecostofthefuelfortheproposedroutesandthefuelconsumedontheexistingroutes.Karadimasetal.(2007)usedtheAntColonySystem(ACS)algorithmintheGISenvironmentfortheidentificationofoptimalroutesforMSWcollection.ApaydinandGonullu(2008)developedshortestpathmodelusingGISsoftwareMapInfoinordertooptimizesolidwastecollection/haulingprocessestominimizeemission.Lietal.(2008)consideredatruckschedulingproblemforsolidwastecollectionintheCityofPortoAlegre,Brazil.Theyattempteddesigning"good"dailytruckschedulesascomparedtoasetofpreviouslydefinedcollectiontrips,onwhichthetrucksusedtocollectsolidwasteinfixedroutesandemptyloadsinoneofseveraloperationalrecyclingfacilities.Themajorobjectivewastominimizethetotaloperating

andfixedtruckcosts.Tavaresetal.(2009)proposedtheuseofGIS3Droutemodelingsoftwarewhichaddsonemoredegreeoffreedomtothesystemandallowsroutestobeoptimizedforminimumfuelconsumptionforwastecollectionandtransportation.Themodeltakesintoaccounttheeffectsofroadinclinationandvehicleweight.Kanchanabhanetal.(2010)haveproposedaGISbasedcollectionandtransportationmodelforMSWM.Theparametersconsideredincludedpopulationdensity,wastegenerationcapacity,roadnetwork,storagebinsandcollectionvehicles.Optimizationoftheroutingsystemforcollectionandtransportofsolidwasteisanimportantcomponentofaneffectivesolidwastemanagementsystem.

II. STUDY AREA PROFILE

VaranasiisthefourthlargestcityofUttarPradeshstateofIndia,situatedat2514'Northlatitudeand8303'Eastlongitude(Fig1).ThecityisknownforitsmysticGhatsandricharchitecturalheritage.Thecitydevelopedintheareafallingbetweentworivers,"Varuna"and"Assi"andisthereforeknownasVaranasi.Itisbelievedtobemorethan3000yearsoldandconsideredastheoldestlivingcityintheworld.RiverGangapassesthroughtheeastofthecity.Aspercensus2001,Varanasicityhasapopulationof1202443andanareaof79.79Sq.Km.Itisdividedinto90administrativewards.AveragehouseholdsizeofVaranasiis7.3whichisveryhighascomparedtothenationalaverageof5personsperhouseholdandstateaverageof6.3personsperhousehold.Theaveragehouseholdsizeinslumsisof10memberswhichismuchhigherthanNationalandStateaverages.Varanasihassome227slumseitherongovernmentorprivatelandsspreadaroundthecity.Totalpopulationinslumsisestimatedas453,222whichisabout37.7%ofthetotalpopulation.Majorityofslumshaveverypoorwatersupplyandsanitationfacilities;andsolidwastesaredirectlydumpedintonearbyopennallas.Theaveragefloatingpopulationofthecityisestimatedtobearound2lakhspeopleperday(VNN,2007).



F**igure1**StudyareaonIndianmap

1. StatusOfMunicipalSolidWasteManagementInVaranasi

AccordingtoVaranasiNagarNigam(VNN)report,forsanitarypurpose,Varanasiisdividedinto7zonesand14sanitarywards.In2007,thecitygeneratedaround600metrictons(MT)ofmunicipalsolidwasteperdayattherateof0.41kg/capita/day.Thecorporationhasaroadlengthof1247.00kmforstreetsweeping.ThecompositionofMSW inVaranasiisgiveninTable1.

Table1CompositionofMSW inVaranasi(Source:VNN,2007)

Component	Percentage
Biodegradable	51.25
Recyclable	15.30
Other inert wastes	33.45

TheMunicipalSolid(ManagementandHandling)Rules,2000ofGovernmentofIndiademandspropercompliancenceofallthesevenstepsforintegratedsolidwastemanagement.However,presentstatusofmunicipalsolidwastemanagemententinthecityisnotverysatisfactory(Figure2).

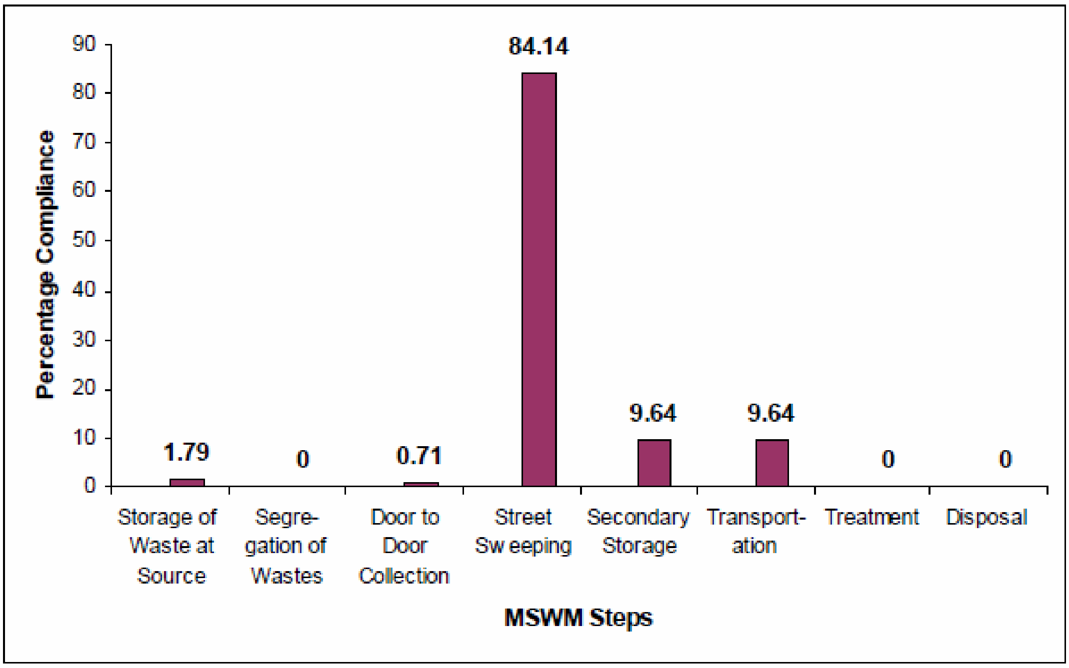


Figure2StatusofcomplianceofMunicipalSolids(ManagementandHandling)Rules,2000inVaranasi(VNN,2007)

Segregationofrecyclablefromwastesisnon-existent.Doortodoorcollectionappearsjustintroducedinthecity.Thesituationofstreetsweepingisreasonablygood.AtpresentVaranasihavearound1650sanitaryworkersforroadsweeping.Around70%ofthestreetsarecleanedeveryday,around15%onalternatedaysand10%twiceaweek .Draincleaningisdonebyseparatesweepersandaround400workersareengagedinthistask.Thefacilityforsecondarystorageinthecityisverypoor.Table2givesthedetailsofavailablesecondarystoragesysteminVaranasi.

Table2SecondarystoragefacilitiesinVaranasi(Source:VNN,2007)

Type	No.
Open waste storage sites	27
Masonry bins	20
Metal containers (4.5 m^3 Capacity)	65
Total	**112**

Clearlythereisinsufficientnumberofwastestoragedepotsandmajorityofthemareopenandunhygienic.Themetalcontainers(designedasdumperplacers)arenotemptiedregularly.Ragpickingfromdepotsandthesecondarystoragecontainersoftenresultinspreadingofwasteoutsideleadingtofurtherlittering.Thedepotsarenotinsynchronizationwiththeprimarycollectionsystemandmultiplehandlingofwasteispracticed.Transportationof75%oftotalwasteisdoneonadaytodaybasisbymostlyuncoveredvehicles.MunicipalCorporationdoesnothaveanytreatmentorscientificdisposalfacilityofwastesatpresent.

Transportationworkisnotscientificallydesigned.NoworkisdoneonSundaysandpublicholidays,whichgiverisetoaccumulationofwasteandconsequentbacklog.Wastetransportationinopentrucksresultsinlotoflittering.Thereispracticallynorouteplanningandwastetransportationismanagedonadhocandrequirementbasis.ThenumberandtypesofvehiclesavailablewiththemunicipalcorporationisgiveninTable3.

Table3AvailablesolidwastetransportvehiclesinVaranasi

Type of vehicle	No.	Volume of each vehicle (m^3)
Tipper/dumper trucks	19	9
Dumper placer	12	3
Tractors	17	3
Hopper	22	1

(SourceVNN,2007)

Thecorporationhasbeenusingmostlyopenvehiclesfortransportationofwaste.Thetransportationefficiencyis85%.Thevehiclesareusedintwoshiftsandonanaveragetractormaketwotrips,whereasdumpers,hoppersanddumperplacersmakefourtripsinoneshift.ThecorporationhasshortageofdriversforMSWtransportationworks.Amunicipalworkshopisthereinthecentraldistrictofthecityandtherepairequipmentsincludegrinder,handgrill,aircompressor,etc.Around63%oftippersandabout88%ofavailabletractorsinthefleetaremorethan10yearsoldandneedfrequentrepairs.Thecitycorporationdoesnothaveanyfacilityforprocessingofmunicipalsolidwaste.Theentirewasteofthecity isdisposedofinlowlyingareaorundesignateddumpinggrounds.Thetotalnumberofopendumpseitherabandonedorinuseinthecityis74.Ofthese,35sitesareonprivatelandsand39sitesareongovernmentland.Thecorporationisplanningtoclosethesesiteswithcoverandbundingaspersiteconditioninordertoprotectpublichealth,groundwaterandGangariverpollution.Thisstudypresentsaconceptualmodelforthewastemanagementpracticestobefollowedtakingcasestudyofthiscityanddefinethemethodologyforanengineeredsystemofwastecollection,transportationanddisposal.

III. METHODOLOGY

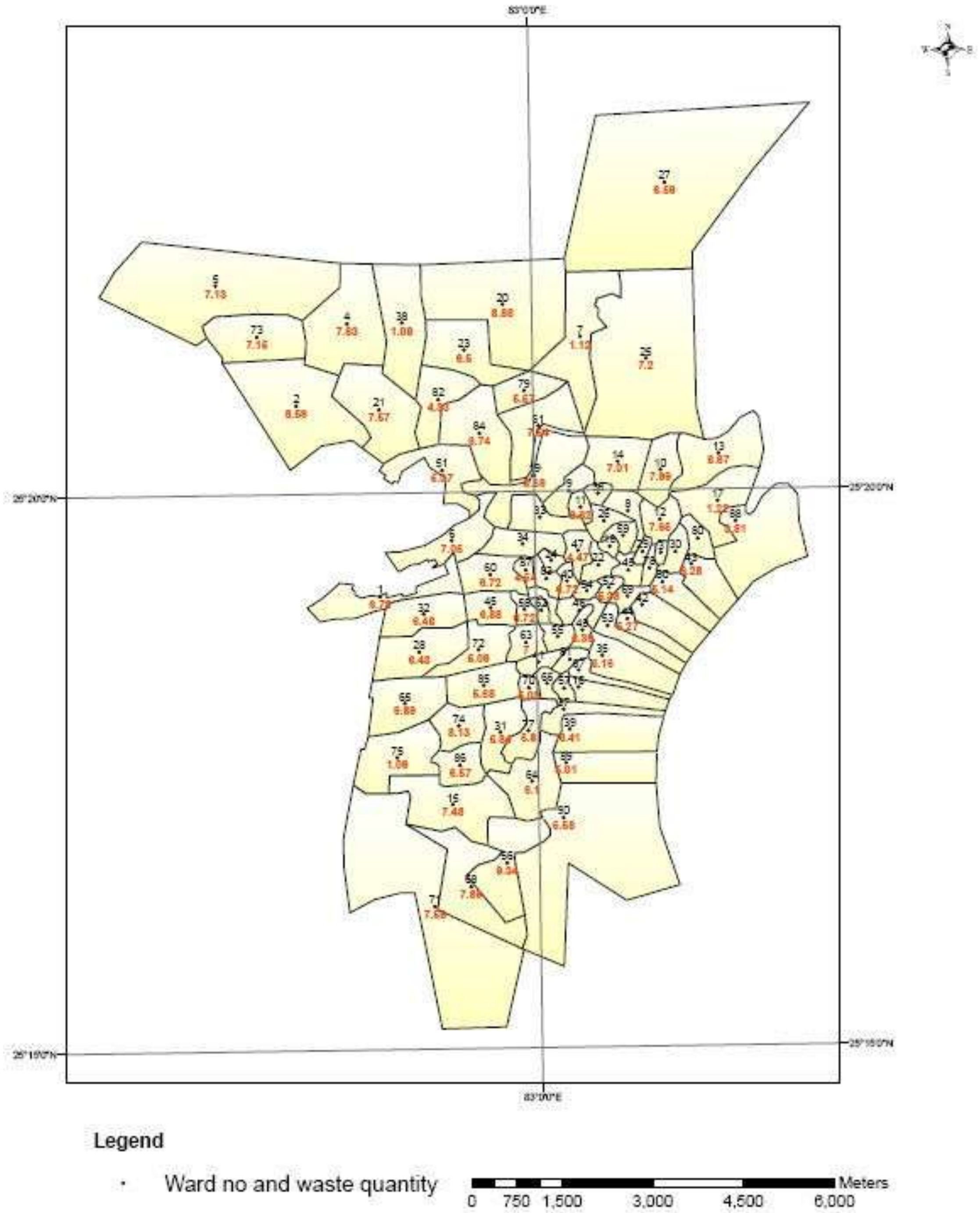
Theframeworkofthewastemanagementplanproposedinthisstudyprimarilyconsistsof:

3.1 Estimationofamountofwasteinthestudyarea

Inordertofindtherequirementofsecondarystorageinanarea,anestimateoftotalquantityofwastegeneratedineachwardisessential.Forthepurpose,wardwisepopulationdataof2001wasobtainedandprojectedfortheyear2011.Forplanningpurpose,thegeometricprogressionmethod(Eq.1)hasbeenusedtoforecastthepopulationofindividualwardswithinthemunicipality.

$$P_{t+n} = P_t\left(1 + {}^{r}/_{100}\right)^{n} \quad (1)$$

HerePt=populationattimet; P_{t+n} =populationattimet+n;n=thenumberoftimeperiods;andr=theaveragepercentagechangeinpopulationoverthepasttimeperiod.Withwastegenerationrateincreasingatarateof1.33%peryear(Pappuetal.,2007;Shekdar,1999;BhideandShekdar,1998;NEERI;Guptaetal.1998;Sharholyetal.,2008),therateofgenerationin2011islikelytobe0.430kg/capita/daywithrespectto 0.410kg/capita/dayintheyear2007.Theprojectedpopulationin2011(P2011)andwastegenerationrateareusedtofindthetotalquantityofwasteonwardwisebasis,asshowninFig3.Thetypeandnumberofstoragebinsorcontainershavetobedecidedbasedonthisquantityandfrequencyofwastecollectionplan.



Fi**gure3**WardmapofVaranasicitywithamountofwasteexpected(2011)

3.2 Evaluationofappropriatemethodforsecondarystorageofwaste:
Doortodoorcollection(DTDC)systemhasbeenproposedfromyear2010inVaranasi.Aspertherecommendationsofdifferentstudies(CPHEEO,2000;Ghoshetal.,

2006),thevolumeofcontainer(s)hastobeatleastoneandhalftotwotimesthevolumeofwasteexpecteddailyinordertoprev entoverflowofbinsduetoexigencies.Asfaraspracticable,largesizedclosedbodycontainersmaybeplacedatthetemporar ywastestoragedepottominimizethecostoftransportation.Consideringawastedensityofto400kg/m3inVaranasi(VNN, 2007),astoragevolumeof2.5m3/tonofwasteisrequired.Providing100%extracapacity,thesecondarystoragewillneed5 m3/tonofMSW.Itwillbemoreconvenientandpracticaltoputtwocontainersofequalcapacityateachstoragesitesothatone isusedfornormalinflowsofwasteandotherremainsreadyforextraloadoroccasionalexigencies.Forinstance,iftwotonsof wasteperdayisexpectedatanylocation,itwillneedaround5m3ofstoragevolumeinnormalsituations.Proving100%extra volume,twocontainersof5.0m3maybeplacedatthatlocationsothattherewillbenooverflowofwasteintheformoflitterso nthestreet.Eachcontainermaybeliftedonalternativedaysingeneralwhenitisfullyfilledtoreducethetransportationcost.A publicawarenessprogrammayhelptoeducatepeopletousefullcapacityofaworkingcontainerbeforethewasteisputinsec ondone.ForVaranasi,astheroadsandlanesarenarrow,mediumsizedcontainershavingcapacity4.5m3 appearsideal.Forslumareas,smallcontainermaybeusedanditshouldbeemptiedregularlyby usinghandcarttolargecontainerkeptoutsidetheslum.

IV. SECONDARYCOLLECTIONANDTRANSPORTATIONOFWASTE:

AsthereisatpresentnoprocessingunitforMSWinVaranasi,thewasteiscollectedfromsecondarystoragepoints anddirectlytransportedtodisposalsite.AsanitarylandfillisbeingplannedanddevelopednearvillageKarsadaaround17k mawayfromcitycentre.A9m3capacitydumperplacerisproposedtobeusedfortransportationofsolidwaste.Eachvehicle willworkintwoshiftsof7.5hrseachexcludingthetimeoflunchandwillcarrytwocontainersatatimetomaximizeutilizatio noffleet.

Hauledcontainersystems(HCS)areusualchoicewherelargequantitiesofwastearegeneratedandmediumorlar gesizecontainersareused.Thisavoidslargescalehumanhandlingofwasteandreducesthetimeofcollectionandtransporta tion.InVaranasi,thissystemisrecommendedbasedonthequantityandpatternofsolidwastemanagementactivities.Inthis system,eachfilledcontainerispickedupfromitslocationandtransportedtothetreatmentfacility,transferstation or disposalsitewhereitisemptied.Theemptycontaineristhenreturnedtoitsoriginallocation.Alternativelyswapcontainersy stemmaybeusedinwhichcontainerisdepositedatthenextpick-uplocationontherouteinexchangeforafullcontainer.Swapcontainersystemisnormallymoreeconomical(Peavyetal.,1985).

InHCS,thetimerequiredpertrip,whichalsocorrespondstothetimerequiredpercontainer,isequaltothesumofpickupatsiteandhaultime,andisgivenbyEq.2(Peavyetal.,1985):

$$T_{HCS}=P_{HCS}+s+a+bx \quad (2)$$

WhereT_{HCS}=timepertripforhauledcontainersystem,h/tripP_{HCS}=pickuptimepertripforhauledcontainersystem,h/trip
s=atsitetimepertrip,h/trip
(0.127-0.133h/tripor7.6-8.0minutes/tripformechanicalloadingoftiltframevehicles)a=anempiricalhaulconstant,h/trip
b=empiricalhaulconstant,h/km
x=roundtriphauldistance,km/trip.
Thepickuptimepertripisgivenby Eq.3.

$$P_{HCS}=p_c+u_c+d_{bc} \quad (3)$$

Wherep_c=timerequiredtopickuploadedcontainer,h/tripu_c=timerequiredtounloademptycontainer,h/trip
d_{bc}=averagetimespentdrivingbetweencontainerlocations,h/trip
Onanaverage(p_c+u_c)istakenas0.4h/trip(24min)andthevalueofd_{bc}isdeterminedlocally.
TypicalvaluesofhaulconstantcoefficientsaandbaregiveninTable4Table4HaulConstantCoefficients,aandb(Peavyetal.,1985)

Speed limit (km/h)	a (h/trip)	b (h/km)
88	0.016 (1 min/trip)	0.011 (0.66 min/km)
72	0.022 (1.3 min/trip)	0.014 (0.84 min/km)
56	0.034 (2.0 min/trip)	0.018 (1.08 min/km)
40	0.050 (3.0 min/trip)	0.025 (1.5 min/km)
20*	0.083 (5.0 min/trip)*	0.050 (3 min/km)*

*

Extrapolatedvalues

Inordertofindthevaluesoftheseconstantsforlowerspeedsofvehicles,curvesfortheirvariationwithspeedweredrawn,asshowninFigure4.Theextrapolatedvaluesofaandbat20km/hspeedhasbeennotedinTable4.

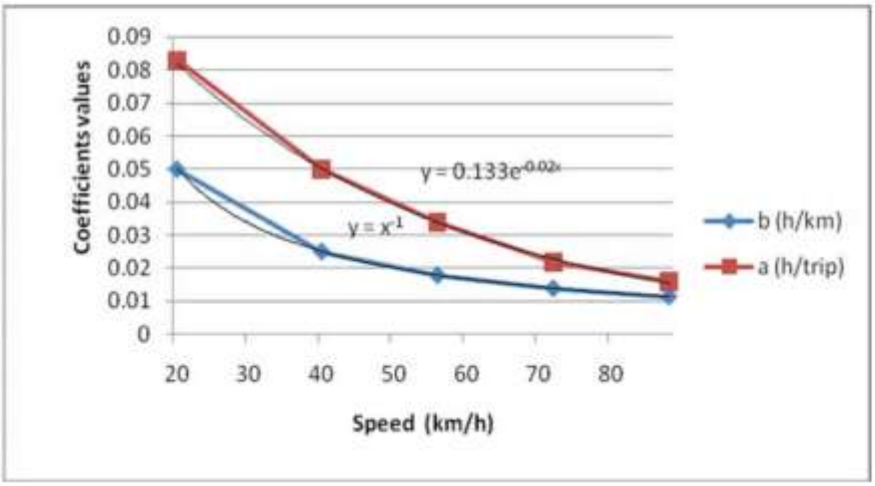


Figure4Speed vs.Timecurvefor HaulConstantCoefficients,

aandbThenumberoftripsthatcanbemadepervehicleperdaywithahauledcontainersystemincluding afactortoaccountforoffrouteactivitiesiscalculatedusingEquation4.

ND =[H(1-W)-(t1+t2)]/THCS (4)

whereNDisthenumberoftripsmadeperday,trip/d;Histhelengthoftheworkday,h/d;
t1isthetimeinhoursrequiredfordrivingfromthedispatchsiteatthebeginningofdaytofirstcontainerlocation,h;and t2isthetimeinhoursrequiredfordrivingfromlastcontainerlocationtothegarageattheendoftheday,h;
Wistheoff-routefactor(normally takenas0.15)(Peavy etal.,1985).
ItisrecommendedthateachvehiclehastofitwithGPSnavigationdeviceandconnectedtocentralserverbyGSMmodemtotransfertherealtimelocationofvehicletotransportmangersforbettermanagement offleetandstoppingmalpracticesintransportation.

4.1 GenerationofGISdatabaseforthestudy:

GISrepresentsasystemofhardwareandsoftwareusedforstorage,retrieval,mapping,andanalysisofgeographicdata.DifferentthematiclayersofroadnetworK,wardmaps,wastedisposalsites,riversetcarepreparedinArcGISsoftware.Roadsaredividedinto3categoriesnamelyHighways,MajorDistrictRoadsandStreets.Centrepointofeachwardismappedaswastegenerationnodeforthatward.Thisnodalpointisusedincalculatingtheaveragedistanceofdisposalsitefromtheward.ArcGISnetworkAnalystofArcGIS8.1isusedinfindingshortestroutesandtraveldirectionsfromlandfillsitetodifferentwastege nerationnodesandisshowninFigure5.

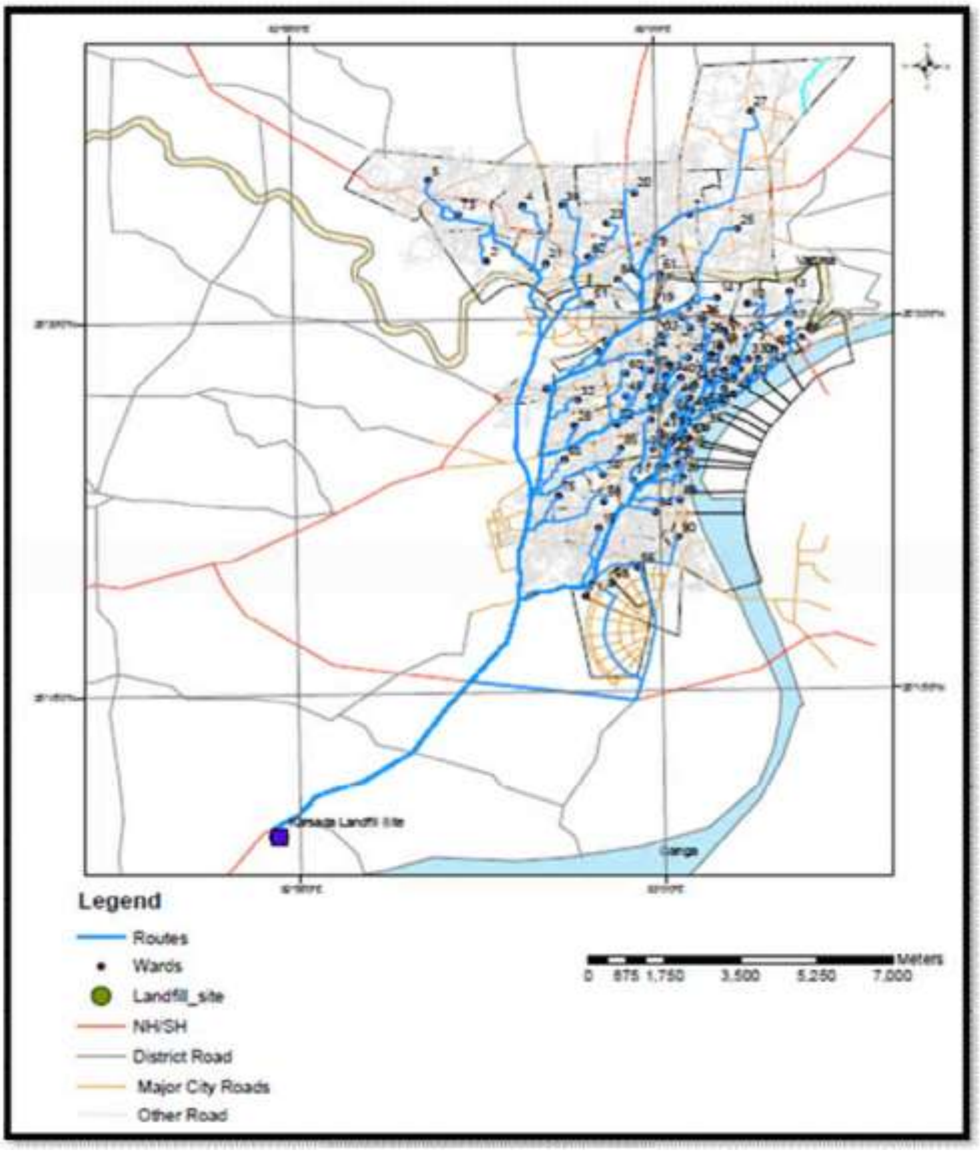


Figure5Routemapshowing leastcostpathfromlandfillsitetodifferentwardsofVaranasi

V. RESULTSANDDISCUSSION:

Basedonthedataof1991and2001,apopulationgrowthrateof23.63%perdecadehasbeenestimatedandusedforforecastingwardwisepopulationofVaranasiintheyear2011bygeometricprogressionmethod(Eq.1).Withtheprojectedpercapitawastegenerationrateof0.430kg/d,thequantityofMSWineachwardisestimated.First,secondthird,fourthandfifthcolumnsofTable5showsthewardnumber(W.N.),Projectedpopulationinyear2011(P2011),Areaofwardinsq.km(A), wastegeneratedineachwardinyear2011(W)andtotalvolumeofcontainersrequiredto storewastegeneratedinanyparticularward(V)respectively.

5.1 Designofsecondarystoragesystem

Closedcontainersofcapacity4.5m3and1m3areproposedtobeusedforsecondarystorageofwaste.Thenumberofcontainersrequiredineachwordiscalculatedbasedonthecriteriongiveninsection4.2.Sincecontainersareusedinpair,evennumberofcontainersisplacedineachword.Thedetailedcalculationsof secondarystoragerequiredandtransportationvehiclesarepresentedinTable5.Columns1,2,3,4and5givewardnumber(W.N),projectedpopulationin2011(P2011),area(A),totalquantity

(W)andtotalvolume(V)ofwastegeneratedperdayrespectively.Thecapacityofeachcontainer(CV)tobeputinaward,numberofcontainerrequired(CR)anddistancebetweenthecontainers(DAVC)areinter-related.Iflargercapacitycontainersareused,dependingontheareaofward,thedistancebetweencontainerswillbecomehigher,whichmaynotbeacceptableforpracticalreasonsofkeepingthemnotbeyond250mofwalkbycollectingstaff.Givingtoosmallcontainerswillmeanaveryshortdistanceseparationbetweenthem,thusincreasingtheoperationalcosts.Basedon preliminarycalculations,4.5m3,3.0m3or1.0m3capacitycontainersareplacedinawardsothattheaveragedistancebetwe enthecontainersdoesnotexceed500mingeneral.Column6,7and8giveoptimumcontainersize(CV)forthearea,numbero fcontainerrequired(CR)beplaced,anddistancebetweenthecontainers(DAVC).Inordertomeetthemandatoryrequireme ntofkeeping100%extracapacityofsecondarystorage(CPHEEO,2000),thenumberofcontainerstobeplaced(CP)isdoub ledineachward,withrespecttocontainersrequired(CR).Column9givesthenumberofcontainerstobeplace(CP)ineachw ard.Basedontheamountofsolidwastegenerated(W)andthetotalnumberandcapacityofcontainersplacedintheward,theti meoffilling(TF)ofstorageprovidedhasbeentabulatedinColumn10.Thefrequencyofcollection(F)isaccordinglydecide dasgiveninColumn11.

5.2 DesignofTransportationsystem:

Thedistanceofthecentroidofeachwardfromthedisposalsite(X)hasbeengiveninColumn12.Timetopickup(pc)andunloadingthecontaineratanystoragesite(uc)isequalto0.4h.Basedonaveragedistance(dbc)betweenthecontainersi naward,averagespeedofthetransportationvehicle,pickuptimepertrip(PHCS)isestimatedusingEq.3,asgiveninColumn 13.

Ifthetimetofillupthecontainerisonedaysthenthevehiclewillliftonecontainereverydayfromeachlocation.The totalnumberof4.5m3,3m3,1m3capacitycontainersrequiredforthecityisequalto607,106,286respectivelywhicharepla cedin500differentlocations.Sinceareaofthecityisapprox.80sq.km.,averagedistancebetweenthecontainerscomesoutt obe400m.

Timespentatdisposalsiteinweighing,waitingandunloadingthewasteisapproximatelyequalsto0.133h/trip.As Varanasiisverycongestedcity,averagespeedofvehicleistakenas20km/h.Thevaluesofempiricalconstantsaandbof Eq.2 aretakenfromTable4accordingly.Inordertofindthenumberoftripsperdaybyavehicle,asperEq.4,timespentdrivingfro mthedispatchsiteatthebeginningofday(t1)anddrivingbacktodispatchsiteintheendoftheday(t2)isapproximatelytaken as0.5h.Valueofoff- routefactorWistakenas0.15(Peavyetal.,1985).InVaranasiwasteistransportedintwoshiftsandworkingtimeofeachshift is7.5hexcludinglunch,thus,totalworkinghour(H)is15h.Thetimetocompleteonetriptodisposalsitefromeachward(TH CS)calculatedfromEq.2isgiveninColumn14.Thenumberoftripsperday(ND)bythevehicletakingwastefromawardisc alculatedfromEq.4andshowninColumn15.Numberofvehicles(Nv)requiredforeachwardiscalculatedbasedonthetotal numberofcontainer(CR),volumeofeachcontainer(CV),volumetriccarryingcapacityoftransportationvehicle(9m3inth iscase)andthenumberoftrip(ND)bythevehiclefromthewardperday.ThevaluesofNvaregiveninColumn16.Inordertout ilizefullcapacityandtimeofthetransportationvehicle,onevehicleissuitablyassignedwithtwoormorewardsorviceversa. Thevehiclenumber(VN)assignedtoanywardfortransportingitswastefromcontainerstothedisposalsiteatKarsadavillag einVaranasiisgiveninColumn17andisaccordinglyshowninFigure6.Taking30%extraasstandbyforanyunforeseencirc umstance,totalnumberofvehiclewith9m3carrying capacityrequiredinVaranasicomeouttobe55.Witheachvehicle,ifonedriverandonesweeperisrequiredineachtrip,indou bleshift110driversandequalnumberofsweepersmayberequiredfortransportationsystem.

Table5Requirementofsecondarystoragecontainersandtransportationvehicles

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
W. N.	P_{2011}	A (km^2)	W (TPD)	V (m^3)	CV (m^3)	CR	D_{AVC} (m)	CP	T_F	F (day)	X (km)	P_{HCS} (h/trip)	T_{HCS} (h/trip)	N_D	N_V	VN
1	15757	0.29	6.78	16.95	4.5	4	145	8	1.1	1	23.4	0.81	3.37	4	0.5	14
2	19969	2.34	8.59	21.48	1	22	213	44	1	1	20.2	1.00	3.23	4	0.6	40,41,42
3	16712	0.09	7.19	17.98	4.5	4	45	8	1	1	19.2	0.80	2.94	4	0.5	20
4	18211	1.86	7.83	19.58	3	7	531	14	1.1	1	19.7	1.28	3.47	4	0.6	21,22
5	16575	4.34	7.13	17.83	1	18	482	36	1	1	20.4	1.12	3.37	4	0.5	40,41,42
6	16384	0.78	7.05	17.63	4.5	4	390	8	1	1	18.5	0.84	2.91	4	0.5	14
7	26091	1.60	11.22	28.05	4.5	7	458	14	1.1	1	19.5	0.85	3.01	4	0.9	23,24
8	20198	0.30	8.69	21.73	4.5	5	120	10	1	1	19.4	0.81	2.97	4	0.6	34,35
9	18527	0.32	7.97	19.93	4.5	5	128	10	1.1	1	21.2	0.81	3.15	4	0.6	32,33
10	18587	0.61	7.99	19.98	4.5	5	244	10	1.1	1	20.8	0.82	3.12	4	0.6	34,35
11	20050	0.17	8.62	21.55	4.5	5	68	10	1	1	19.8	0.81	3.00	4	0.6	32,33
12	17799	0.40	7.65	19.13	4.5	5	160	10	1.2	1	17.5	0.82	2.78	4	0.6	34,35
13	20172	1.07	8.67	21.68	4.5	5	428	10	1	1	17.7	0.84	2.83	4	0.6	17
14	16315	0.78	7.02	17.55	4.5	4	391	8	1	1	17.8	0.84	2.84	4	0.5	27
15	17392	0.95	7.48	18.7	4.5	5	380	10	1.2	1	17.1	0.84	2.76	4	0.6	3
16	15198	0.06	6.54	16.35	4.5	4	30	8	1.1	1	18.1	0.80	2.83	4	0.5	10
17	28467	0.88	12.24	30.6	4.5	7	252	14	1	1	15.4	0.83	2.58	5	0.7	18
18	16131	0.08	6.94	17.35	4.5	4	40	8	1	1	17.4	0.80	2.76	5	0.4	38
19	19986	1.25	8.59	21.48	4.5	5	499	10	1	1	16.4	0.85	2.71	5	0.5	27

20	20648	3.31	8.88	22.2	1	23	288	46	1	1	17.5	1.00	2.96	4	0.6	40, 41,42
21	17592	1.47	7.56	18.9	3	7	420	14	1.1	1	18	1.26	3.28	4	0.6	25
22	14062	0.26	6.05	15.13	4.5	4	130	8	1.2	1	18	0.81	2.83	4	0.5	38
23	15117	1.13	6.5	16.25	4.5	4	566	8	1.1	1	16.3	0.86	2.70	5	0.4	23,24
24	9152	0.11	3.94	9.85	4.5	3	73	6	1.4	1	16.8	0.81	2.70	5	0.3	31
25	16756	4.88	7.21	18.03	1	19	513	38	1.1	1	16.1	1.13	2.96	4	0.5	40,41 ,42
26	20443	0.23	8.79	21.98	4.5	5	92	10	1	1	15.9	0.81	2.62	5	0.5	36
27	15331	7.53	6.59	16.48	1	33	456	66	2	2	16.2	1.11	2.94	4	0.5	40,41 ,42
28	14959	1.05	6.43	16.08	3	6	350	12	1.1	1	16.3	1.25	3.10	4	0.5	13
29	12857	0.09	5.53	13.83	4.5	4	45	8	1.3	1	16.6	0.80	2.68	5	0.4	39
30	18210	0.26	7.83	19.58	4.5	5	104	10	1.1	1	17.1	0.81	2.74	5	0.5	20
31	13594	0.47	5.85	14.63	4.5	4	235	8	1.2	1	17.6	0.82	2.80	4	0.5	5
32	15074	0.81	6.48	16.2	4.5	4	406	8	1.1	1	17.9	0.84	2.85	4	0.5	13
33	17164	0.60	7.38	18.45	4.5	5	240	10	1.2	1	17.4	0.82	2.78	4	0.6	36
34	20256	0.53	8.71	21.78	4.5	5	212	10	1	1	18	0.82	2.84	4	0.6	28
35	12012	0.11	5.17	12.93	4.5	3	73	6	1	1	17.5	0.81	2.77	4	0.4	12
36	18561	0.14	7.98	19.95	4.5	5	56	10	1.1	1	17.5	0.81	2.77	4	0.6	32,33
37	14258	0.20	6.13	15.33	4.5	4	100	8	1.2	1	17.7	0.81	2.80	4	0.5	8
38	25034	1.48	10.76	26.9	4.5	6	493	12	1	1	18.1	0.85	2.88	4	0.8	21,22
39	14911	0.22	6.41	16.03	4.5	4	110	8	1.1	1	19.2	0.81	2.95	4	0.5	4
40	15618	0.16	6.72	16.8	4.5	4	80	8	1.1	1	17.1	0.81	2.73	5	0.4	29,30
41	12342	0.21	5.31	13.28	4.5	3	140	6	1	1	16.9	0.81	2.72	5	0.3	11
42	13677	0.06	5.88	14.7	4.5	4	30	8	1.2	1	16.4	0.80	2.66	5	0.4	15
43	14602	0.06	6.28	15.7	4.5	4	30	8	1.1	1	16.5	0.80	2.67	5	0.4	19
44	12265	0.07	5.27	13.18	4.5	3	47	6	1	1	15.6	0.80	2.58	5	0.3	15
45	16001	0.46	6.88	17.2	4.5	4	230	8	1	1	15.4	0.82	2.58	5	0.4	29,30
46	16262	0.26	6.99	17.48	4.5	4	130	8	1	1	15.1	0.81	2.54	5	0.4	16
47	10404	0.27	4.47	11.18	4.5	3	180	6	1.2	1	15.9	0.82	2.62	5	0.3	36
48	14786	0.20	6.36	15.9	4.5	4	100	8	1.1	1	15.4	0.81	2.57	5	0.4	12
49	12002	0.20	5.16	12.9	4.5	3	133	6	1	1	15.3	0.81	2.56	5	0.3	39
50	11961	0.07	5.14	12.85	4.5	3	47	6	1.1	1	14.9	0.80	2.51	5	0.3	19
51	11798	0.95	5.07	12.68	3	5	378	10	1.2	1	14.8	1.26	2.95	4	0.4	25
52	12521	0.13	5.38	13.45	4.5	3	87	6	1	1	14.5	0.81	2.47	5	0.3	16
53	6793	0.16	2.92	7.3	4.5	2	160	4	1.2	1	14.3	0.82	2.46	5	0.2	12
54	11812	0.10	5.08	12.7	4.5	3	67	6	1.1	1	14.6	0.81	2.48	5	0.3	16
55	10521	0.20	4.52	11.3	4.5	3	133	6	1.2	1	14.9	0.81	2.52	5	0.3	11
56	21717	0.65	9.34	23.35	4.5	6	216	12	1.2	1	13.8	0.82	2.42	5	0.6	2
57	9671	0.13	4.16	10.4	4.5	3	87	6	1.3	1	14.6	0.81	2.48	5	0.3	9
58	15632	0.17	6.72	16.8	4.5	4	85	8	1.1	1	15.2	0.81	2.54	5	0.4	29,30
59	16957	0.20	7.29	18.23	4.5	5	89	10	1.1	1	15.6	0.81	2.58	5	0.5	37
60	15636	0.63	6.72	16.8	4.5	4	315	8	1.1	1	14.1	0.83	2.46	5	0.4	28
61	17534	0.94	7.54	18.85	4.5	5	375	10	1.2	1	14.2	0.84	2.47	5	0.5	26
62	14803	0.10	6.37	15.93	4.5	4	50	8	1.1	1	13.5	0.81	2.37	5	0.4	29,30
63	16271	0.33	7	17.5	4.5	4	165	8	1	1	12.5	0.82	2.28	5	0.4	11
64	14177	0.80	6.1	15.25	4.5	4	401	8	1.2	1	13.2	0.84	2.38	5	0.4	3
65	23007	1.03	9.89	24.73	4.5	6	342	12	1.1	1	12.7	0.83	2.32	5	0.6	6
66	17046	0.09	7.33	18.33	4.5	5	36	10	1.2	1	11.6	0.80	2.18	6	0.4	9
67	7684	0.09	3.3	8.25	4.5	2	90	4	1.1	1	13.1	0.81	2.34	5	0.2	10
68	18340	0.55	7.89	19.73	4.5	5	220	10	1.1	1	11.7	0.82	2.21	6	0.4	1
69	10536	0.18	4.53	11.33	4.5	3	120	6	1.2	1	10.1	0.81	2.04	6	0.3	15
70	11689	0.13	5.03	12.58	4.5	3	87	6	1.1	1	13.4	0.81	2.36	5	0.3	9
71	17638	1.59	7.58	18.95	3	7	455	14	1.7	1	13.2	0.85	2.38	5	0.5	1
72	11837	0.68	5.09	12.73	4.5	3	453	6	1.1	1	13	0.85	2.36	5	0.3	6
73	16637	1.21	7.15	17.88	3	6	404	12	1	1	13	1.26	2.78	4	0.5	21,22
74	18914	0.54	8.13	20.33	4.5	5	216	10	1.1	1	13.4	0.82	2.38	5	0.5	7
75	25274	2.92	10.87	27.18	1	28	209	56	1	1	13.8	0.99	2.59	5	0.6	40, 41,42
76	9312	0.14	4	10	4.5	3	93	6	1.4	1	14.3	0.81	2.46	5	0.3	29,30
77	13484	0.46	5.8	14.5	4.5	4	230	8	1.2	1	14.4	0.82	2.48	5	0.4	8
78	11697	0.12	5.03	12.58	4.5	3	80	6	1.1	1	15.2	0.81	2.54	5	0.3	19
79	12956	0.52	5.57	13.93	4.5	4	260	8	1.3	1	15	0.83	2.54	5	0.4	23,24
80	10585	0.24	4.55	11.38	4.5	3	160	6	1.2	1	15.6	0.82	2.59	5	0.3	18
81	10935	0.21	4.7	11.75	4.5	3	140	6	1.1	1	15.8	0.81	2.61	5	0.3	10
82	10060	0.76	4.33	10.83	3	4	380	8	1.1	1	16.2	1.26	3.09	4	0.3	23,24
83	8789	0.20	3.78	9.45	4.5	3	133	6	1.4	1	16.5	0.81	2.68	5	0.3	31
84	15670	1.24	6.74	16.85	3	6	415	12	1.1	1	17.2	1.26	3.20	4	0.5	26
85	13215	0.73	5.68	14.2	4.5	4	366	8	1.3	1	17.6	0.84	2.81	4	0.5	7
86	15291	0.50	6.58	16.45	4.5	4	250	8	1.1	1	18.8	0.83	2.92	4	0.5	5
87	10557	0.13	4.54	11.35	4.5	3	87	6	1.2	1	20	0.81	3.02	4	0.4	31
88	8853	0.67	3.81	9.53	4.5	3	446	6	1.4	1	19.6	0.84	3.02	4	0.4	17
89	11645	0.16	5.01	12.53	4.5	3	107	6	1.1	1	18.4	0.81	2.87	4	0.4	4
90	12974	1.02	5.58	13.95	3	5	408	10	1.1	1	16.8	1.26	3.16	4	0.4	2

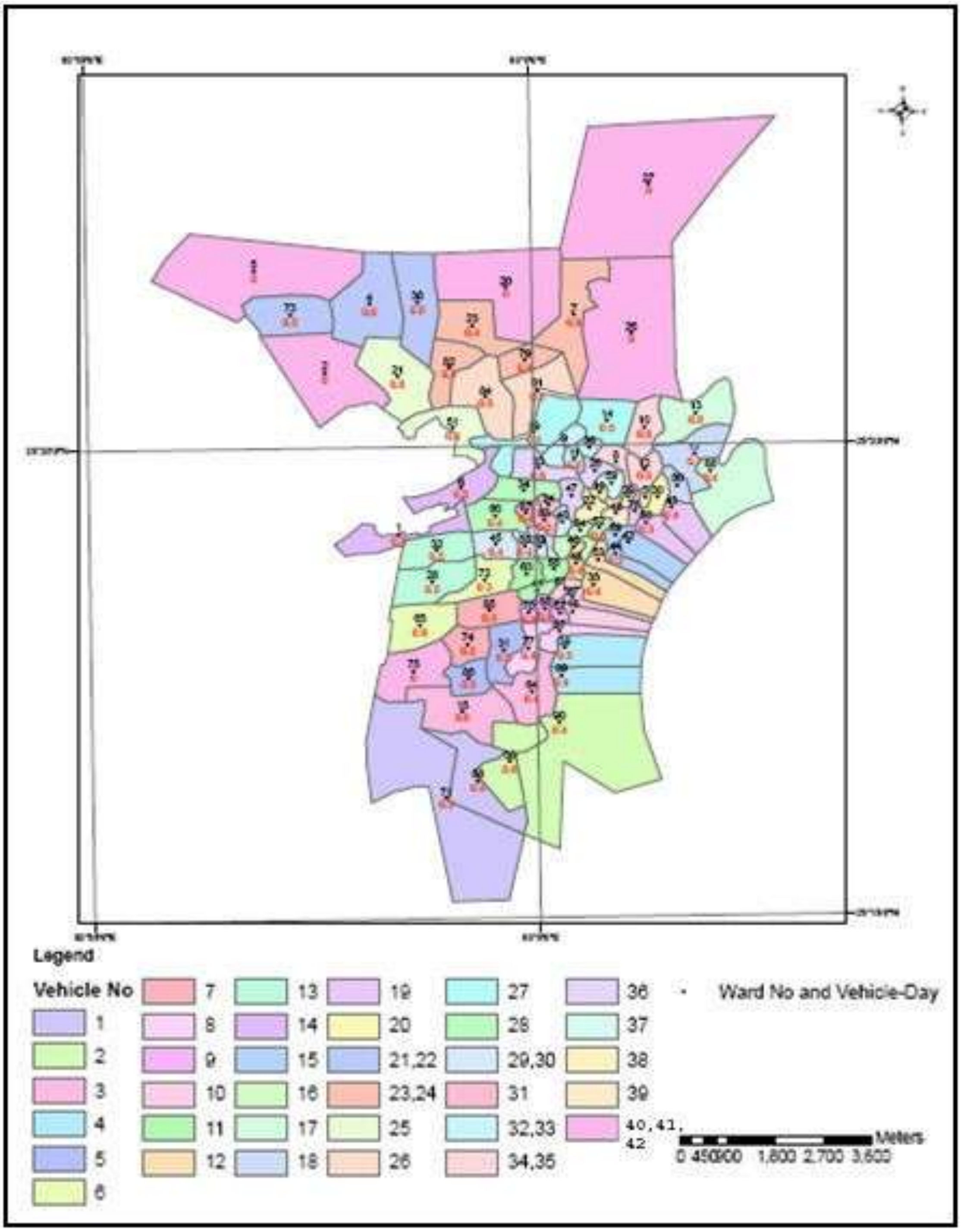


Figure6Wardmapshowing theVehiclenumberassignedtoaward

VI. COSTANDEXPENDITURE

Beingapublicutilityandanessentialservice,investmentinsolidwastemanagementdoesnotrequirejustificationintermso fpositivereturnoninvestmentorminimumprofits.Suchaninvestment,however,needstobejustifiedonthebasisof beingtechnologicallyfeasibleoptionforachievingtherequireddegreeofefficiencywiththeleastcost.Basedonunitpriceo fequipments/vehiclesadoptedforsolidwastemanagementplanningbyVaranasiNagar Nigam(VNN,2007)thetotalcostforthedesignedstorageandtransportationsystemasproposedinthisstudy,isestimatedto bearoundRs. 76.45million,asgivenTable6.Annualoperationandmaintenancecostcomesouttobe Rs.52.40millionandisshowninTab le7.

Table6InvestmentcostsofstorageandtransportationsystemforVaranasi

Sr. No.	Items of Expenditure	Quantity Required	Quantity Existing	Shortfall	Unit Price	Total Expenditure (million Rs.)
1.	4.5m^3 capacity containers	607	65	542	40000	21.68
2.	4.5 m^{3}capacity containers	106	-	106	30000	3.18
3.	4.5 m^{3}capacity containers	286	-	286	15000	4.29
4.	Large capacity vehicles (Dumper placer/tipper)	55	12	43	1100000	47.30
					Total	**76.45**

Table7AnnualOperationandmaintenanceofstorageandtransportationsystemforVaranasi

Sr. No.	Items of Expenditure	Quantity	Unit cost	Total Expenditure (million Rs.)
1.	Annual salary of drivers	110	72000	7.92
2.	Annual salary of sanitary workers	110	48000	5.28
3.	Average distance in one trip=33 km No of trips per day=412 Total distance traveled/d =33x412=13596 km Total distance traveled/ year =13596x365=4962540 km Cost of fuel=Rs. 40/liter Mileage=8 km/liter Cost per km=40/8=Rs. **5**	4962540	5	24.81
4.	Maintenance and Depreciation Cost@ 25% per year of initial investment cost on storage containers=29.15x0.25			7.29
5.	Maintenance and Depreciation Cost@ 15% per year of initial investment cost on vehicles=47.30x0.15			7.10
			Total	**52.40**

VII. CONCLUSION

Inthepresentstudy,anattempthasbeenmadetodesignanddevelopanappropriatestorageandtransportationplan fortheVaranasiMunicipalCorporation,UttarPradesh,India.Theproposedmodelsuggeststhenumberofsecondarystora gecontainersrequiredonwardwisebasesandtransportationplantothedisposalsiteusingGIS.Thehauledcontainersystem proposedintheworkuses4.5m3,3m3,and1m3capacitycontainerswithhydraulicloading/unloadingattachments.9m3ca pacityvehicle(Dumperplacer/tipper)aresuggestedfortransportationofwastefromwastestoragepointtodisposalsite.Itis observedthatthepresentwastestorageandcollectionsysteminVaranasiisinadequateandunplanned.Aninitialinvestmen tofapprox.Rs.76.45millionisestimatedforimprovementofwastestorageandtransportationsystemandapproximatelyR s.52.40millionisrequiredperannumforefficientlymanagethesetwoservices.AGIS-basedoptimalroutingmodelwasusedtodeveloparoutemapforefficienttransportplanning.Theproposedmodelcanbeuse dasadecision-supporttoolbythemunicipalauthoritiesforefficientmanagementofthedailyoperationsfortransportingsolidwaste,loadd istributionwithinvehicles,managingfuelconsumptionandgeneratingworkschedulesforthesanitaryworkersandvehicle s.

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