APPENDIX

Population Estimates of Sampled Pumping Stations for Environmental Surveillance in Kolkata, India

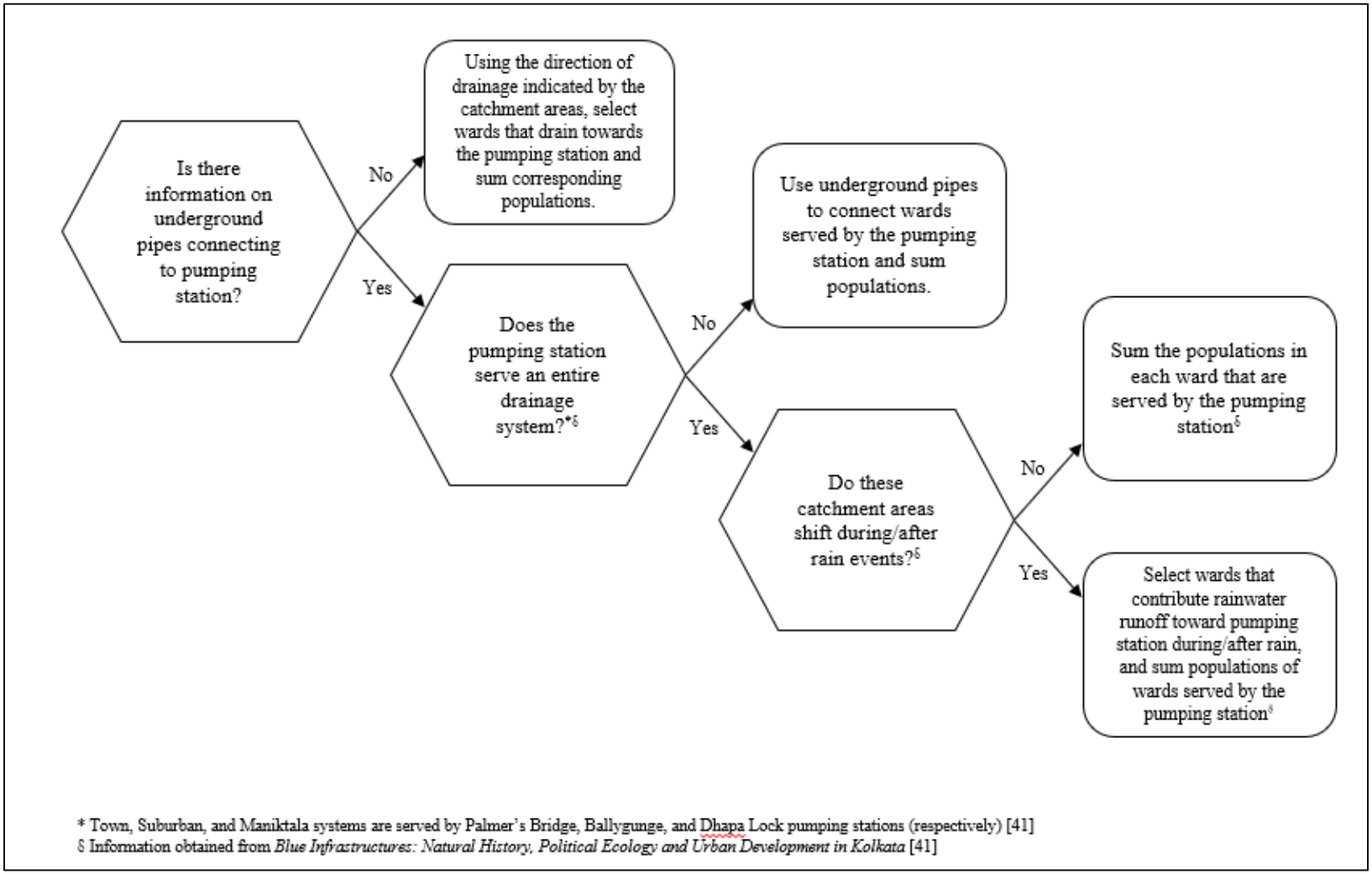


Figure 1. Process Flow Diagram for Population Estimates of Sampled Pumping Stations in Kolkata, India

Ambedkar Bridge Pumping Station

Step in the Process Flow Diagram:

> Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The Ambedkar Bridge PS does not have information regarding underground sewer and storm water lines that connect directly to the facility. Therefore, the catchment delineation grid was used to guide population estimate calculations. A zone was drawn to capture the upstream catchment area of the Ambedkar Bridge PS (Figure 2). The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment zone. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Ambedkar Bridge PS sample location is estimated to be 34,517 people.

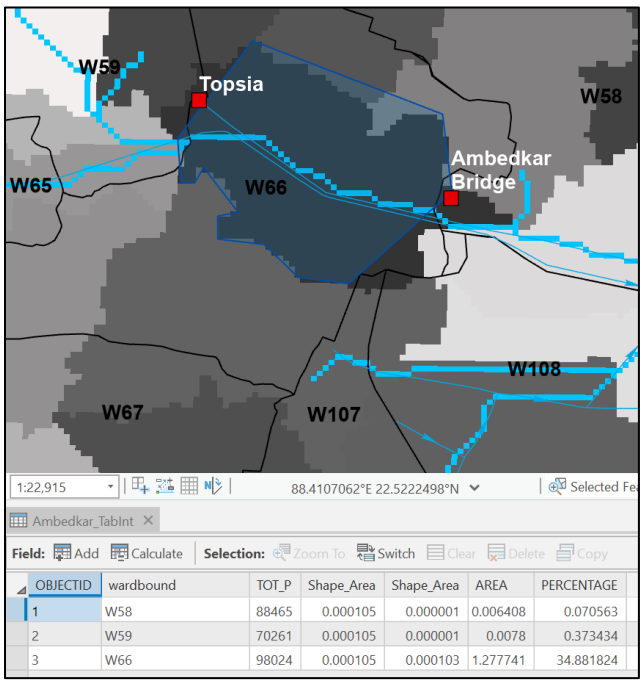


Figure 2. Upstream catchment zone of Ambedkar Bridge Pumping Station.

Baishnabghat Pumping Station

Step in the Process Flow Diagram:

> Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The Baishnabghat PS does not have information regarding underground sewer and storm water lines that connect directly to the facility. Therefore, the catchment delineation grid was used to guide population estimate calculations. A zone was drawn to capture the upstream catchment area of the facility (Figure 3). It was noted that this zone contains area outside of the ward boundaries, and therefore the final estimate is not counting people who live in this area.

The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment zone. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Baishnabghat PS sample location is estimated to be 5,916 people.

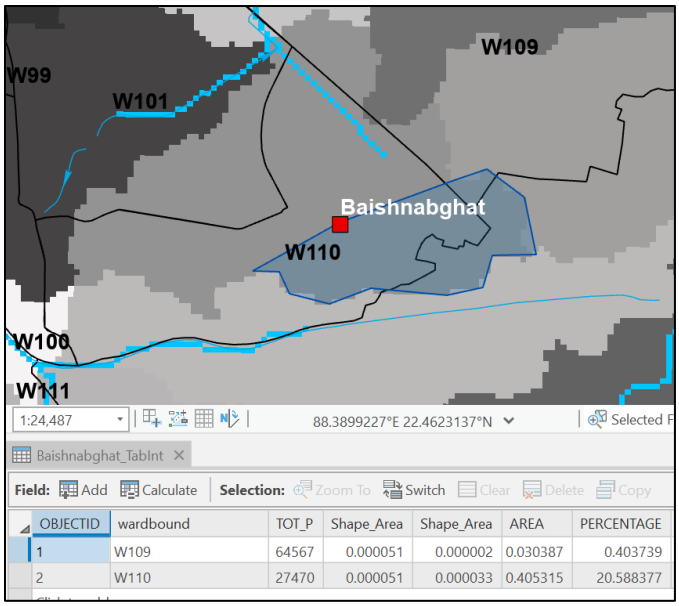
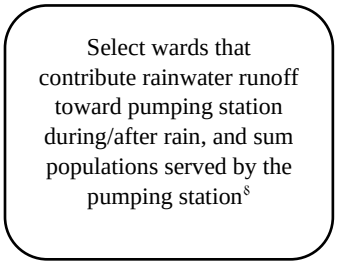


Figure 3. Upstream catchment zone of Baishnabghat Pumping Station.

Ballygunge Pumping Station

Step in the Process Flow Diagram:



Ballygunge serves the Suburban System and is the largest pumping station in the KMC[1–3]. There is information about underground pipe connections leading to this facility; however, these connections were particularly difficult to interpret in the "Suburban System Sewer Network" diagram due to disjointed lines, lack of directionality indicated for some sewers, and an incomplete legend that specifies the symbology used. Additionally, these diagrams do not completely agree with data from KMC (2005) regarding the wards fully and partially covered within the Suburban System[3]. As Figure 4 shows, the partially covered wards are distributed randomly amongst the fully covered wards in an unintelligible pattern. It is not possible from this information to surmise how much of each ward is actually covered under the Suburban System and sent through the Ballygunge PS. For this reason, the catchment delineation grid will be used to help guide the population size calculation for partial wards. The external sources of information will be consulted and applied through logical reasoning.

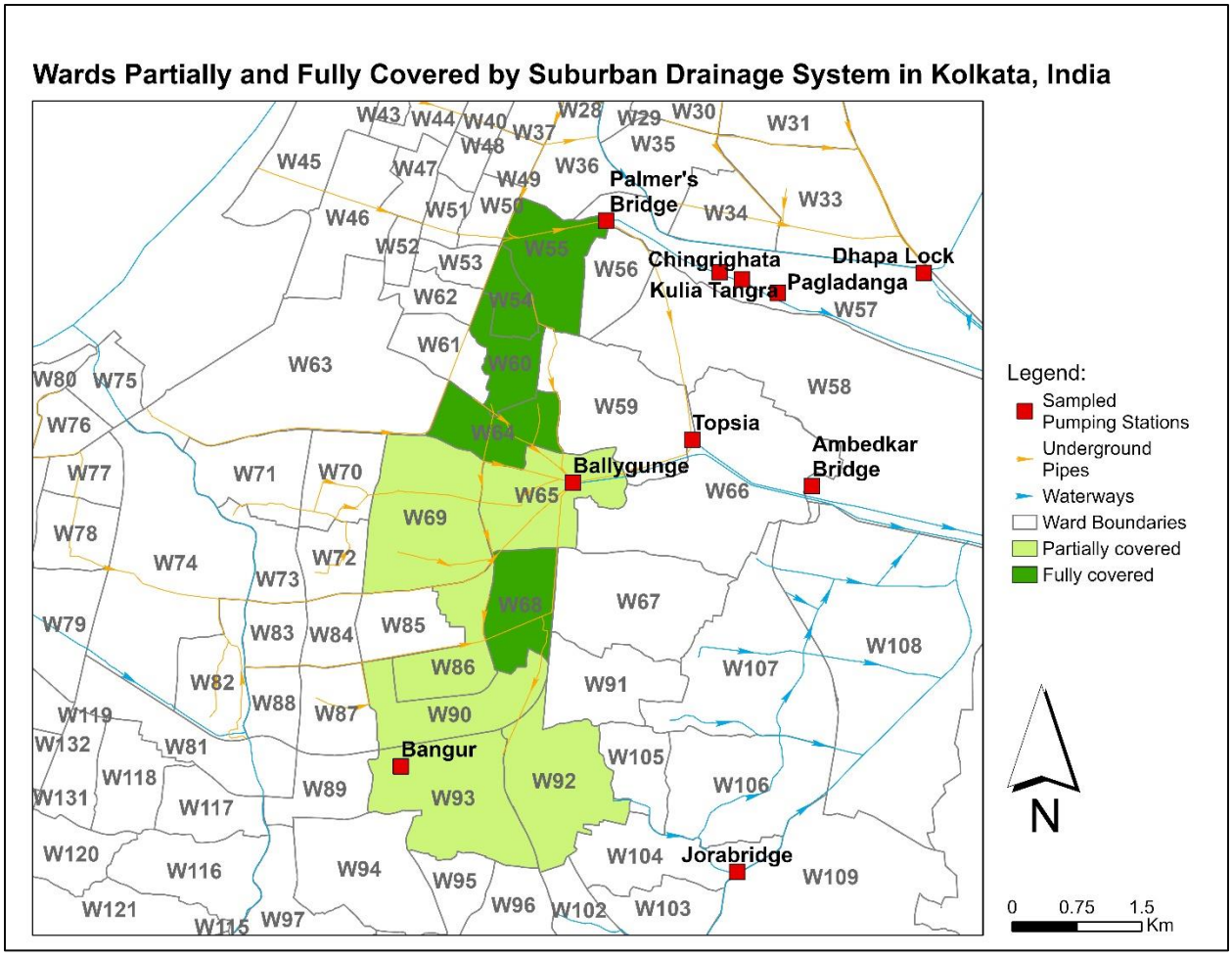
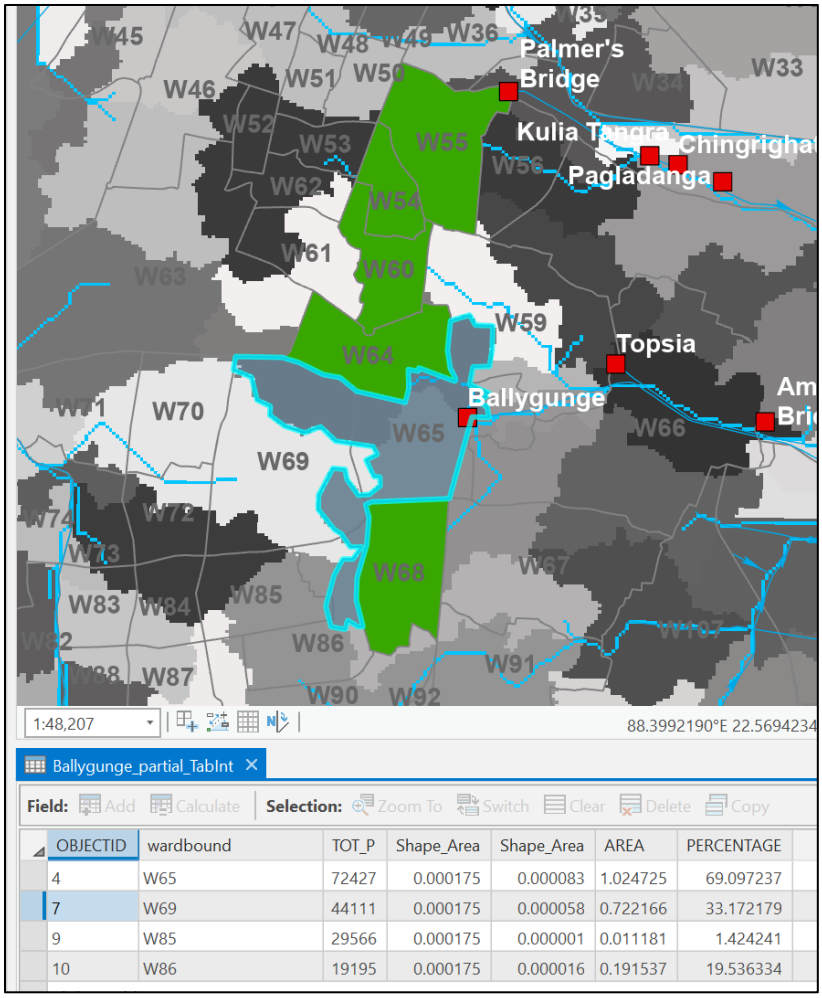


Figure 4. According to KMC (2005), these wards are partially and fully covered by the Suburban System, which discharges to the Ballygunge Pumping Station.

A zone was drawn over catchment areas that intersected with the partially covered wards and drained towards the Ballygunge PS (Figure 5). The “Tabulate Intersection” tool was then used to determine the percentage of area the wards shared with the zone, and these percentages were multiplied by the corresponding total population in each ward. These calculations were added to the population numbers from fully covered wards. Therefore, the population size contributing to the Ballygunge PS is estimated to be 225,074 people.



OBJECTID	wardbound	TOT_P	Shape_Area	Shape_Area	AREA	PERCENTAGE
4	W65	72427	0.000175	0.000083	1.024725	69.097237
7	W69	44111	0.000175	0.000058	0.722166	33.172179
9	W85	29566	0.000175	0.000001	0.011181	1.424241
10	W86	19195	0.000175	0.000016	0.191537	19.536334

Figure 5. Upstream catchment zone of Ballygunge PS for wards partially covered in the Suburban System.

Bangur Pumping Station

Step in the Process Flow Diagram:

> Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The Bangur PS does not have information regarding underground sewer and storm water lines that connect directly to the facility. Therefore, the catchment delineation grid was used to guide population estimate calculations. The Bangur PS is located near the watershed boundary line where two catchment areas flow away from one another. Therefore, the zone drawn to capture the upstream catchment area of the facility is relatively small (Figure 6). Unfortunately, the Irrigation and Waterways Department does not have Bangur PS listed on its website to cross-reference the installed capacity[2].

The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment zone of the Bangur PS. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Bangur PS sample location is estimated to be 1,525 people.

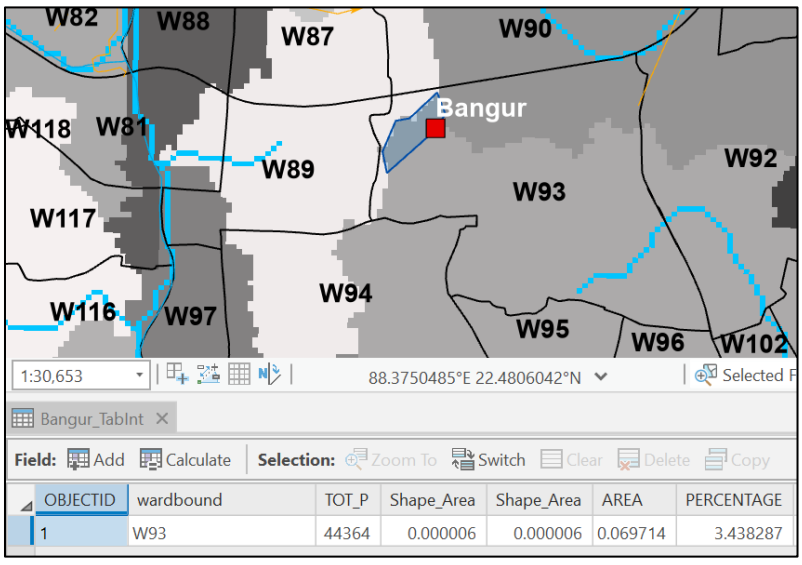


Figure 6. Upstream catchment zone of Bangur PS.

Chingrighata Pumping Station

Step in the Process Flow Diagram:

> Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The Chingrighata PS does not have information regarding underground sewer and storm water lines that connect directly to the facility. This facility is situated along the Town Head Cut (THC) Channel that the Palmer's Bridge PS discharges into, and it is downstream of the Kulia Tangra PS (Figure 7a). The capacity of Chingrighata PS (100 cusecs) is well below the capacity of Palmer's Bridge PS (1,184 cusecs)[2]. With this knowledge and drawing from the catchment delineation map, it can be surmised that the facility does not receive water from the THC Channel, but rather that it discharges wastewater into it.

A zone was drawn to capture the upstream catchment area of Chingrighata PS (Figure 7b). The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment area. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Chingrighata PS sample location is estimated to be 9,405 people.

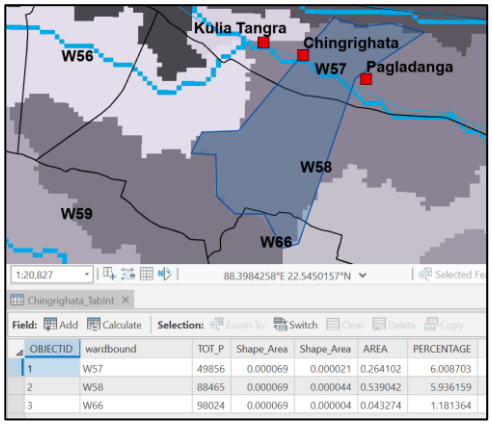
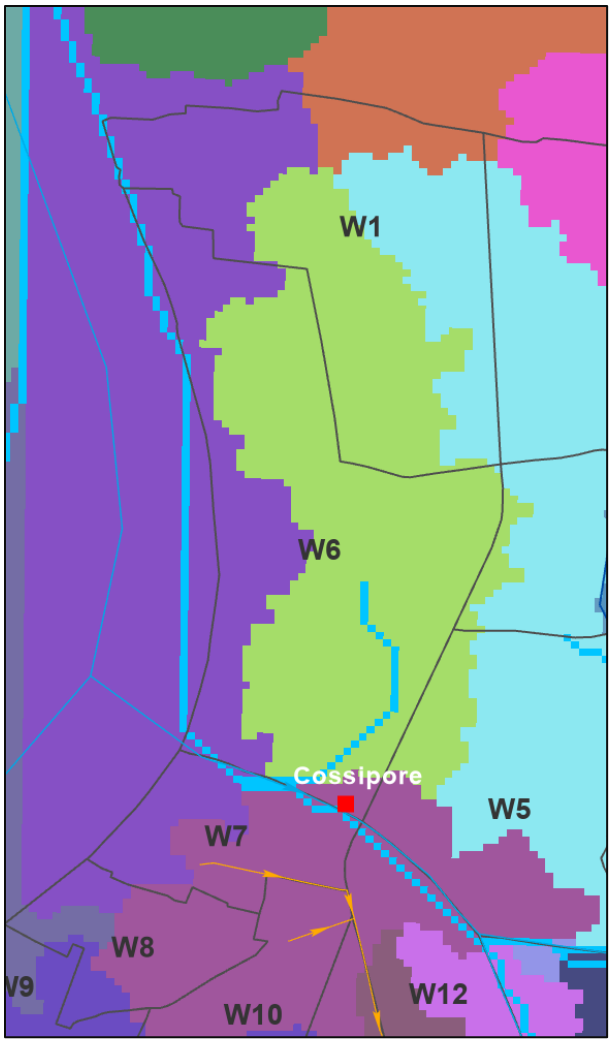


Figure 7a (left). Location of Chingrighata PS relative to other stations and canals. **Figure 7b** (right). Upstream catchment zone of Chingrighata PS.

Cossipore Pumping Station

Step in the Process Flow Diagram:

Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.



Although the Cossipore PS does not have information regarding how sewer and storm water lines connect to the facility, it is adjacent to the Town System, which is entirely served by the Palmer's Bridge PS. Factoring in this proximal information, it appears that Wards 1 and 6 (north of the facility) are most likely served by the Cossipore PS (Figure 8). Unfortunately, the Irrigation and Waterways Department does not have Bangur PS listed on its website to cross-reference the installed capacity[2]. However, due to a lack of competing pumping stations in the area, it is reasonable to assume that entire populations of Wards 1 and 6 are served by this PS. Therefore, the population size for the Cossipore PS is estimated to be 95,471 people.

Figure 8. Wards 1 and 6 were assumed to drain to the Cossipore Pumping Station due to lack of competiting pumping stations in the area.

Dhapa Lock Pumping Station

Step in the Process Flow Diagram:

Sum the populations in each ward that are served by the pumping station[δ]

The Dhapa Lock PS is one of the largest pumping stations in the KMC, and it serves the Maniktala System[1,3]. Sewer diagrams were available for this system, so it was possible to trace underground pipes to the Dhapa Lock PS[1]. KMC (2005) indicates that several wards are fully served (wards 13-14 and 29-35) by the Maniktala System and that Ward 5 is partially served by this system (Figure 9)[3].

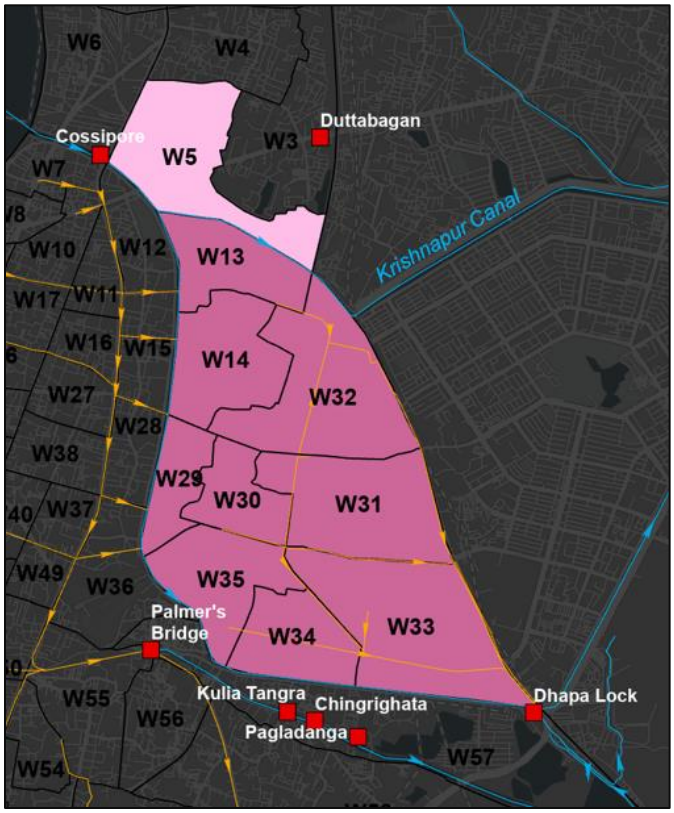
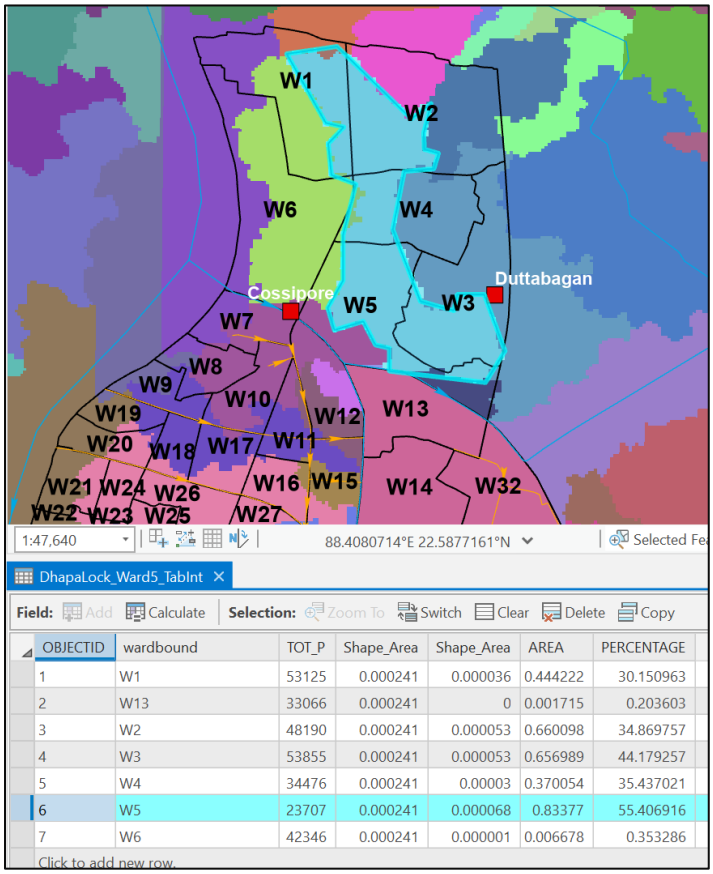


Figure 9. Wards partially (light pint) and fully covered (dark pink) by the Maniktala System, which drains to the Dhapa Lock Pumping Station.

Building off this knowledge, the populations of the fully covered wards were summed. To account for the partial service of Ward 5, the catchment grid layer was used to estimate the percentage of area from Ward 5 that may be contributing to the Dhapa Lock PS through unknown underground pipes. It was noted that rainwater runoff that does not find its way into underground storm water lines will drop into the Krishnapur (or Kestopur) Canal, and therefore it will not flow overland to the Dhapa Lock PS.

A zone was drawn to capture the upstream catchment area in common with Ward 5 (Figure 10). The "Tabulate Intersection" tool was then used to determine the percentage of area, which was then multiplied by the total population of Ward 5. Adding this to the population numbers from fully covered wards, the population size contributing to the Dhapa Lock PS sample location is estimated to be 378,753 people.



OBJECTID	wardbound	TOT_P	Shape_Area	Shape_Area	AREA	PERCENTAGE
1	W1	53125	0.000241	0.000036	0.444222	30.150963
2	W13	33066	0.000241	0	0.001715	0.203603
3	W2	48190	0.000241	0.000053	0.660098	34.869757
4	W3	53855	0.000241	0.000053	0.656989	44.179257
5	W4	34476	0.000241	0.00003	0.370054	35.437021
6	W5	23707	0.000241	0.000068	0.83377	55.406916
7	W6	42346	0.000241	0.000001	0.006678	0.353286

Click to add new row.

Figure 10. Upstream catchment area of Maniktala System to estimate how much of Ward 5 potentially drains to the Dhapa Lock Pumping Station.

Duttabagan Pumping Station

Step in the Process Flow Diagram:

> Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The was no information available about the underground pipe network that connects sewer and storm water to the Duttabagan PS, and it is therefore in the first "No" box in the process flow diagram. The delineated catchment grid shown in Figure 11a suggests that the catchment area that houses the Duttabagan PS drains southward. A polygon was drawn to represent the smaller catchment area that drains toward the facility (Figure 11b). This process revealed that partial areas of Wards 2, 3, and 4 drain to the Duttabagan PS. The "Tabulate Intersection" tool was then applied to determine the percentage of area that Wards 2, 3, and 4 overlap with the drawn polygon. The percentages were multiplied by the total population in each ward and summed to calculate the total population size of the catchment area.

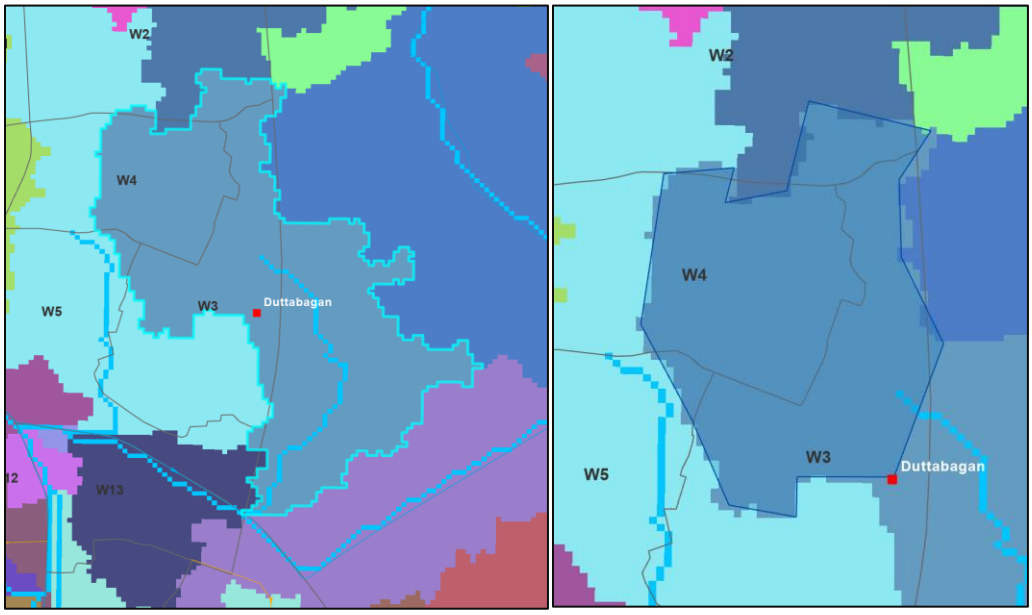


Figure 11a (left). Watershed in which Duttabagan PS is situated. **Figure 11b** (right). Perceived zone of catchment area that drains to the Duttabagan PS.

OBJECTID	wardbound	TOT_P	Shape_Area	Shape_Area	AREA	PERCENTAGE
1	W2	48190	0.000122	0.000011	0.131143	6.927617
2	W3	53855	0.000122	0.000054	0.672131	45.19749
3	W4	34476	0.000122	0.000053	0.653586	62.588479
4	W5	23707	0.000122	0.000003	0.033649	2.236103

Figure 12. Screenshot of outputs from the "Tabulate Intersection" operation. The percentage column is used to approximate how much of the total population in each ward is served by the Duttabagan PS.

The percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Duttabagan PS sample location is estimated to be 49,788 people.

Jorabridge Pumping Station

Step in the Process Flow Diagram:

Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The Jorabrige PS does not have information about how underground sewer and storm water lines that connect directly to the facility, but it is one of the pumping stations situated within a robust canal system. The upstream catchment area was estimated using the catchment delineation grid with the assumption that much of the drainage in this area drops into the canals before reaching the Jorabridge PS (Figure 13).

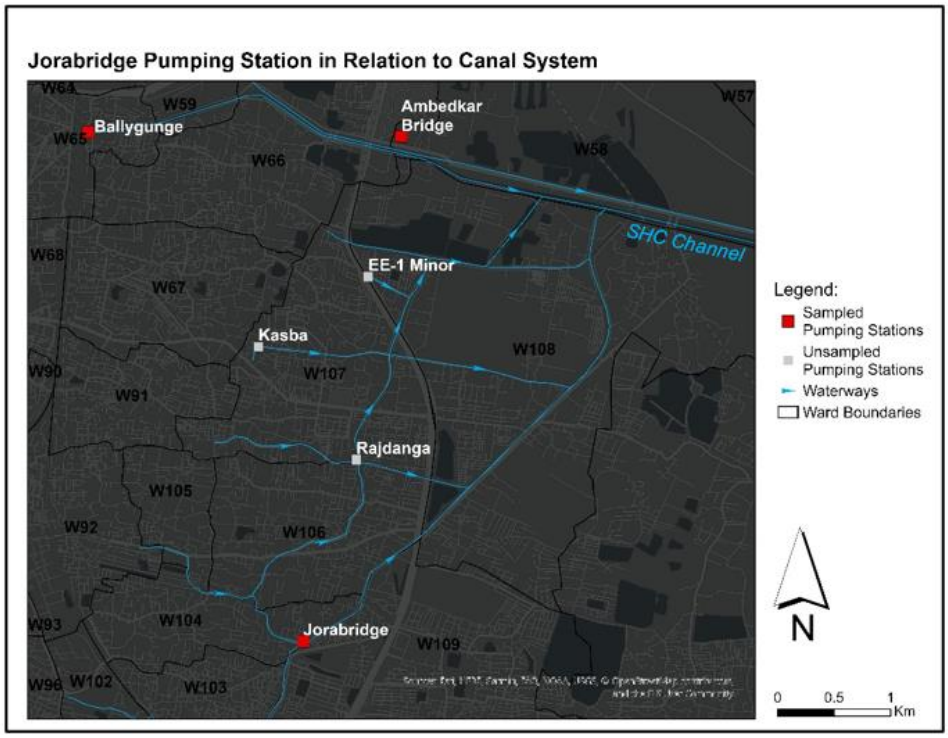
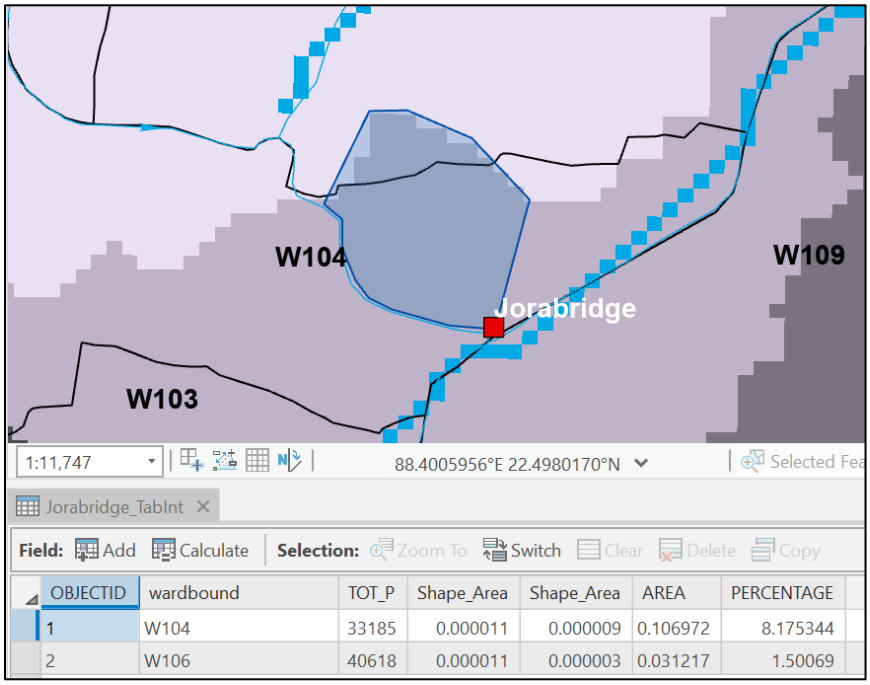


Figure 13. The Jorabridge PS is situated within a robust network of open, man-made canals. It the southern-most pumping station in the network, which generally flows northeast toward the SHC Channel.

A zone was drawn to estimate the upstream catchment area leading to the Jorabridge PS (Figure 14). The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment area. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Jorabridge PS sample location is estimated to be 3,323 people.



OBJECTID	wardbound	TOT_P	Shape_Area	Shape_Area	AREA	PERCENTAGE
1	W104	33185	0.000011	0.000009	0.106972	8.175344
2	W106	40618	0.000011	0.000003	0.031217	1.50069

Figure 14. Upstream catchment area of the Jorabridge Pumping Station.

Kulia Tangra Pumping Station

Step in Process Flow Diagram:

Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The Kulia Tangra PS does not have information regarding the sewer and storm water lines that connect directly to the facility, but it is situated between the Maniktala and Town systems. The proximal information helps inform which areas are draining to this location. From Figure 15a, it can be seen that the Kulia Tangra PS is situated along the THC Channel that Palmer's Bridge PS discharges into. The capacity of Kulia Tangra (40 cusecs) is well below the capacity of Palmer's Bridge (1,184 cusecs)[2]. Similar to the Chingrighata PS, it can be surmised that the Kulia Tangra PS does not receive water from the THC Channel, but rather that it discharges wastewater into the channel.

A zone was drawn to capture the upstream catchment area of Kulia Tangra PS (Figure 15b). The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment area. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Kulia Tangra PS sample location is estimated to be 1,493 people.

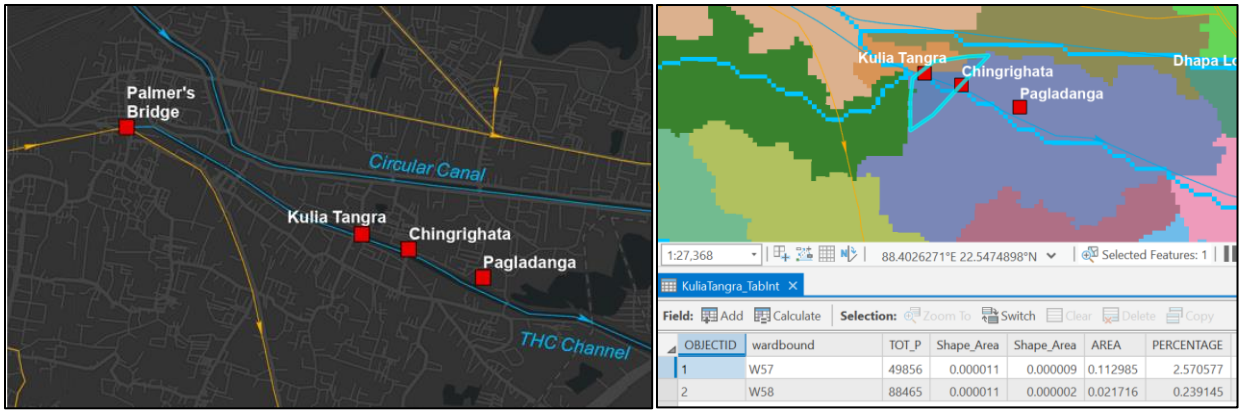


Figure 15a (left). Location of Kulia Tangra PS relative to other stations and canals. **Figure 15b** (right). Upstream catchment zone of Kulia Tangra PS.

Pagladanga Pumping Station

Step in the Process Flow Diagram:

Using the direction of drainage indicated by the catchment areas, select wards that drain towards the pumping station and sum corresponding populations.

The Pagladanga PS does not have information regarding the sewer and storm water lines that connect directly to the facility, but it is situated between the Maniktala and Town systems. The proximal information helps inform which areas are draining to this location. From Figure 16a, it can be seen that the Pagladanga PS is situated along the THC Channel that Palmer's Bridge PS discharges into, and it is downstream of the Chingrighata and Kulia Tangra pumping stations. The capacity of Pagladanga PS (48 cusecs) is well below the capacity of Palmer's Bridge (1,184 cusecs)[2]. Similar to the Chingrighata and Kulia Tangra stations, it can be surmised that the Pagladanga PS does not receive water from the THC Channel, but rather that it discharges wastewater into the channel.

A zone was drawn to capture the upstream catchment area of Pagladanga PS (Figure 16b). The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment area. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Pagladanga PS sample location is estimated to be 13,160 people.

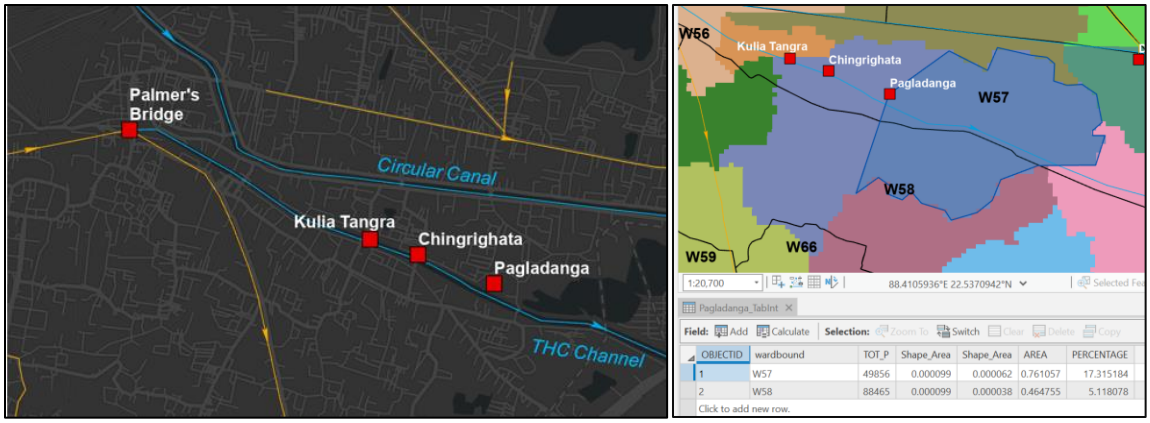
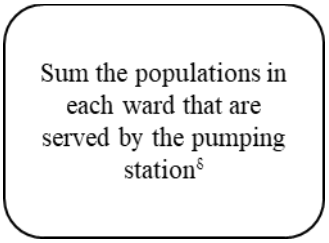


Figure 16a (left). Location of Pagladanga PS relative to other stations and canals. **Figure 16b** (right). Upstream catchment zone of Pagladanga PS.

Palmer's Bridge Pumping Station

Step in the Process Flow Diagram:



The Palmer's Bridge PS is one of the largest pumping stations in the KMC, and combined sewer and storm water from the Town System is funneled to this facility[1,3]. Coherent integration of the various sources of information is difficult for Palmer's Bridge because there are inconsistencies in the data. In the book *Blue Infrastructures: Natural History, Political Ecology and Urban Development in Kolkata* by Jenia Mukherjee (2020), Table 5.4 (source: KMC, 2005) summarizes how wards are covered by major drainage systems[3]. The table specifies that Wards 6 and 63 are partially served by the Town System, however Map 5.1 shows Ward 63 in its entirety draining towards Palmer's Bridge[3]. Regarding Ward 6, it was determined from the catchment delineation grid that it most likely drains to the Cossipore PS, where wastewater then discharges into an open canal and bypasses the Palmer's Bridge PS (see Cossipore PS for more information). Therefore, it was assumed that Ward 6 does not contribute wastewater to the Palmer's Bridge PS, while Ward 63 was assumed to be fully covered by Palmer's Bridge PS due to lack of competing pumping stations in the area. The populations from wards fully covered by the Town System plus the total population from Ward 63 were summed (41 wards total) to estimate the population size (Figure 17). Therefore, the population size for the Palmer's Bridge PS is estimated to be 890,681 people.

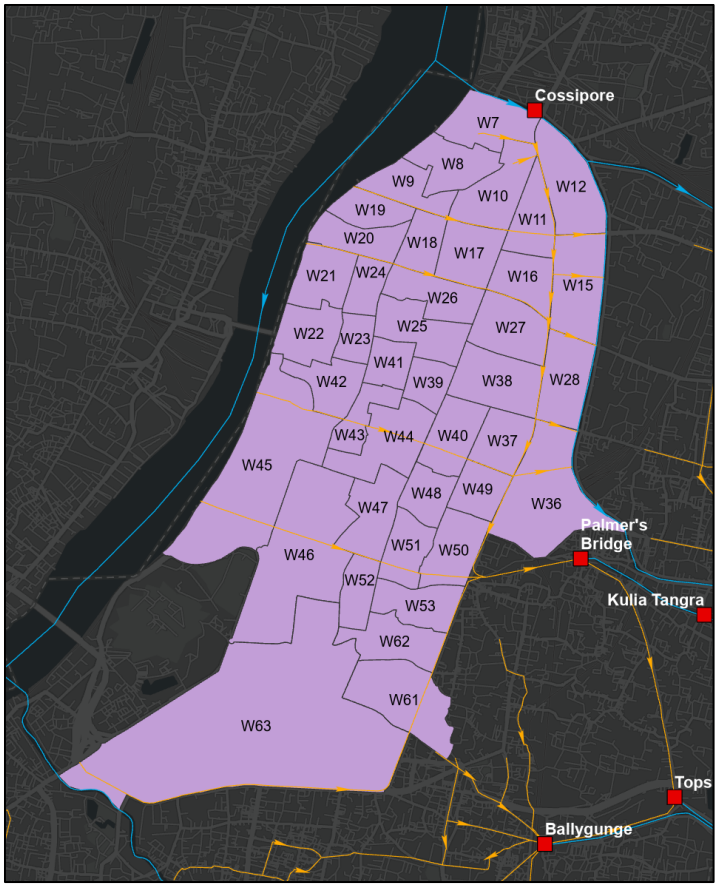
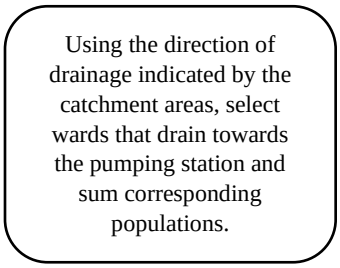


Figure 17. Wards included in the population size estimate for the Palmer's Bridge PS.

Topsia (Old) Pumping Station

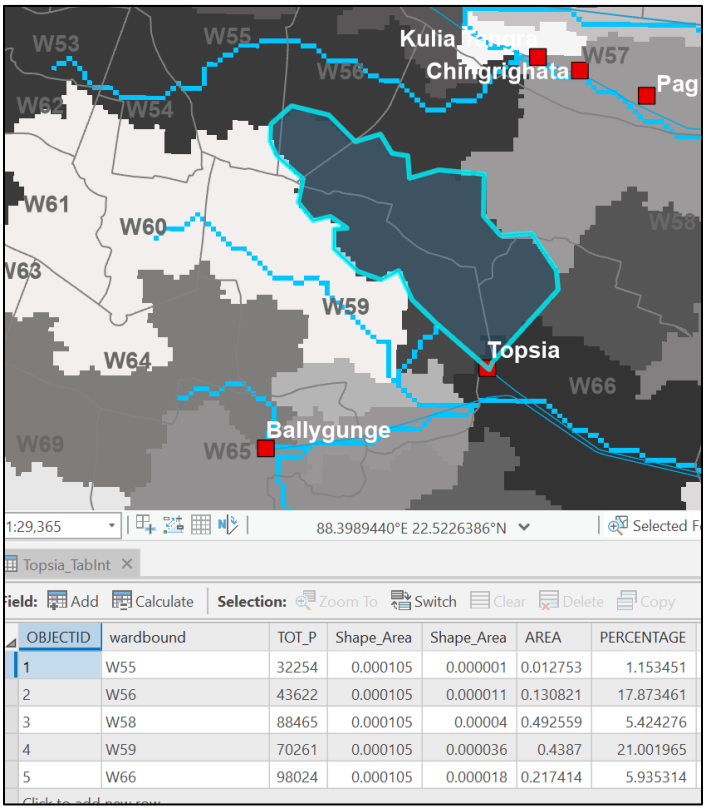
Step in the Process Flow Diagram:



According to the Irrigation and Waterways Department's list of pumping stations with installed capacity figures, there is only one facility referred to as "Topsia" with a capacity of 65 cusecs[2]; however, referring to the official website of KMC, the list of pumping stations shows two pumping stations (Topsia DPS and Topsia Point 'A') with the same number of pumps (N = 7)[4]. After referring to the results from ES activities, it appears that only "Topsia (Old) DPS" was sampled and that Topsia Point 'A' was not sampled. This creates confusion because according to the literature, sewage is conveyed through high-level sewers to Topsia Point 'A' from Ballygunge and Palmer's Bridge stations[3]. Although it is uncertain form the literature whether these two stations are separate or one in the same, it is assumed that they are not due to the unique pumping station names on the KMC website. For this reason, the catchment delineation grid was used to guide population size calculations, and it was assumed that the sampled pumping station does not receive wastewater from Ballygunge PS or Palmer's Bridge PS. This assumption should be verified with local experts.

A zone was drawn to capture the upstream catchment area of the Topsia PS (Figure 18). Although the catchment grid delineation map indicates a drainage pattern slightly southeast of this station, it was assumed that the direction of flow is generally towards the Topsia PS. The "Tabulate Intersection" tool was then used to determine the percentage of area that each ward shares with the upstream catchment area. These percentages were multiplied by the total population in each corresponding ward and summed to calculate the total population estimate. Therefore, the population size contributing to the Topsia (Old)

PS sample location is estimated to be 33,542 people; however, it is uncertain how much of this estimate overlaps with Topsia Point ‘A’ PS.



OBJECTID	wardbound	TOT_P	Shape_Area	Shape_Area	AREA	PERCENTAGE
1	W55	32254	0.000105	0.000001	0.012753	1.153451
2	W56	43622	0.000105	0.000011	0.130821	17.873461
3	W58	88465	0.000105	0.00004	0.492559	5.424276
4	W59	70261	0.000105	0.000036	0.4387	21.001965
5	W66	98024	0.000105	0.000018	0.217414	5.935314

Figure 18. Upstream catchment area of the Topsia (Old) PS

Appendix References

1. Rainfall monitoring. http://www.meteocal.in/rain_flood.php. Accessed February 26, 2021.
2. Government of West Bengal. Irrigation & Waterways Department. https://wbiwd.gov.in/index.php/applications/kolkata_drainage. Accessed March 21, 2021.
3. Mukherjee J. *Blue Infrastructures : Natural History, Political Ecology and Urban Development in Kolkata*. Vol 1st ed. 20. Singapore: Springer; 2020. https://login.proxy.library.emory.edu/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=2486075&site=ehost-live&scope=site.
4. Kolkata Municipal Corporation. Official Website of Kolkata Municipal Corporation. https://www.kmcgov.in/KMCPortal/jsp/PumpingStation.jsp. Accessed March 23, 2021.