# Underground spaces construction technology and its impact post COVID-19 Pandemic in Kenya

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## Abstract

Underground spaces and other subsurface infrastructure like shopping malls, sewer lines and nuclear waste storage repositories are becoming increasingly important for society's development. Recently, many cities and towns in Kenya and around the world are being overrun spatially by rapid urban population growth, booming metropolises, scarcity of urban land, environmental awareness, as well as an increase in specific needs for protection, storage, security, and sheltering, have all contributed to the use and development of underground spaces population growth and the movement of the people from rural to urban areas has resulted in significant demands for growth in city infrastructures, especially in megacities throughout the world. Such growth can only be supported by the efficient use of underground space.

This paper explores the impacts of underground infrastructure on social, environmental and economic in Kenya in relation to COVID-19 pandemic. Two case studies will be evaluated in this paper to demonstrate the impacts gained so far.

## Introduction

Underground space development is an important part of city planning and is included in the majority of existing urban plans. Benefits of using underground spaces include relieving surface congestion, connecting people thought the region, protecting residents and wildlife from noise pollution, poor air quality and overcrowding and provision of green spaces[1]. Efficient utilization of underground infrastructures can fast track Sustainable Development Goals(SDG's) by improving urban environment, preserving natural resources, and offers long-term economic benefits [2]. The fastest growing urban agglomerations are medium-sized cities and cities with less than 1 million inhabitants located in Asia and Africa. As the world continues to urbanize, sustainable development challenges will be increasingly concentrated in cities, particularly in the lower-middle- income countries where the pace of urbanization is fastest. Integrated policies to improve the lives of both urban and rural dwellers are needed.[3] Underground spaces mostly affect the population in terms of mobility, quality of life and social sustainability [4].Nairobi city is also experiencing water deficit of 125,000m$^3$/day and government of Kenya has prioritized improvement of water services in Nairobi city and its neighborhood [5].Corona Virus Disease 2019(COVID-19)originated from Wuhan, China and has affected the more than 5 million people globally and since there is no vaccine discovered so far, the disease may continue for some years. Coronavirus disease (COVID-19) is an infectious disease caused by a newly discovered coronavirus.

Most people infected with the COVID-19 virus will experience mild to moderate respiratory illness and recover without requiring special treatment. Older people, and those with underlying medical problems like cardiovascular disease, diabetes, chronic respiratory disease, and cancer are more likely to develop serious illness.

**Northern Collector Tunnel**

The Northern Collector Tunnel (NCT) Phase 1 is a proposed new raw water transfer tunnel along the eastern fringe of the Aberdare Conservation Area approximately 60 km north of Nairobi, Kenya. The tunnel project will transfer raw water from intakes at the Maragua, Gikigie and Irati Rivers to an outlet at the Githika River near Makomboki, upstream of the existing Thika Reservoir.

Maragua Intake Weir consisting of main weir, control weirs, compensation channel and associated river formation and erosion protection works, tunnel inlet and permanent tunnel access ramp; Gikigie Intake Weir consisting of main weir, control weirs, compensation channel and associated river formation and erosion protection works and tunnel inlet (to branch tunnel);Irati Intake Weir consisting of main weir, intake weir, stilling basin, compensation channel and associated river formation and erosion protection works, inlet channel and drop shaft vortex chamber; Githika River Outfall including outfall portal, outlet cascade, receiving river formation and erosion protection works; Collector Tunnel between Maragua Inlet and Githika Outfall, 11,775m long at approximately 0.22% gradient, nominal 5 m diameter, and horse shoe profile. A single tunnel portal at each end; Gikigie Intake Adit to transfer water from the Gikigie Intake to the main collector tunnel. Irati Drop Shaft, 45 m deep (vertical), 4m nominal diameter containing 1m diameter drop pipe, ladders and intermediate platforms, water cushion and side entry to the main collector tunnel; Kaanja Access Adit ,temporary 600 m long construction access decline at approximately 6.5% gradient(assuming portal at elevation 2116 Meters Above Ordnance Datum and main tunnel at 2067 Meters Above Ordnance Datum. Profile is nominally the same as the main collector tunnel to enable use of same support elements.

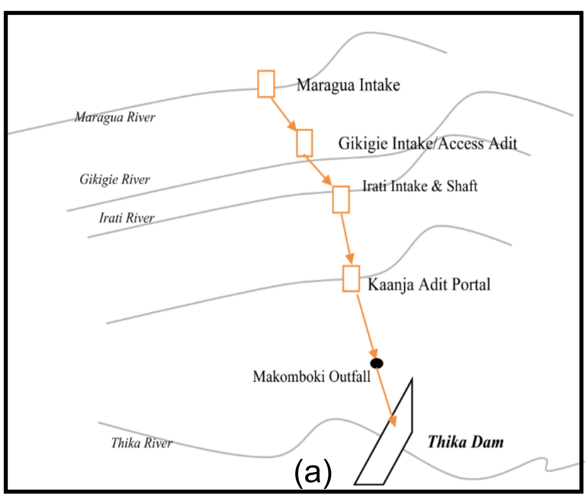


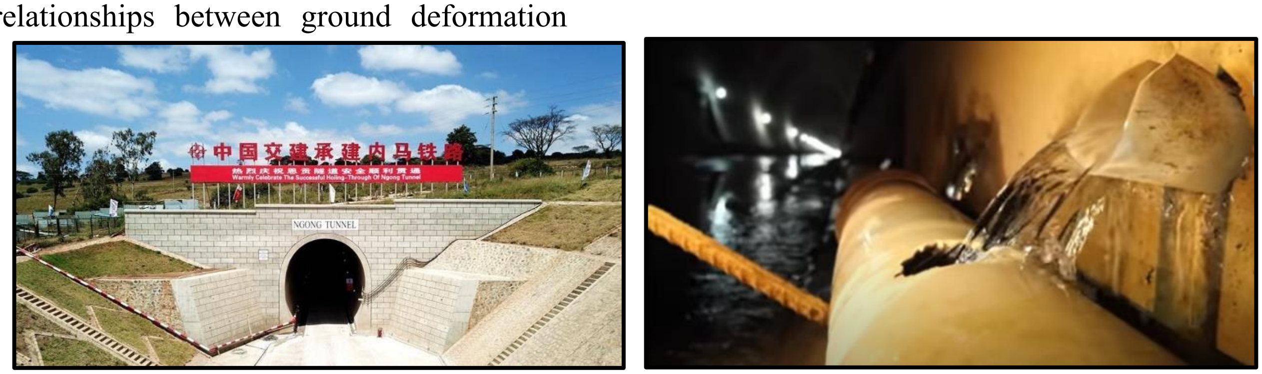


*Figure 1: (a) shows the NCT crossing four rivers, (b) concrete lining of NCT tunnel*

**Standard Gauge Railway (SGR) Ngong' Tunnel**

The Ngong' tunnel has been designed as a single-track railway tunnel with a clearance height of nine meters and a width of 7 meters. A 533-meter wide emergency rescue channel has also been built within the tunnel, to allow for vehicle access in case of emergencies. The New Austrian Tunnelling Method (NATM) of drilling and blasting to build the tunnel, being the first time that such a technology has been used in the country. NATM involves a combination of several tunnelling aspects from ground characterization via rock mechanics and tunnel design to construction principles, rock support design and monitoring during tunnel excavation. The main principle of the method is, however, utilization of the bearing capacity of the ground surrounding the tunnel. The development of NATM made use of earlier experience gained from decades of tunnelling but has taken advantage of the support technology in rock bolting and sprayed concrete (shotcrete) that was made available in the late '50s and at the beginning of the '60s.Officially, the NATM was introduced by Rabcewicz at the 13th Geocolloquium in Salzburg 1962. The use of this requires a knowledge of the interrelationships between ground deformation and load, support deformation and load, and time.[6] The initial support is often carried out as an outer lining designed to stabilize the rocks during excavation. It consists mainly of shotcrete, systematically bolted and reinforced by additional steel ribs if required. In addition a closing of the invert is carried out in very weak ground. The final support is often carried out as a concrete lining. It is generally not carried out before the deformations of the initial support have reached an acceptable, decreasing trend. The tunnelling method is economical, efficient and has strong adaptability for different geological and groundwater conditions. What is more, the method controls surface collapse effectively, and enhances the working environment during construction.

Kenya's SGR project envisages the rail link between Mombasa Port and Malaba (at Uganda border) on a 472-km line, and the first phase was put into commercial operation in 2017.The second phase comprises two other stages which include a 120 km line between Nairobi and Naivasha, the Naivasha– Kisumu section, towards Malaba, on a 107-km rail link. The second phase includes the construction of four tunnels with a total length of 8 km and nine bridges with a total length of 24 km




(a) (b)

*Figure 2(a) newly constructed Ngong Railway Tunnel, (b) clean water discovered during tunneling*

## Impact of Underground Space Technology in Kenya.

### Environmental impact

Railway networks provide links to global and local markets for goods and services and reduce transaction costs. They are the most cost-effective mode of transport for moving bulk cargo for long distances over land. They are suited to container traffic between ports and capitals. Unfortunately, much of the current railway infrastructure in Africa is in poor condition. Estimates indicate that the poor quality of African overall infrastructure has the effect of decreasing the productivity of industries by about 40 per cent, thus contributing to the higher cost of doing business[7]Transportation tunnels: including rail tunnels (length less than 3 km), road tunnels, subway tunnels, sea tunnels and sidewalk tunnels. Industrial tunnels: including water transfer tunnels (fewer cross section and length of less than 40 km, sewage tunnels and tunnels to ware houses, bunkers, nuclear waste disposal areas. Mining tunnels: including opening tunnels exploration tunnels, extraction tunnels, service tunnels, drainage tunnels and inspection tunnels

Tunnelling has some positive and negative impacts. SGR tunnels have some impact on the community as some underground water encountered during construction have directly been provided to the community for domestic use, wild animals and domestic animals. The tunnels have shortened the route to Naivasha inland depot and assisted maintaining the desirable gradient for standard gauge railways. There is drastic reduction of traffic along Mombasa-Nairobi road, reduced snarl up traffic snarl up along Changamwe, Port-Reizt, Shimanzi and hence improved traffic flow, reduced emission of toxic gases augmenting climate change management initiatives in Mombasa county[8].The SGR passes through Nairobi national park, the only park located in the city around the world shown in fig 3.During construction of SGR phase 2 there were seven option routes. Options 4,3 and 1 were most preferred respectively as having minimum impact on environment. Despite other options cutting across the Nairobi National Park, Option 1 was having minimum interruption of the ecosystem during operations as compared to 3 and 4.Option 4 was preferred, however there was no option for tunnelling that was presented as mitigation measures to conserve the park

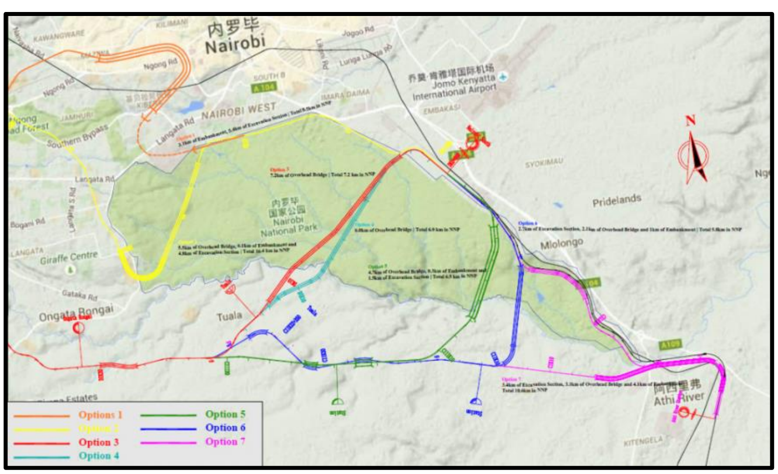



*Figure 3; SGR Phase II passing through Nairobi National Park*

**Decongestion and expansion of Nairobi Metropolitan**

Population census conducted on 2019 revealed the population increased from 37.7 to 47.6 million in 2009 and 2019 respectively. Nairobi county population stand at 4,397,073 an increase of 53% since 2009 population census. According to[9]4majority of them cited crowding (69%); vehicles not reaching desired destinations (72%); arbitrary fare increases (75%); chaos and menace (69%); lack of comfort (58%); unpredictability of traveling time schedules (60%); and, lack of adequate transportation alternatives such as rail and air (55%), as key problems related to the public transportation system in the city. Railway Tunnels makes the routes shorter since Standard gauge lines don't follow the contours, this ensures faster delivering of products reduction of transportation cost in the country and East Africa region making Kenya an attractive investment destination and competitive in the region. The new rail has shortened passenger travel times from

Mombasa to Nairobi from more than ten hours to a little over four hours. Freight trains now complete the journey in less than eight hours[10]

Expansion of railway network in Nairobi will decongest the traffic, creating the more green spaces, minimize air and noise pollution emitted by the traffic and facilitating efficient and economical mobility of people across Nairobi metropolitan. Underground subways will be required for this purpose.

**Improved working conditions and Training**

The construction industry is set to embrace remote working both in the short term and in the long term in order to help reduce costs in addition to the interest of workers' health and safety. Social distancing is one of recommendation that will assist transmission and infections COVID-19 in Africa[11] has highlighted that a lot of the work which is done in the sector can be done remotely with ease. Prioritized planning of good wellbeing and effective communication, employee experience, engagement motivation and responsible work redesign together with balanced short-term cost concerns with medium-term resilience and rebound [11]Video conferencing has made team meetings much easier. Many engineers, architects, technologists, and project management personnel will be able to work from home during and after Covid-19 pandemic. It is definitely something that will stick around in the long term and this isn't limited to just the construction industry, either.

The Covid-19 pandemic could see a brighter future for cutting-edge technology in the industry such as drone tech, communication tools, augmented reality (AR), virtual reality (VR), building information modelling (BIM) and much more. These technologies actively encourage health and safety in the industry whilst helping employees meet social distancing requirements. These technologies are set to stay and develop further long after COVID-19 vanishes. Research into the fusion of multi-sensor data that would allow noninvasive technologies to accommodate a wider range of ground conditions and to improve their ability to resolve ground properties and the presence and location of buried objects is under way both in the United States[12]

One of the most important impact is employment of the community around the project sites, Ngong' Tunnel and Northern Collector Tunnel(NCT) has directly and indirectly provided employment of Kenyan and hence improvement of their lifestyles. Kenyan youths are benefiting from advanced construction-based skills and Engineers embracing new underground space construction technology. Researchers and engineers in Kenya will gain new ideas, technologies and expertise related to the planning, design, construction and maintenance of the underground space facilities.

**Access, distribution of affordable clean water in urban areas**

The present water deficit in Nairobi City is 125,000m$^3$/day. In line with the National Development Plan, Vision 2030, the Government of Kenya has prioritized improvement of water services in Nairobi City and the surrounding areas.

Hand hygiene is extremely important to prevent the spread of the COVID-19 virus. All health-care facilities should have regular programs aimed at promoting best hand hygiene practices and ensuring the availability of the necessary infrastructure[13]. Reliable water services in health facilities in Kenya and households are critical to ensuring both sufficient quantities of safe drinking water and the ability to maintain hygiene (including hand hygiene, laundering, cleaning, and disinfection).

To achieve this objectives the Northern Collector Tunnel Phase 1 project is a priority

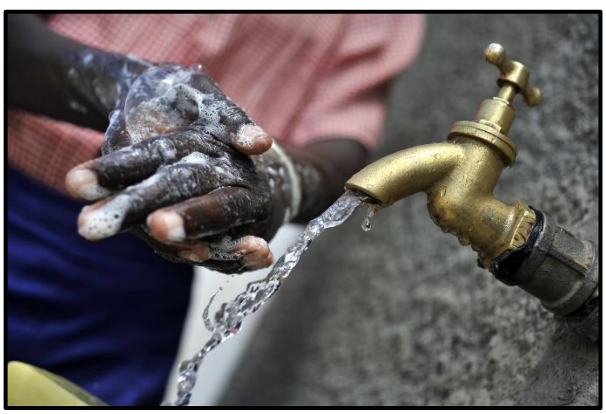


*Figure 5; Handwashing as one of the measures to curb spread of COVID-19; Source (UNICEF, KENYA)*

project. The project has been subjected to environmental Impact assessment and proved to be beneficial to the community and to the government. The tunnel will convey flood water Ndakaini dam which supply the water to Nairobi, part of Muranga and Kiambu Counties. The water tunnel will have minimum effect on the environment in the long run since the maintenance is very low. Tunnels minimize the cost and distance to the dam. There is minimal community displacement and hence low cost of compensation.


*Figure 4: Health Officer Disinfecting the Airport; source (WHO)*

Water flows in the springs and where the water naturally comes out, may be decreased due to groundwater discharge from drainage of surrounding grounds of the tunnel site[14].This can be corrected by concrete lining as shown in fig 1(b). The aggressive groundwater outflow during tunnel excavation may incur secondary environmental impacts such as abrupt changes in the fauna and flora ecology near the upper part of the tunnel sites. The aggressive water due to high sulfate contents is generally determined at design stage; however, the sulfides in rocks to be excavated are often ignored, mainly due to a lack of appreciation of the environmental impacts[15]However during construction of Ngong' tunnel, an water aquifers was discovered with flow rate of

1700cubic meter per hour and upon laboratory analysis, it was deemed fit for human consumption and directed to benefit Kimuka Community in Kajiado county where access to water stands at 35%.The fresh water will benefit 2500 families and 10,000 cattle.

**Underground automated waste management facilities**

The Government of Kenya identifies four priority initiatives to be implemented between the years 2018 to 2022, core among them being the delivery of 500,000 affordable housing units in major urban areas. Three quarters of the population is below 35 and the country is urbanizing at a rate of 4.3 percent per year. Urban centres face a shortage of 200,000 housing units annually whereas only 50,000 new housing units are being constructed every year.

House quality comprises three aspects namely: Type of house in terms of building material, Housing conditions or housing quality comprises three main aspects, namely; type of house in terms of building materials, size of house in terms of living space per person, quality of neighbourhood and available amenities such as kitchen, toilets, water and electricity. [16]Quality of neighbourhood means the surrounding environment in terms of cleanliness and green spaces. The reasons for poor housing conditions in developing countries is a combination of poor policies and the limited resources available to meet the investment needs of rapid urban population growth.

Currently, the waste management of waste in Nairobi County is a conventional one where trucks are loaded by casual workers around residential areas, then transported to Dandora Municipal Waste dumping site which occupies 30 acres of land. Nairobi County produces around 3000 tons of waste and approximately 2000 tons are dumped at Dandora. There is presence of all sort of waste ranging from domestic, biomedical and industrial. The waste collection and dump site workers are at high risk of contracting COVID-19 when they come into contact with waste materials such as especially from hospitals. The closure plan should be compiled with consideration given to minimizing local environmental impacts and stabilizing (rendering harmless) the land-filled waste as quickly as possible. A negative environmental impact of Dandora Dumpsite as a source of leachate is a major contributor of groundwater and Nairobi River [17].Bacterial isolates collected and analyzed showed high antibiotics resistance A high level of resistance has been found with members of the family Enterobacteriaceae which are increasingly becoming multi drug resistant [18].Innovative and creative ways of garbage collection in our upcoming affordable housing projects is critical for health and safety and improving the image of the surrounding public space.

Small and large scale Automated vacuum (pneumatic) waste collection systems (AVAC) provide an advanced integrated framework for the tacking of the waste handling problem. Not only do they provide temporal storage but also the transportation of waste is taking place through underground pipeline network to a waste collection terminal. By doing so, AVAC systems provide an attractive alternative to conventional vehicle-operated waste collection, as they offer advantages in terms of reduced traffic-related problems, such as noise, accidents, $CO_2$ emissions, congestion and improve overall safety and hygienic levels. This speeds up the whole garbage collection process, especially at difficult cases as overcrowded urban centers, allowing at the same time a smooth operation of the system even at difficult situations either as a result of severe weather conditions (e.g. storms) or external events (e.g. strikes, protests, etc.) hence influencing the environmental sustainability of waste management. Major benefit from the usage of AVAC system is the minimized operating cost for the waste handling; 2 to 3 times lower than conventional collection methods.[19]

Songdo smart city in South Korea perhaps is the most extreme example of the city's inflexibility of the infrastructure is Songdo's pneumatic waste collection systems. The networked pneumatic waste collection system below the streets of Songdo is connected to every planned commercial and residential dwelling with a focus on efficiency and carbon emission reduction to eliminate the need for rubbish collection trucks. On the streets of Songdo, public waste bins are inaccessible to non-residents because, to access them, you must have an official resident key[20].

**Underground Research Laboratories (URL's) and nuclear waste disposal facilities**

The Vision 2030 comprises three pillars namely; Political stability, social development and economic growth[21]. The increasing population in Kenya will demand for more electric power for industrial and domestic purposes. The new standard gauge railway is already complete and connected the Nairobi and Naivasha inland ports from Mombasa port. There is a plan of powering it through our national grid. The new affordable housing projects, ICT (Konza) city, Naivasha economic zone and Lamu port are projects under construction that will more energy. The projected energy demand in Kenya will be approximately 17000Mw by year 2031, the nuclear energy will contribute 4000Mw by 2031.More than 30 countries are operating nuclear reactors currently, and USA, France and Japan are the leading producers of nuclear power with 100000MW, 63000MW and 40000MW respectively. Energy should be available for domestic consumption and manufacturing industry use, affordable by consumers and supplying companies and acceptable for being environmental friendly[22]Spent fuel and radioactive waste are byproducts of nuclear power generation and other uses of radioactive material in medicine, industry and research. Spent fuel is highly radioactive and needs to be handled with shielding and cooling. It also contains substantial amounts of long lived isotopes, which means that the fuel (if not reprocessed) and its components need to be disposed of with appropriate care [23]. Nuclear power plants produce three levels of radioactive waste: low; intermediate; and high. Low-level waste such as paper, rags, tools and clothing contains small amounts of mostly short-term radioactivity. Intermediate-level waste includes resins, chemical sludge and reactor components. High-level waste is the spent fuel from the power plants or the principal waste separated from reprocessing the fuel. Policies of most States, is to dispose of it in a geological repository, typically at depths of several hundred meters. Kenyan government will fast track laws and regulations framework for radioactive waste management. This will facilitate setting up an underground research facility, underground radio waste reprocessing plant and waste disposal repository. Radioactive waste remains dangerous to humans for millennia. Finland is currently constructing radioactive repository. The facility's construction began in 2004 and, by the time it is completed, will consist of 60 to 70 kilometers of tunnels within an area of around 2km$^2$. ONKALO is an acronym based on the Finnish language expression for .Olkiluoto Rock Characterization for Final Disposal. The word ONKALO also means a “cave” in Finnish. Disposal of the spent fuel will begin in the early 2025 and continue for the next 100 years. By the time the final disposal is completed, 3,250 canisters will have been deposited in the tunnels. The canisters will contain around 6,500 tons of uranium. The main access tunnel will be backfilled with bentonite clay and concrete, and the entrance sealed. It is designed to last must last for 100,000 years. The characterization and monitoring programs included investigations of geological, rock-mechanical, thermal, hydrogeological, geochemical and migration properties[24].The geological investigations focuses on the identification of bedrock volumes suited for final disposal and on a detailed definition of the properties of these volumes[25].This assists to critically characterize the rock, identify the shear zones and fractures that can allow seepage of groundwater into repository. A successfully built and finished geological disposal system should guarantee the isolation from near surface processes, protection of the biosphere, isolation from human activities, early containment of short lived radio-nuclides as well as limitation of releases and dispersion - dilution functions[26]

**Underground Waste water Treatment Plant**

Nairobi City Water and Sewerage Company (NCWSC), owned by the Kenyan Government, provide sewerage services in Nairobi. The sewerage system is also characterized with frequent chokes and flooding is eminent especially in slums like Kibera, Mathare and Dandora, Kawangware and Kangemi [27].The government is expanding the sewerage coverage which stands at 30% in Nairobi County. However, there is great concern of environmental impacts especially the air pollution[28].The high population has exerted pressure on the existing physical facilities including housing, especially for the low and middle income earners. It’s difficult to provide social amenities at a pace that matches the population growth hence facilities like water and sewerage have been overstretched. The County faces the challenge of providing all the social amenities to this population especially in the informal settlements like Kibra, Kawangware, Mathare, Viwandani and Mukuru which are characterized with high population and poor living conditions. Expansion of water and sewerage network Sewer line extensions and rehabilitations of various lengths and diameters in formal areas [29].The conventional sewer treatment is harmful to the environment as compared to advanced underground treatment plants. Wastewater contains a number of pollutants and contaminants, including: Heavy metals (e.g. cadmium, chromium, copper, mercury, nickel, lead and zinc); organic pollutants (e.g. polychlorinated biphenyls, polyromantic hydrocarbons, pesticides); and biodegradable organics (BOD, COD); and micro-pollutants (e.g. medicines, cosmetics, cleaning agents). All of these can cause health and environmental problems and can have economic/financial impacts (e.g. increased treatment costs to make water usable for certain purposes) when improperly or untreated wastewater is released into the environment; nutrient contamination and microbial water quality issues are detrimental to safety and health of the people and environment[30].The study shows the wastewater around Njiru and Ruai are used to irrigate the vegetable farms. Soil and vegetables were contaminated with heavy metals beyond the Food and Health Organization(FAO) and World Health Organization (WHO) recommendation [31].

Underground Wastewater Treatment plant is the solution for the rapidly expanding population since it has more advantage in terms of environmental impact as compared to conventional one. The underground treatments allows air purification all the air that is "passed" through underground plant, which is contaminated by odors, will be purified by bio-filtration prior to discharge into the atmosphere[32].The tunnels used as conveyance of waste water are economical in the long run[33].Underground treatment plant can easily incorporate sustainable treatment technology that will require less energy. Application of microbial cell as new source of renewable energy from will reduce the cost of wastewater treatment by supplying energy required off the national grid[34] and may produce useful products from wastewater treatment. Many countries are adopting underground space technology to solve mentioned problems in this paper. Fig 6 shows the comparison between conventional and underground treatment plants.

Henriksdal Waste Water Treatment Plant (WWTP) was built in the 1930s at Stockholm in Sweden, it was more cost-effective to build in rock than above ground. Building underground also enabled the facility to be extended later, without using up valuable land. The area footprint of the plant is minimized by building it at several levels in the rock. The treatment basins can be made considerably deeper than usual, as they are blasted out of rock. The naked rock surface can be used instead of constructing concrete basins, which reduces costs. Noise, Odor and accessibility by animals is minimized and very little impact on the surrounding.

The plant is being extended to double the treatment capacity to serve 1.6 million people and to comply with new, more stringent treatment requirements. A pilot project to test the MBR technology, taking into account a load equal to Stockholm's projected population in 2040, was concluded in 2014. GE's LEAPmbr technology which integrates its ZeeWeed 500 membrane is an advanced ultrafiltration technology that separates solids, bacteria and viruses from water or wastewater. The expansion and renovation will enable the WWTP to treat 864 million liters of wastewater a day.

In addition to installing the new membrane distillation units at the Henriksdal site, the project will involve the construction of a 15km underground tunnel, bored from 30m to 90m below ground level, to divert the wastewater from Bromma to Henriksdal. A new pre-treatment facility comprised a new pump station, new coarse screening and primary sedimentation basins will also be built at Sickla.

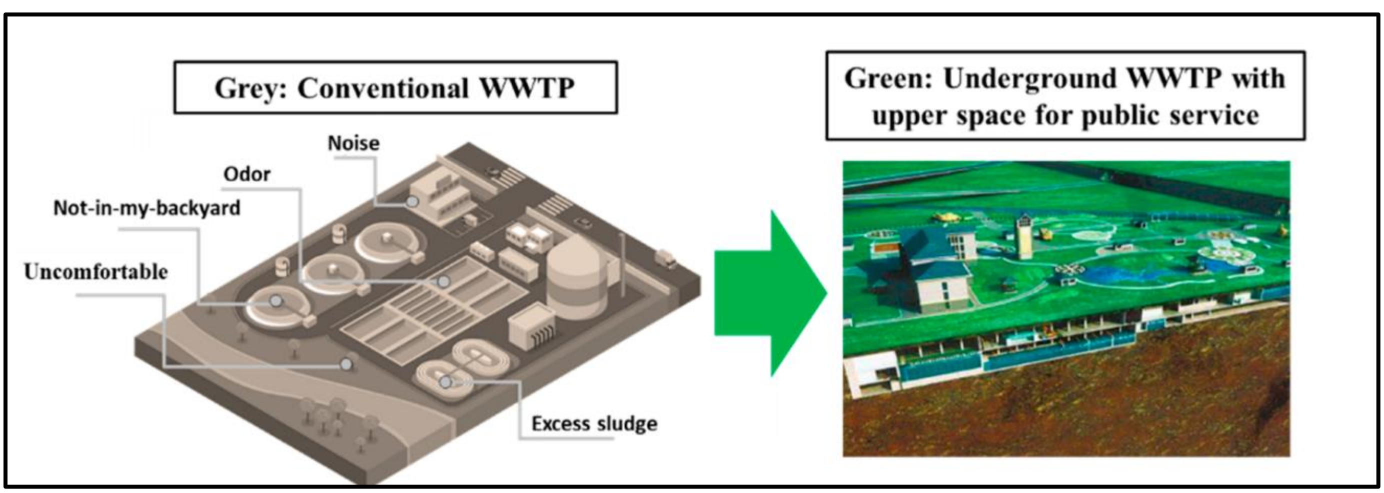



*Figure 6: Conversion of conventional waste water treatment to modern underground plant*

## Conclusions

The current study was aimed to demonstrate the need to encourage more underground space structures in Kenya to solve the underlying challenges of environmental conservation through underground waste water treatment plants, collection of solid waste and recycling. Additional tunnels and underground tanks will guarantee constant supply of clean water to the industries and communities.

Decongestion of the cities and its environs post COVID-19 pandemic is very important to curb more infections and transmission of COVID-19 and related diseases. Economically, they will create more employments to the local experts, accelerate research in energy sector, and improve mass transport in the cities, facilitate easier access of remote areas and assist on capacity building to the Kenyan youths. Underground spaces will be important to assist on combating infection of Underground spaces will assist Kenya to realize its vision 2030.


## Acknowledgement

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