Developing a decentralized and integrated water management System for Neighborhood Communities within Indonesia's informal urban Settlements

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Abstract

Decentralized water management systems can be a viable solution to the sanitation problems of informal urban areas. To be successful, they have to be tailored to the specific context of an area by using its social and cultural potentials instead of thinking in solely technical system measures. This is shown for the example of Kampung Tamansari, an informal settlement located at a riverbank in Bandung, Indonesia. The area's water issues relate to problems that occur in many parts of the country's metropoles, making an exemplary solution approach a possible tool to deal with areas that cannot be connected to a central sewage system. First, a quantitative and qualitative analysis of existing water sources and uses reveals that the current handling of water has a destructive impact on human health and the environment, primarily caused by the lack of save drinking water and contamination by sewage water that is led directly into the river. At the same time, rain water as a clean water source is not used and unsustainable behavior due to a lack of knowledge increases the existing problems. Based on field research, the potential of community institutions and involved stakeholders in Tamansari is examined, identifying neighborhood communities, their leaders and religious institutions as most promising catalysts for the implementation of a new system. A high level of self-organization, strong social cohesion, democratic mechanisms and educational infrastructure within neighborhoods are to be mentioned. In a next step, three case studies are compared in terms of their technical systems and implementation strategy. Their relevance lies in creating synergies between technical components and public space, using religious institutions to improve water use efficiency and creating an extendable bottom-up system. Finally, a decentralized and integrated water system is proposed. The cluster system for one neighborhood of approximately 500 people consists of rainwater collection, storage, septic tanks and vertical flow constructed wetlands as main components. The implementation, management and water education is realized through the use of the identified potentials within the community. Interdependent relationships and mutual benefits for all involved stakeholders ensure the system's stability as a result.

Introduction

The rapid expansion of cities in the global south comes along with massive challenges in the sanitation sector. The government's failure to provide enough affordable living space results in the uncontrolled growth of informal settlements where the lack of clean drinking water and adequate sanitation is omnipresent. This is a clear contradiction to the UN Resolution A/Res/64/292, defining them both as human rights[1]. 32% of the world's population lives in informal settlements by now, the total number is still increasing[2]. Indonesian cities have a social housing demand of almost a million per year[3], creating a huge backlog that doesn't seem solvable at the moment. The disproportion of urban growth and planned infrastructures and buildings shows us that the informal building sector is not a transitional phenomenon but a reality that has to be dealt with.

One of the main problems in the informal urban areas is the lack of water infrastructure for both, drinking supply and sewage. However, centralized water supply and sanitation models as they are apparent in almost all westernized countries have strong limitations for several reasons. First, they have to be implemented before the settlement and hence are not applicable to already squatted areas. Second, huge investments have to be done to implement and maintain the system which is why they are often not realized or don't work well. Third, most centralized supply systems rely on clean water sources from outside the city. Many of them have already exceeded their limits and accessing further sources is either impossible or very expensive.

The unfeasibility of central systems has put decentralized alternatives more into the public's focus. Relying on local water sources such as rain -, storm and re-used water are seen as opportunities to overcome the scarcity. Besides, health issues due to fecal water contamination create an urgent demand for solutions that can be implemented fast and without big investments. In contrast to central systems, decentralized solutions cannot be based on textbooks only. They are highly complex systems that do not only include pure technology but have to be tailored to the specific social, economic and cultural characteristics of a place.

In this paper, this is done by looking at Kampung (Def. informally grown area) Tamansari, an informal settlement that is located at the river bench of Cikapundung river in the centre of Bandung, Indonesia. Tamansari is defined as a slum area (defined by municipality) with insufficient access to clean water and no working sewage system. The density is already very high (prove) and continuous influx of people is expected. The choice of the site is based on the relatively good availability of data as well as the Kampung's typical character that makes it representative for many other cases in Bandung and comparable metropoles. An in depth analysis of local water sources, stakeholders, community institutions and international case studies works as a solid basis to deal with the question of *how to develop a decentralized and integrated water management system* (DIWMS) *for neighborhood communities within Indonesia's informal urban settlements*.

Methodology

Part I consists of a qualitative and quantitative analysis of Tamansari's existing water sources and how they are used by residents. The analysis provides a sufficient body of knowledge to further investigate the topic and come up with suitable solutions. Supporting data comes from different health related studies on water quality and a one month field research including interviews with locals, officials and professionals, observation and photographic documentation.

Part II is an analysis of Tamansari's social structure. The focus lies on the potential of stakeholders and community institutions to contribute to the successful implementation of a DIWMS. Field research and interviews with locals have been the main sources to reveal the potential while demographic data from former surveys helps to sharpen the area's profile.

Part III is a comparative analysis of three case studies, selected because of their overlap with the identified local potentials. The systems are compared against their technical and spatial components, their implementation method and the involvement of stakeholders. Findings are judged on applicability to the case of Tamansari.

Part IV is a conclusive proposal for a decentralized and integrated water management system in RW 20, Tamansari. Findings from part 1-3 are applied to a specific site, technical and spatial components of the system are defined exemplarily. The system's flows are presented qualitatively and quantitatively.

I. Tamansari's Water sources and Uses

The analysis shows that the handling of water and sewage in Tamansari is unsustainable, uneconomic and unhealthy. These circumstances can be explained by the unforeseen squatting of the area that made it impossible to build adequate water and sewage infrastructure in advance. Informal settlements developed in the late 50's and early 60's during political upheavals that followed the Indonesian independence. The area around the riverbed used to be the Bandung's green belt, led by the concept of the garden city while it is now classified as a slum and one of the densest areas of the city. People in Tamansari spend around 3.3% of their income on water which equals 61.000 Rp/month and is slightly above the maximum expenses that is recommended by the UNDP, the WHO and UNICEF[4].

Water Sources and Flows in Tamansari

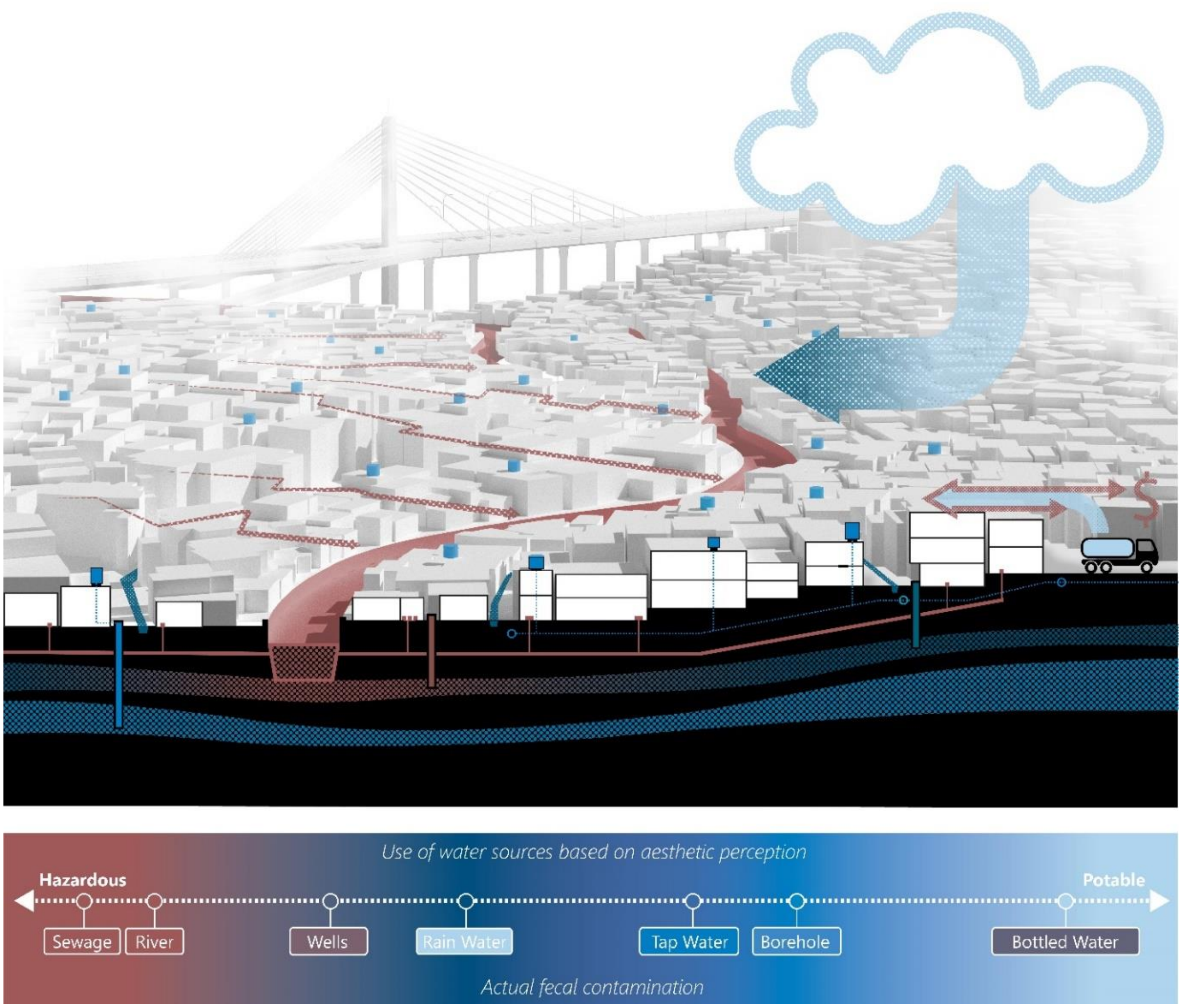

Figure 1: water sources in Kampung Tamansari (own image)

1.2. Bottled Water

Bottled water is the main source of drinking water in Tamansari: 66.5% of the inhabitants rely on it as a drinking water source[5]. People equally rely on branded bottled water in different bottle sizes and refill bottled water that is usually bought or delivered in 19-liter plastic containers. Both sources have serious drawbacks: The branded bottled water is quite clean but about three times more expensive than refill water, hence being unaffordable for many. Refill bottled water has a high risk on fecal contamination. More than 50% is contaminated, causing Diarrhea and a high child mortality[6]. The probability of getting infected is higher as tap water and borehole water. This is a problem because the aesthetic perception of water, namely odor, color and taste doesn't correspond to the actual safety of a water source *(Figure 1)*.

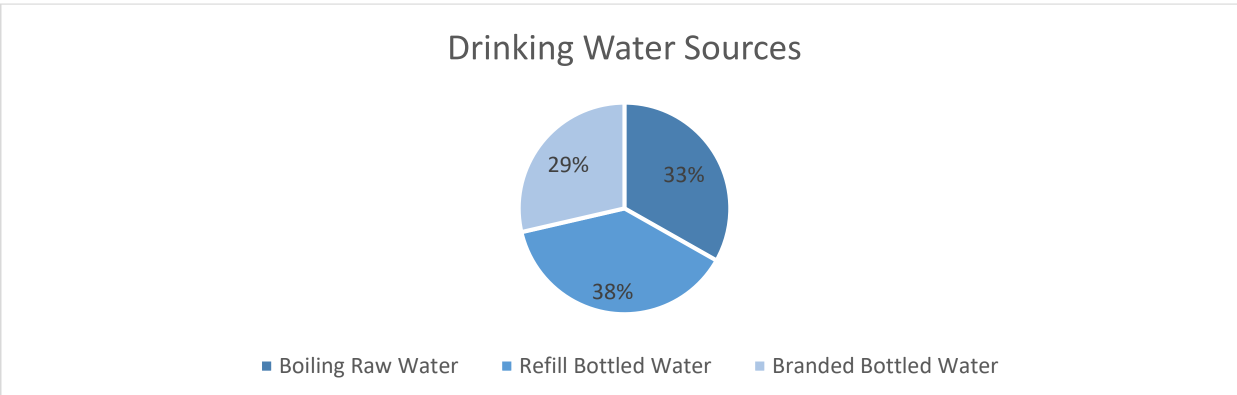

Figure 2: Drinking Water Sources[7]

1.3. Rainwater

The precipitation in Tamansari is quite high with significant differences between dry season (June – September) with a minimum of 34 mm/month and wet season with a maximum of 306 mm in January. The average annual rainfall is 210 mm. However, there is no evidence that rainwater has been used as a water source yet. At the moment it affects the area only in a negative way because the high percentage of sealed ground fosters flooding in the downstream parts of the city. Additionally, puddles stay quite long because the narrow streets are often covered from the sun. This is one reason why parents don't like to see their children to play on the streets.

1.4. PDAM Tap Water

The PDAM (Regional Drinking Water Company) is a government owned water company that operates all over Indonesia. They provide several tap water connections in Tamansari that are used by 51.5% of the households as main raw water source[8]. However, people in the Kampung are not satisfied with the supply for several reasons: First, water is only available for certain time intervals, sometimes only a few hours during the night[9]. This happens especially during the dry season and is caused by the PDAM's low capability of water treatment production and a high percentage of leakage (30%)[10]. Second, while not being dangerous to health, the water often tastes bad and has a high turbidity that is caused by rust and particles[11].

Only 23% of the people use it for drinking and a majority of 77% for household purposes[12]. The water has to be cooked and stored to settle, some people store it in open containers which increases the risk for bacterial contamination.

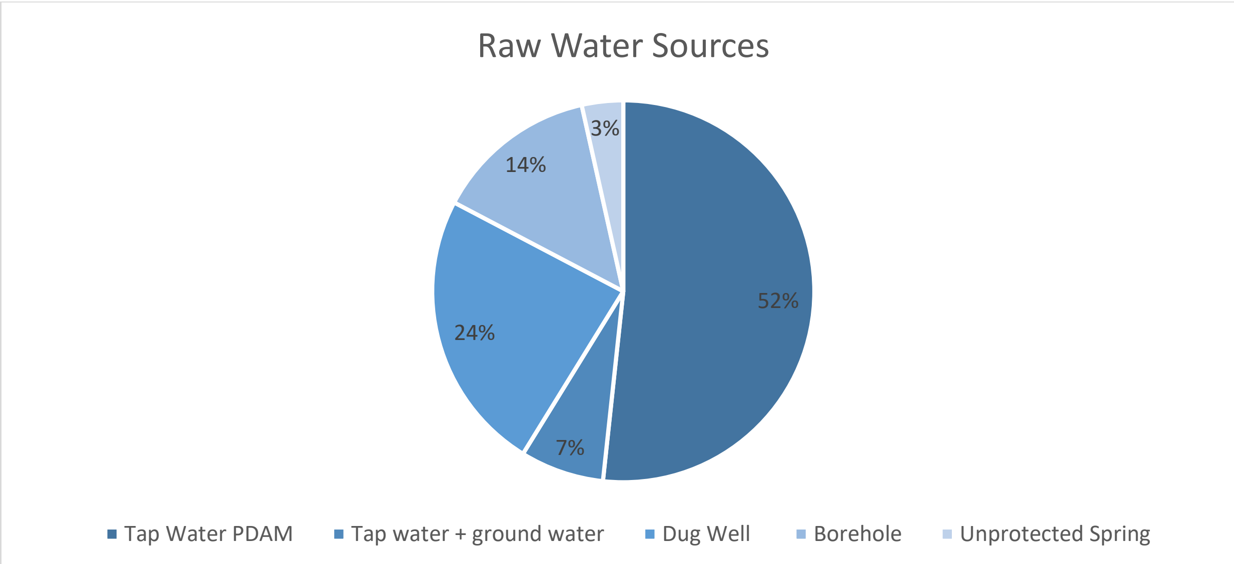

Figure 3: Raw Water Sources[13]

1.5. Wells & Boreholes

There are three kind of ways to extract groundwater in Tamansari. Dug Wells, around 9 meters deep and unprotected springs access an upper layer of groundwater. The wells are usually shared between 3-5 houses[14]. The closer they are located to the riverbed, the higher their contamination with fecal *Coliform* bacteria[15] and other pollutants from Cikapundung river. People who rely on well water have the highest infection risk in Tamansari, even if they cook the water as it is the usual practice. Some of the wells close to the water are not used anymore because of their contamination. A smaller part of the population uses water from much deeper boreholes that is quite clean and doesn't bear such risks. However, the water table sinks very fast which causes land erosion. This is mostly due to excessive use by the industry and illegal boreholes which is why this cannot be seen as a reliable source in the future.

1.6. Sewage Water

91 % of the sewage water from communal toilets and private toilets enters Cikapundung river without any treatment[16]. It flows through multiple small pipes that are located under the streets. Only 3.5% of the sewage water is treated in communal septic tanks[17] that are located north of the Pasopati flyover. The tanks are not functioning well because poor structural quality leads to leakages. Furthermore, missing standardization, accessibility and economical incent make their maintenance difficult and economically unattractive[18]. The desludging, that should be done every 3 years hasn't been done for 10 years in some cases[19]. Another 3% use a hole in the backyard and only 2 % are actually connected to the sewerage system of the PDAM[20]. Besides economic and legal reasons, the main problem is that the municipal sewage system is based on gravity and cannot connect to houses that are located lower than one of the central treatment plants. Since this is the case for the Kampung, a future connection is not probable.

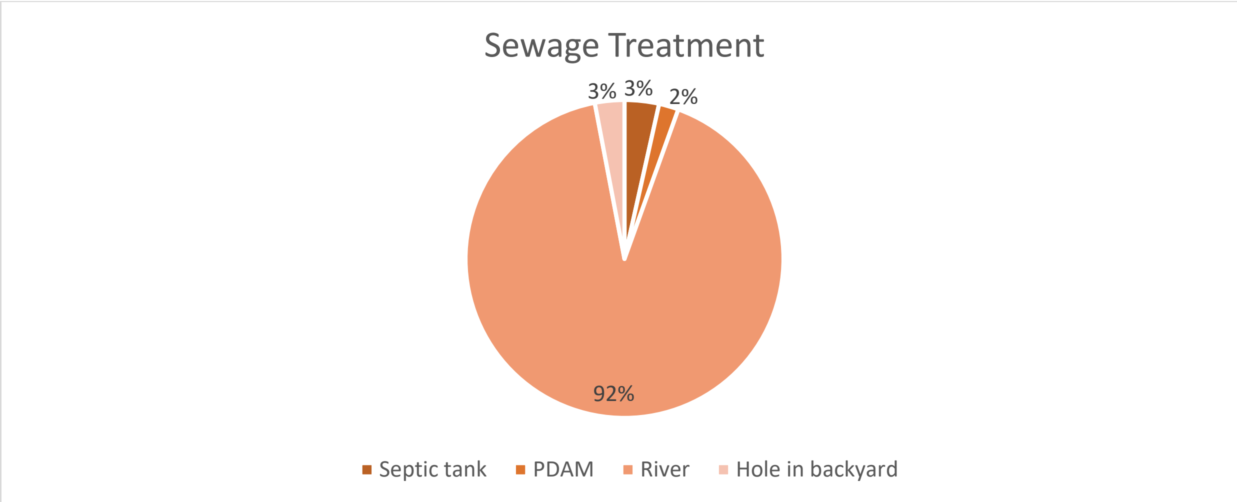

Figure 4: Sewage Treatment[21]

1.7. Cikapundung River

Cikapundung River is one of the most polluted rivers in Indonesia, mostly due to its use as a sewage system but also because people throw their garbage into it. The contamination with fecal bacteria could be found everywhere while heavy metal concentrations are only found downstream close to industrial sites[22]. High and low water during over the season has become more extreme in recent years. This is caused by deforestation and increasingly sealed surfaces along the river bed. Flooding of the houses has been prevented with higher flood protection walls some years ago[23]. People are still using the water for fish farming. Apart from that, there are no qualities of the river that people could relate to. While using it as a sewage system and garbage dump, they try to stay as far away from it as possible. The poorest people always live next to the river.

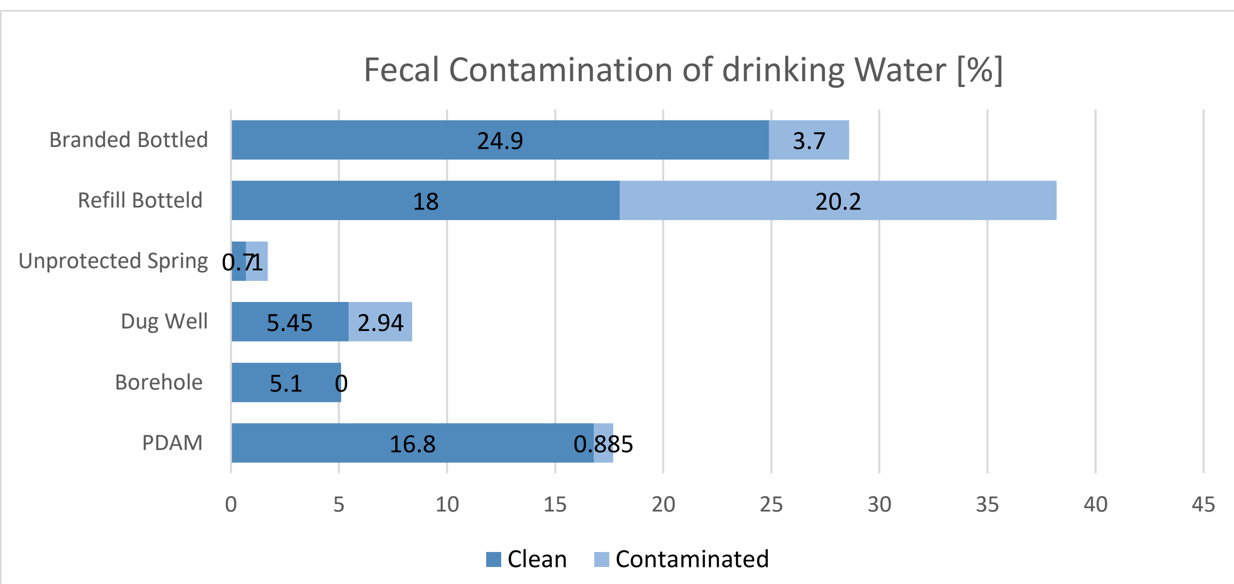

Figure 5: Drinking water fecal contamination[24]

1.8. Potential of Water Sources for a DIWMS

Based on the findings in 1.1.-8., only some of the water source bear the potential to be used in a decentralized, integral water system. Bottled water should be replaced due to its high price, health risks and unsustainable footprint. Wells, Springs and boreholes should not be used either because they are mostly contaminated, already overexploited and increase the risk of land erosion and even landslides. PDAM tap water should stay a source for raw water but it should not be relied on. There are no health risks but the unreliable distribution and water quality make it a second-choice source. Rainwater has a good quality and therefore the potential to become the main source for potable and clean water. Sewage water must be treated before entering the river to prevent further pollution and health issues. The treated water can be used for other purposes that do not require drinking water quality. River water as a result of its misuse as a sewage canal cannot be considered as a supply source. With a long-term change of bad habits, less pollution and less affection of the groundwater, people could develop a better relation to it and use its potential for leisure, public space and economy.

II. Stakeholders and communal Institutions

The successful implementation of a small scale water system is highly dependent on the local economic, social and cultural context[25]. Identifying needs, interests and motivations, potentials of the involved stakeholders is therefore a crucial part of the planning process. Using existing community institutions can possibly catalyze the process.

2.1. Rukun Warga (RW) and Rukun Tetangga (RT)

The Subdistrict *(Kelurahan)* Tamansari is divided into 20 RWs *(Rukun Warga = Division of Subdistrict)* , administrative districts, which again are divided in a varying number of RTs *(Rukun Tetangga = neighborhood unit)* which are not part of the governmental administration anymore. With an average of 7.5/RWs. The average population of one RW is 1250 people (=330 households), the average RT population is 210 people (=51 households) although there are big fluctuations in area and density[26]. Apart from their administrative function, the zones are often identical with social neighborhood communities. People feel responsible for each other and strongly identify themselves with their neighborhood. For most of them, this is the main quality of the area and a main reason to stay. The communities often take initiative when the government is unable or unwilling to give support. Activities based on a neighborhood level include the management and funding of educational facilities such as childcare and primary schools, a solidary tax for waste management, elderly care and funerals, cultural activities such as dancing, sports, cleaning the streets and the river as well as funding of public facilities and beautification of the environment[27]. Apart from donations, a lot of voluntary work is done and everybody contributes what he can. The social cohesion of neighborhoods differs between RWs and has a visible effect on the environment and living comfort of the residents.

Apart from that, the attitude of the RW/RT leaders plays an important role. As persons of public trust, they become elected democratically and communicate on a regular, at least monthly basis. Being residents themselves, they aim to improve the neighborhood. Their engagement and personal interests are often positively reflected in the whole neighborhood. For example, one RW leaders fascination in botany resulted in a lot of vertical greenery including medical plants. Another one’s interest in painting led to many colorful murals and collaborations with artists. RW/RT leaders are well informed about water, waste and sewage problems, often have a progressive mindset and are open to sustainable solution approaches. Apart from that, they are concerned about the lack of educational facilities, public space greenery, parking lots for motor bikes and the growing population.

2.2. Mosques and Imams

87.2% of Indonesia's population is Muslim[28] , within Kampung Tamansari it is even 99%. According to the World Muslim Report 2012, 72% of them attend Friday Prayers while many of them pray up to 5 times per day[29]. This explains that small Mosques and Musholas, smaller praying rooms, are omnipresent; in Tamasari there are 22 Mosques in use, making it the most significant built community institution. Apart from praying and due to limited public space they are used for childcare, child education, religious workshops, women's meetings and Quran reciting. Some of them are able to provide water in case of scarcity because their direct connection to the PDAM[30]. Mosques are financed, maintained and owned by the community. They usually have 1 or 2 floors, with a big prayer room and an optional multi-purpose room.

Imams are personalities of public trust and religious knowledge that are chosen by the neighborhood community. The often have a close relationship to RW/RT leaders, sometimes they are the leader themselves. Imams within Tamansari also have a good relationship and communicate on a regular basis[31]. They hold the speeches on Fridays and take a main role in other religious and educational activities. One of their concerns is the insufficient capacity of praying space especially on Fridays and during Ramadan[32].

2.3. Residents

The average household consists of 4.1 members. Women mostly have the role of a housewife while men are creating the income. 51% of the family heads have their own business which is often located within the Kampung. Around 22% are employees and another 23% without job. 42% of them have a very low income (< 1 m. Rp), 37% a low income (1-2 m. Rp), 13% earn 2-4 m. Rp and only 8% more than 4m. Rp.[33], which is where Bandung's average salaries start. Most of the people have lived for longer than 10 years in Tamansari. Many of them live in families that have been living here since the initial settlements in the late 50s/early 60s. Houses are 1 to 3 floors high and often have rooms for subletting. Especially in RW 13, 14 and 20 rooms are rented out to students from the Islamic University (UNISBA)[34].
Most of the residents have the strong desire to stay within their house because of their neighborhood community, their neighborhood related business and their rooting in the area. However, they are concerned about their children's education and their children playing on the streets instead of safe places[35]. Many complain about the lack of public and green space as well as broken or old drainage, and sewage channels [36]. The majority of them does not trust in governmental initiatives to solve these problems.

2.4. Potential of Stakeholders and communal Institutions

When designing an integrated communal water system, existing communal institutions could be catalysts for the implementation process. As shown in 2.1, Neighborhood communities are already taking care of many public responsibilities. Adapting size, organization and maintenance of the system to the existing social dynamics is therefore favorable. Besides, the existing funding and tax system could contribute to either the initial investment or the operation and maintenance costs of the system.

RW and RT leaders can be important connectors between the involved planners, residents and other stakeholders. They are commonly trusted and have a positive attitude towards sustainable solutions. Besides, their regular meetings with the residents could be a good way to inform people, make democratic decisions about the systems features and further investigate the people's needs. The regular meetings on RW and Subdistrict levels could be used to spread the knowledge.

While RW and RT leaders are mostly aware of the environmental threads of garbage and sewage disposal into the river, most of the residents are lacking financial or different incentive as well as opportunities to change their behavior. Their support could be won by combining new infrastructural measures with their expressed needs, namely public space, greenery and educational facilities for their children. Another way of approaching the people is creating financial opportunities. The low average wage and working places that are preferably in the same neighborhood are good prerequisites.

The religious infrastructure is maybe the most developed in the area. This bears opportunities on multiple levels. The regular Friday Prayers with high attendance of the residentials has a high educational potential. The Imam can be considered as a key person to address the behavior of people as long as there is a link to Islam. The existing role of some Mosques to overcome water scarcity could be a chance for development, because of their strategic position within the Kampung and the high visitor frequency.

When educating people, the target group for water conservation, reuse, waste- and sewage treatment is the same: house wives. This makes approaching them much easier, especially because there are already existing communal activities that are only carried out by women

III: Case Studies of integrated communal Water Systems

3.1. Água Carioca, Rio de Janeiro

Based on the work of Ooze Architects and Urbanists, Rotterdam[37],[38],[39]

3.1.1. Contextual Background

Rio de Janeiro suffers from fresh water scarcity, competing with São Paolo for the same limited sources. Besides, only 30 % of the households has a domestic sewage treatment which is why the 263 small rivers of the city are used as a sewage system. This causes serious health issues and heavy pollution of the environment, especially the Guanabara bay. The municipal water company has not been able to solve these problems with a centralized system. The case study has its focus on one of the typical squatted housing areas which releases all their sewage into the river Carioca. An integral water system on household level that releases only clean water into the river is proposed by the architecture and urbanism office Ooze. A pilot project with educational purpose has been built. The concept includes the possible extension to neighborhood, district and even city scale.

3.1.2 Technical and spatial Design Components

The technical components of the system are simple. They consist of a metal roof as rainwater collector that is combined with a small storage tank for potable water. Waste water is treated in a septic tank and then led to a constructed wetland. The water can be reused as non-potable water in household, garden and is finally released into the river. The design for the favelas is as minimalistic as possible. The urban prototype at Sitio B. Marx also fulfills an educational function and is therefore designed to make the circular process visible and enjoyable. The different elements and their connections are clearly visible. They are marked in different colors, the wetland and the septic tank are slightly raised. Not only the wetland is contributing to the beauty of the garden, also the other elements have an aesthetic quality.

The treatment on household level is the smallest unit on the overall urban strategy that can be upscaled to the whole city. Multiple households and public buildings can be clustered dynamically with shared wetlands and gardens. Educational facilities such as schools are places where the purifying process is made perceptible like in the prototype. According to ooze, the positive effects of clean water become visible on household level, later in districts along the whole river and finally even in the Guanabara bay.

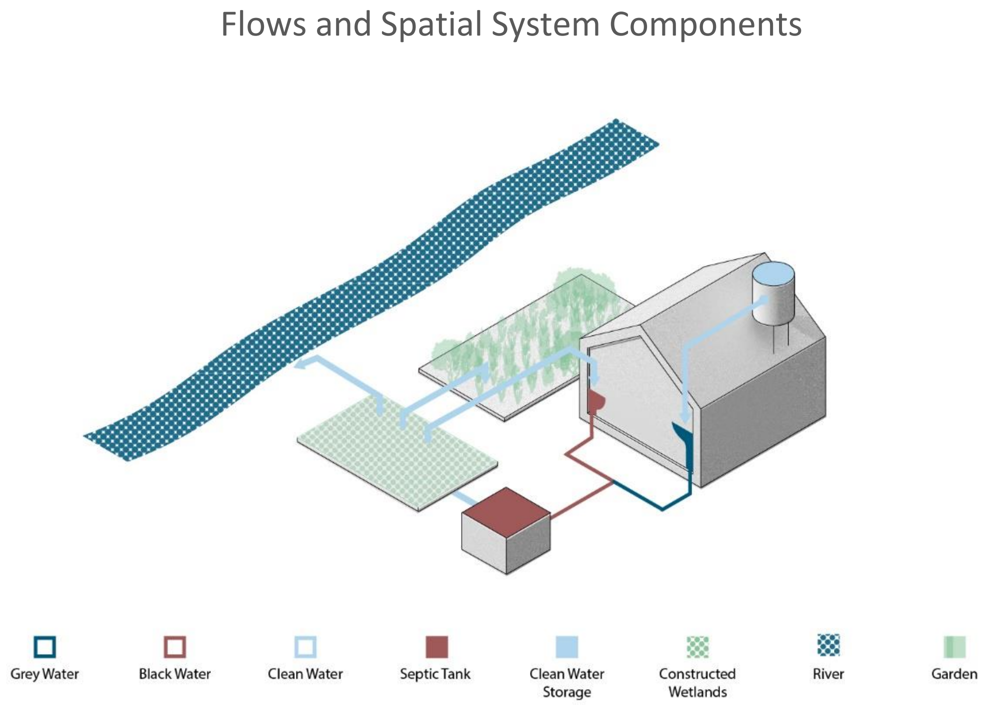

Figure 6: Flows and spatial system components (own image)

3.1.3. Implementation Method and Stakeholders

On a 3 month journey, Ooze has done many interviews with locals, local specialists, officials and professionals that are involved into water and sewage management. This contextual knowledge serves as a basis for the wetland systems proposal. The project is not realized yet, residents and other stakeholders still have to be convinced to participate. Ooze uses an urban prototype as described in 3.2.2. to do so and to raise awareness for decentralized sewage treatment solutions. The prototype is sponsored by a Dutch fond not located on the site but at the scientific institution Sitio Roberto Burle Marx. This way, residents don’t have direct access to it but wider public awareness and a possible change of mind in the administration might be more probable.

3.1.4 What we can learn

The multiscale approach in combination with a built prototype is a promising concept. Small investments are more likely to be done and can serve as an experimentation place and role model to work towards a more circular urban vision. Small communities are given the chance to help themselves instead of waiting for the help from above. The double function of constructed wetlands as efficient sewage treatment facilities and attractive green area with leisure functions has been proven to work even with limited space and budget. Furthermore, other components of the system don’t necessarily have to be hidden but have aesthetic as well as educational potential too.

3.2. Clustered Wasterwater Management System at Koh Phi Phi island, Thailand

Based on "Sustainable Wastewater Management in Developing Countries" [40]

3.2.1. Contextual Background

Koh Phi Phi, a small island in the South of Thailand has become a popular tourist destination. The growing island community had a malfunctioning public sewage system and a working privately owned system before the 2004 Tsunami destroyed all existing infrastructure. Danish funding provided the opportunity to build a new wastewater system that would serve the whole community for the first time. Besides, the system should be cheap to operate and maintain, without bad smelling and aesthetically pleasing because of the tourists in the area. All stakeholders agreed to cooperate and come up with a communal system with the help of international and local specialists.

3.2.2 Technical and Spatial Design Components

The specialists came up with an integrated cluster water management system with constructed wetlands (CWs) as a treatment facility. The capacity is around 400m³/day with 200 housing blocks and 75 businesses connected to the system. Grey- and Blackwater are collected separately in every household, hotel and restaurant. Rain- and stormwater is collected in a separate drainage system to prevent dilution and clogging of the pipes.

Flows and Spatial System Components

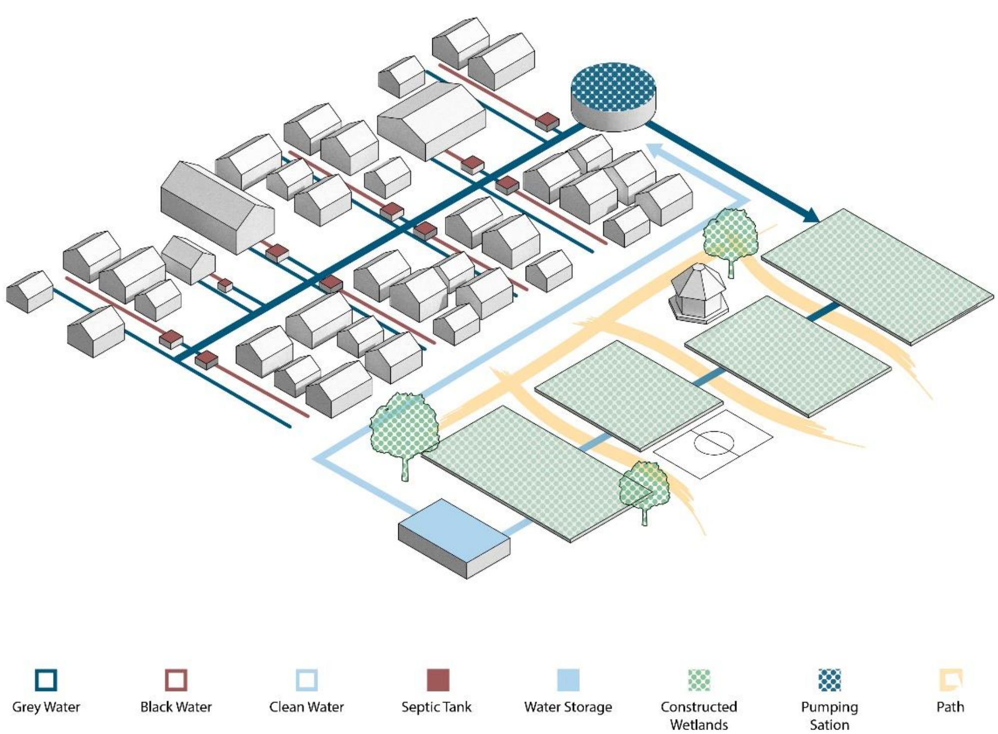

Figure 7 : Flows and spatial system components (own image)

Blackwater is treated in local septic tanks before it enters the gravity based small pipe system that leads all the water to a central solar powered pumping station in the center of the village. From there, water is pumped to the treatment site consisting of an array of a vertical subsurface-flow CW, horizontal subsurface-flow CW, free-water surface-flow CW, a polishing pond and a reuse storage tank. The water is equally distributed by a syphon instead of an electrical pump. Additionally, the system is designed as a public park with flowerbeds on the wetlands, benches, little paths, a pavilion and a kick volleyball field.

3.2.3. Implementation Method and Stakeholders

The main initiator of the project was the mayor who had a special interest in CWs. Furthermore hotel owners took initiative. They owned over 50% of the island and had an economical interest in a clean and beautiful environment. Local residents overall wanted a working sewage system that did not smell as bad as the last one. The executors were a team of international and local consultants, followed by a local contractor and the local community leader who acted as a mediator between all stakeholders and was hired as construction supervisor.

To come up with a beneficial solution for all stakeholders, public hearings and a vote on the system requirements were done. Households and businesses were free to decide whether they wanted to be connected to the sewage system. The system was designed on basis of the identified needs and concerns, namely cheapness, easy maintenance, aesthetic appearance and neutral smell. After the construction, a one year adjustment phase with careful observation of the processes was necessary to optimize the system. The initial investment was done through international funding. The observation and maintenance was financed through fees, the selling of flowers and clean tap water.

As many win-win situations as possible were created within the project. The mayor earned prestige, the contractor knowledge that opened him a new market, the inhabitants a nice park and cheap tap water, the hotel owners saved costs for a private plant, the community leader got a well-payed job, the international consultants had a chance to build a high standard sustainable system. Besides, interdependent relationships played an important role. Being dependent on each other, everybody cared about the project’s success because they didn’t want to lose their face by failing.

3.2.4 What we can learn

The double function of subsurface flow CWs as treatment facility and park creates many benefits for the involved stakeholders. They are a chance to enhance the living quality of dense areas by implementing green space. Apart from that, as many win-win potentials as possible should be spotted which don’t necessarily have to lay within the same discipline. This requires a comprehensive analysis of the stakeholder’s motivations and needs. Not only additional wins are strongly motivating but also the chance of losing one’s face can be a driver. The initial investment is the biggest barrier for a projects realization while maintenance costs can be covered by monetizing the system’s products. To reduce the chance of technical failure and costs, the system should be as simple and energy efficient as possible. The replacement of expensive pumps by a gravity based pipe system and water distribution by a syphon are very good examples. A clustered system is a promising option if on-site treatment is limited by the high population density of an area. Finally, organic treatment systems cannot be unobserved after completion and require an adjustment period. This should be included into the cost calculations.

3.3. Water Conservation Through Community Institutions: Mosques and Religious Schools

Based on "Watermanagement in Islam"[41]

3.3.1. Contextual Background

This case study was done in 1991 in Dijkot, a small town in Pakistan by a local NGO. The town suffered from water scarcity, the only fresh water source was a central basin. The study analyzes the water consumption habits and how to influence them positively through existing community institutions such as mosques and religious schools. The aim is the reduction of water wastage, illegal pumping and a more just distribution of water. The approach was chosen after all governmental initiatives for water conservation had failed. Instead of adding technical or spatial components, a new purpose is added to the existing religious infrastructure.

3.3.2. Implementation Method and Stakeholders

To identify the target groups with water scarcity, a household survey was done. Four groups could be identified, based on the level of scarcity that stood in direct relation to the distance to the water basin *(fig. xz)* Group 1 and 2 did not complain. Furthermore, both were wasting water. Around half of the households of group 3 had supply problems and in group 4 75-80% suffered from scarcity. Group 2-4 were using illegal pumps with decreasing success. To address these problems, the NGO collaborated with local Imams and religious school teachers. The Imams agreed to use 1-2 Friday Prayers speeches á 30-40 minutes per month to educate people about the responsible use of water. Based on the surveil, they were able to target either water wastage, illegal pumping or both. They Imams developed their speeches based on their own knowledge of the Quran but were provided with additional information about useful passages by the NGO. Religious schools provided hand drawn posters that promoted water conservation. The program went on for ten month but a second surveil after two months already revealed a 50% improvement of water supply in Group 3 and almost 50% in group 4.

Conservation Improvement through Friday Prayers

		Group 1 (30%)	**Group 2** (25%)	**Group 3** (20%)	**Group 4** (25%)
Before	**Water Scarcity**	0 %	0 %	50 %	75 - 80 %
	Behavior	Water Wastage	Water Wastage Illegal Pumps	Illegal Pumps	Illegal Pumps
After 2 months	**Water Scarcity**	-	-	25 %	43 %

Figure 8: Conservation Improvement through Friday Prayers

3.3.3. What we can learn

The case study shows that water usage behavior is a fundamental part of a functioning supply system. The improvement of behavioral patterns can be done through existing communal institutions. Mosques bear a special potential for areas with a mainly Muslim population because they reach people far better than governmental initiatives can. Friday Prayers area a useful educational format because most believers attend it and the words of Imams are trusted and have an actual effect on the people. Water education on basis of the Quran and other religious texts is not a big problem because many passages deal with the responsible use of resources and water specifically. One example is a quote from Mohammad's wife Ayeshah who said: "The prophet used to use a very small quantity (equal to 2/3 liter) for ablution and a bit more (equal to 2-3,5 liter) for bathing."

IV: Proposal for a decentralized cluster system in Tamansari

The systems components are chosen according to the specific demands of the site and its inhabitants. This does not exclude alternative solution approaches because the weighting of different interests, economic, social and cultural factors is everchanging. Once the active planning process has started and all stakeholders are involved, changes have to be expected and should be considered as part of the dynamic nature of integral systems.

4.1. Location & Supply Capacity

Three neighborhood communities of RW 20 are chosen for a possible pilot project, being representative in their population density, income and well organized neighborhood communities. This means that approximately 500 people or 135 households are served by the system. Very little space within the building blocks makes a clustered system favorable which means that a bigger number of households is served at a central but close spot. Additional advantages over single household systems are that clustered facilities usually work more efficiently, are potentially cheaper and allow better control and maintenance of the technical components. RW 20 has a strategic position with better access roads than other RWs, a bridge and the Islamic University with many students living in the Kampung.

For several reasons, the best place for the treatment facilities is next to the river: Cheap and low-maintenance require a pipe system that is based on gravity and therefore leads to the lowest point in the area. Besides, the existing drainage system can be reused and goes the same direction. The risk of landslides and flooding is most apparent next to the river[42]which is why only the poorest settle there in buildings that are under the worst condition. This is one reason why the city plans to clear some space along the riverbank and relocate the people[43]. However, the optimal clearing range would not be static as it is planned now but determined by the number of informal settlers that live next to the riverbank and their need for sewage treatment and green space.

4.2. Technical and Spatial Design Components

4.2.1. Rainwater

As mentioned in 1.4., the yearly precipitation is around 2164 mm and rainwater the most suitable source for potable water. The daily needs include water for drinking (2 l), cooking (3 l), praying (1.1 l) and basic hygiene (5 l) and therefore 11.1 liter/person/day. [44]

4.2.1.1. Collection

This results in a catchment area of 2.2 m² per person and a total area of 1100 m² including 18% loss compensation[45]. Roof collection is the most common way of collecting rainwater and the existing roofs are generally suited. Corrugated steel roofs are to be preferred over tiles because there is less risk for pollution. In any case, the first rainwater should be used to clean the roof with a roof washer device[46]. Providing a suitable roof for rainwater collection could be rewarded with a fee reduction. The distribution should be done in a closed pipe system, the main pipes could lay under the existing drainage system which is mostly covered by concrete tiles and easily accessible. Roof connections should be installed individually by a skilled worker. As mentioned, the pipe should lead down towards the central storage tank.

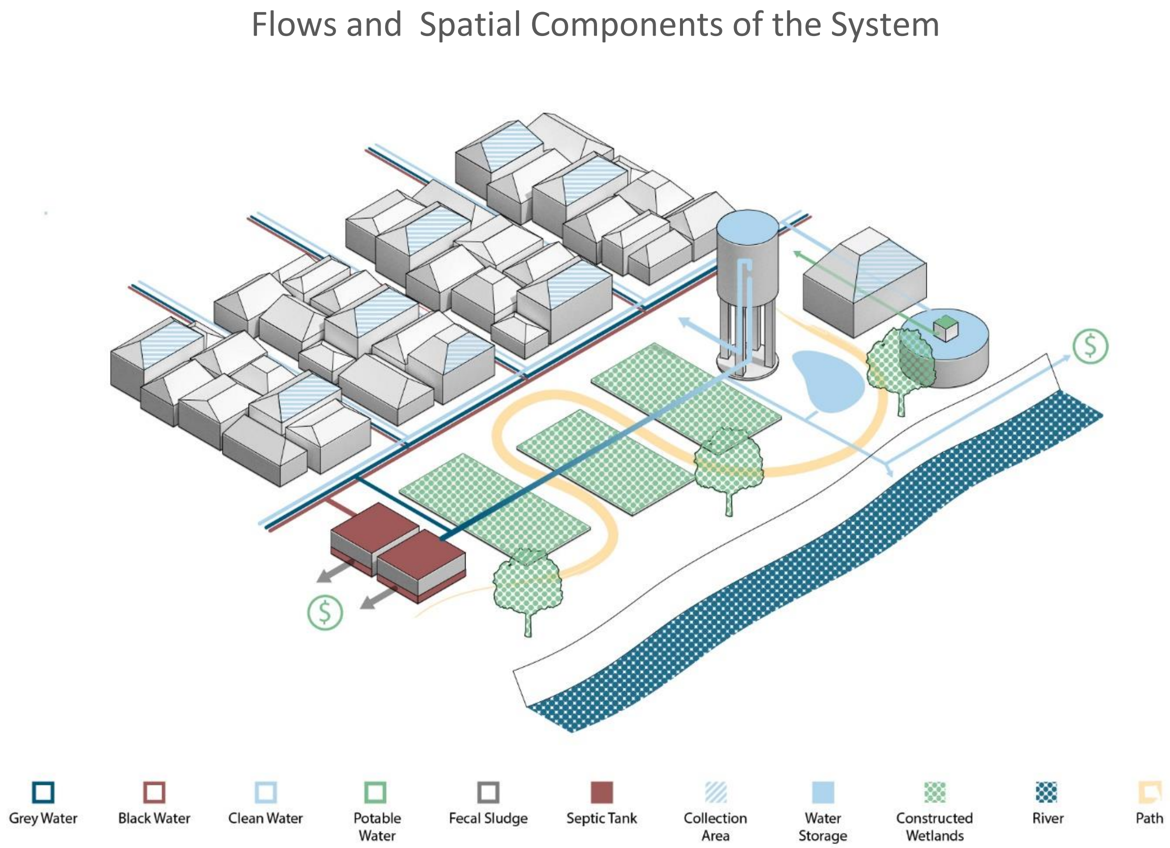

Figure 9 : Flows and Spatial Components of the System (own image)

4.2.1.2. Storage and Filter

A central storage is a smaller investment than individual ones and reduces the existing risk of contamination due to wrong handling. It should be sized to overcome the annual water scarcity during the dry season. Under these circumstances, 500 people need a storage with around 420 m³ capacity that should be placed underground. Before given away, the water must be filtered and disinfected, preferably by using UV light. This technique has been proven to be reliable, being cheaper than chlorine and less complicated than ozone treatment. The UV crystal tube should be replaced every year when running 24/7[47].

4.2.1.3. Distribution

Having a clustered supply system also means having a central spot of water distribution. Depending on their budged, people can just collect bottles of disinfected water or even connect their houses with the tower. Strict limits of use are necessary to ensure that everybody gets enough drinking water.

4.2.2. Sewage

The estimated total water use of 90 Liters/person/day is most probably higher than Tamansari's current water use because of the insufficient sanitary facilities. However, it is less than the desired standard of Indonesia's government because water saving sanitation such as dual flush toilets should be used when improving the area. The mandatory reuse of greywater for toilet flushing on household level will reduce the actual output of wastewater to 30 liter greywater and 39 liter blackwater per capita/day.

4.2.2.1. Collection

Grey- and blackwater streams are collected separately. The main collection pipes should be placed under the drainage system along the streets to be accessible in later stages. Again, the whole system should go downwards to avoid pumping and keep the maintenance low. Blackwater is pretreated in septic tanks and then enters the constructed wetlands together with the grey water.

4.2.2.2. Primary Treatment - Septic Tank & Fecal Sludge Management

Blackwater has to be pretreated in a communal septic tank before entering the constructed wetlands. At least two septic tanks with a volume 49 m³ are recommended to process the sewage. Apart from the population's wastewater flow, the tank size is dependent on temperature (Bandung average: 26.8˚C), hydraulic retention time and desludging interval (3 years). One tank for 500 people would make the construction unnecessarily complicated[48]. The Fecal Sludge that should be removed every three years is often not dealt with, mostly due to a lack of economic incentive. However, due to his high nutritional value, there are many business opportunities. One example that is suitable for Tamansari is feeding the sludge to the black soldier fly larvae, preferably mixed with 50% market waste. The larvae don't require much space and can be sold as a high protein substitute for fish powder[49].

4.2.2.3. Secondary Treatment – Subsurface Vertical Flow Constructed Wetlands

Subsurface Vertical Flow Constructed Wetlands (SVFCW) are the most efficiently working wetlands which is why they are most suited in dense areas. Besides, subsurface CWs don't attract mosquitos. Around 500 m2 wetland of 70 cm depth are required to deal with the wastewater[50]. The choice of plants should be made from local species with deep roots and strong rhizomes and considerable biomass to work efficient. There are countless known plants such as *Phragmites karka* and *P. australis* (Common Reed) who have been proven to be efficient[51] Ornamental plants such as Spathiphyllum wallisii and Zantedeschia aethiopica work well[52], have an aesthetical value and their flowers can be sold and therefore provide an additional business opportunity. Paths, benches, playgrounds and trees will improve the wetlands quality for leisure activities.

4.2.2.4. Water storage

Almost 35 m³ of clean water leave the SVFCW every day. The water quality isn't sufficient to be used as potable water. However, it has advantages over current water sources such as PDAM tap water, being cheap, always available and with low turbidity. The water should preferably be stored in a tower for several reasons: To ensure basic water supply in case of power failures, to have a buffer during peak times of water demand, to create enough water pressure to lay supply pipes to households and therefore enable advanced sanitary systems, to have a visible element that can work as a public attractor, to have an emergency storage in case of a fire. The storage should be able to buffer daily fluctuations in demand, around 50 m³ are recommended. Even if the current water sources are completely replaced by the improved sources, there will be a surplus of at least 12 m³ that can be sold, preferably with a gravity based supply line for settlements down the river. Besides, there are leisure and business opportunities by creating water pools and fishponds instead of using the polluted river as a breeding tank.

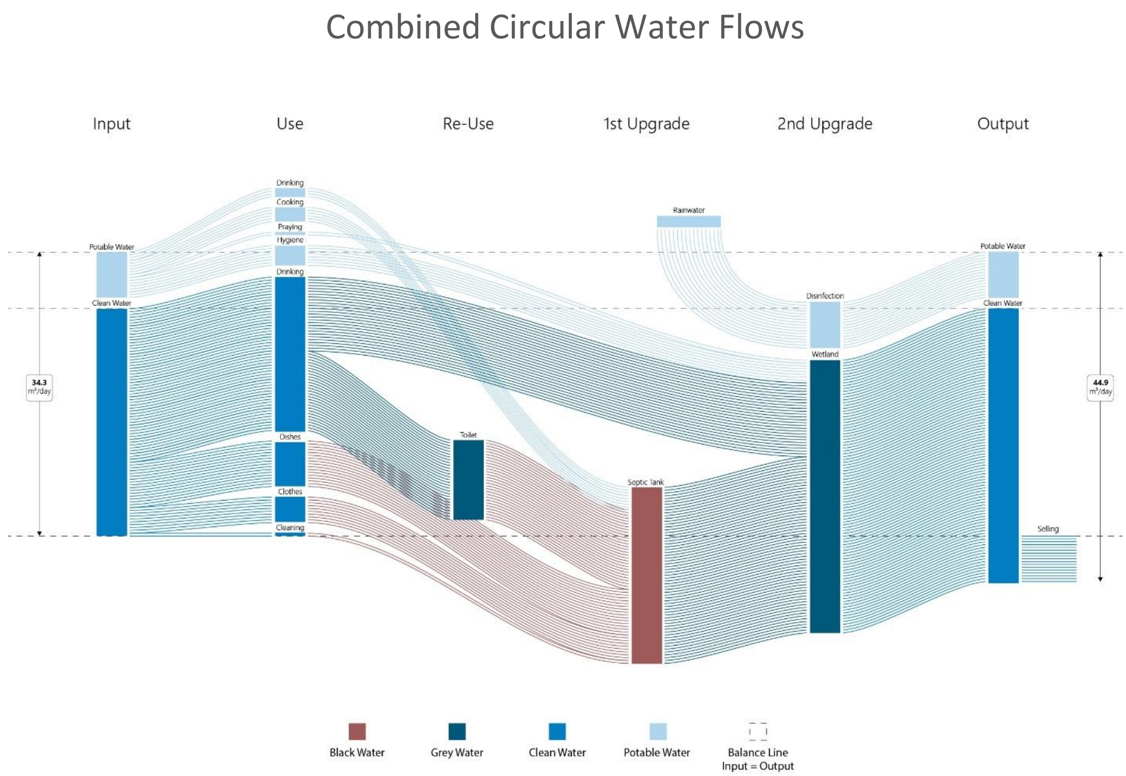

Figure 10 : Combined Circular Water Flows (own image)

4.3. Implementation Method and Benefits for Stakeholders

The cases in chapter 3 have shown that a successful implementation relies on the clever use of existing communal potential and that the stakeholder's wishes, interests and fears should be taken into account. It isn't necessary that they are related to sanitation because economic opportunities and win-win situations are especially created in between different fields. In the end, all involved parties should be benefitting.

4.3.1. Neighborhood Communities

The potential of stakeholders and community institutions has been identified in chapter 2. The well-organized neighborhood communities of Tamansari should be the basis for the clustering of the DIWMS. The organization and decision making about needs, wishes, participation, investment, fees, profits and benefits can be expected to be much easier and social friction is kept to a minimum.

4.3.2. Local Leaders

The RW and RW leaders are key figures in their role of connectors between experts, residents and executors. The monthly assemblies can be used to communicate the technical possibilities and find common ground. Their positive attitude towards a more sustainable lifestyle and their understanding of the local problems make them ideal supervisors. They can coordinate the construction process and recruit local builders (Tukangs) and volunteers. Their personal benefits are that the success of the project will add to their reputation of a visionary leader. Solving of some of their citizens biggest problems will bring additional satisfaction and finally, their role as coordinator can be a lucrative job.

4.3.3. Imams and Mosques

The DIWMS's success depends on the people's willingness for participation and sustainable behavior; even though the cluster system prevents wrong usage on household level, they must be willing to connect to the piping system and to handle different water sources appropriately. The role of reaching and educating people can best be done by Imams. The weekly Friday Prayer will be far more efficient than any governmental attempt of education. Women as the most important target group can be targeted separately. Mosques can be useful to spread the idea after completion because Imams reach at least on RW and are well connected. Equally to RW/RT leaders, Imams can have the role of connectors between experts and locals. The clustered system includes a central supply point. With their central position, frequent visitors and the need for a clean ablution water storage, mosques would be an ideal access point for potable water. Water can be taken back home from the daily prayers without any extra effort and water tower can be integrated into the Minaret which is often built but has no functional use. If constructed wetlands gardens and ponds are part of the complex, no vandalism or littering is to be expected. Besides, the funding for mosques could give access to new types of sponsors. Religious institutions would benefit too because of their growing importance as a clean water supplier, the easy access to clean water which is prescribed by Islam and potential investors from non-religious backgrounds.

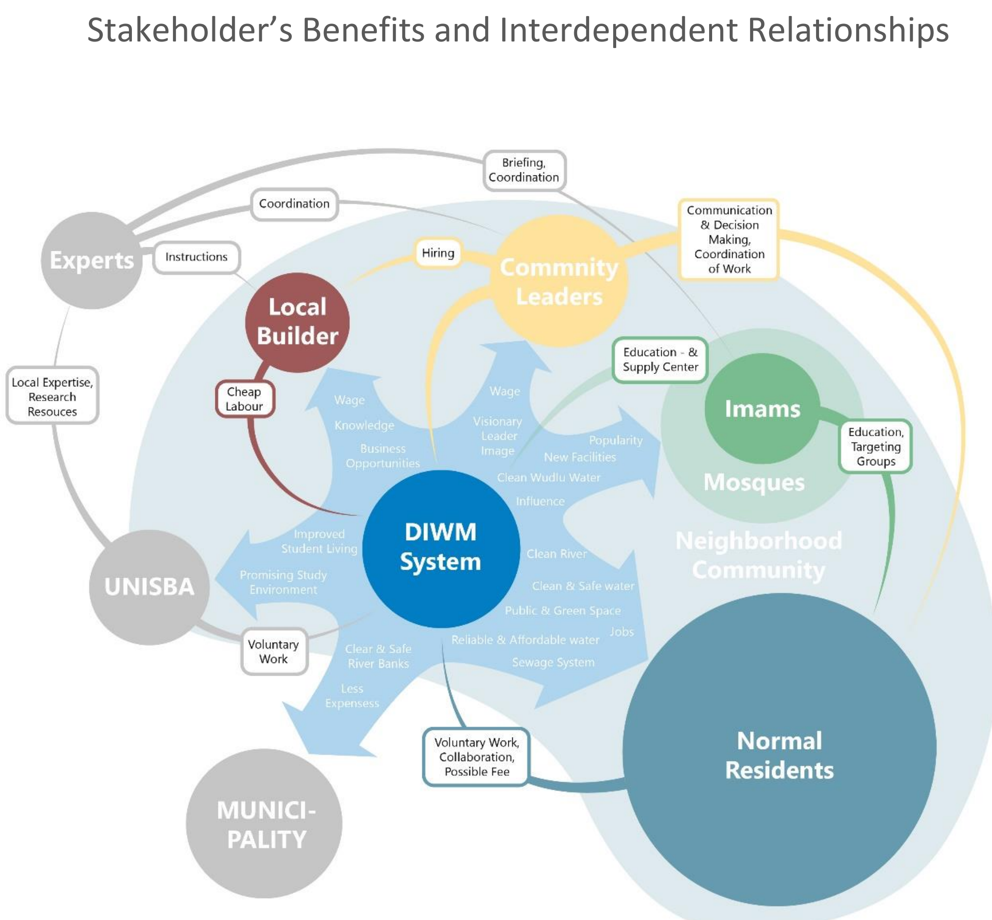

Figure 11:Stakeholder's Benefits and Interdependent Relationships (own image)

4.3.4. Islamic University (UNISBA)

Many students of the UNISBA are living in kampung Tamansari, especially in RW 13, 14 and 20. The University has shown its interests in improving the kampung situation[53]. The institution could provide additional expertise and research capacities while gaining a perfect study environment for their students. Students living in RW 20 will directly profit from the improved water supply.

4.3.5. Local Builders

Local builders are called Tukangs and responsible for most of the construction works within the Kampung. Very few have had real education and a DIWMS is certainly new to them. However, they are cheap labor and used to learning by doing. With the right guidance, costs can be saved and the sustainable principles can be applied elsewhere in the area, even without the instructions of experts. Apart from their wage, the builders are given the opportunity of a new and profitable working field.

4.3.6. Residents

The main idea of the whole project is to improve the resident's living conditions. Consequently they are the main beneficiaries. They have to be convinced to support the new supply system and to act more sustainably. Due to the fact that voluntary work within the neighborhood community is quite common, free labor can help to keep the costs low while the involvement will strengthen the acceptance of the system at the same time. Cases of Diarrhea and therefore child mortality would decrease which is why the absence of safe and reliable water sources is already a sufficient reason for some rapid action. Anyhow, the residents will also profit financially: At the moment they spend around 3.3% of their income on water, excluding the costs for gas to boil water. The DIWMS is a public facility that only has to cover the costs for observation and maintenance. Rainwater is free and the sewage facilities even provide business opportunities for the reuse of sludge and selling of flowers and surplus of clean water. Finally, the omnipresent need for public and green space can be satisfied. Recreational spaces and safe areas for children could upgrade the area. If the project succeeds in becoming the initial impulse for a general change of habit within the informal settlements along Cikapundung, the river could be regained as the green artery through Bandung that it used to be.

V. Appendix

5.1. Household Usage and Water Sources

Source	**Use**	**Amount** *[Liter/Person/Day]*	**Amount** [%]
Purifies Rainwater	Drinking	2	2.2
Purifies Rainwater	Cooking	3	3.3
Purifies Rainwater	Praying	1.1	1.3
Purifies Rainwater	Basic Hygiene	5	5.6
Constructed Wetland	Shower	45	50.1
Constructed Wetland	Dishes	6	6.7
Constructed Wetland	Clothes	5.7	6.3
Constructed Wetland	Household	0.8	0.9
Re-Used Grey Water	Toilet	21.2	23.6
Total		**89.8**	

5.2. Calculation: Rainwater Catchment Area

Description	**Result**
Need [l/pers/day]	11.1
Total need [l/pers/year]	4048.3
Precipit. [mm/year]	2164
Area/Person [m2]	2.2
Total Area [m2]	1103.7
Loss compensation [%]	18
Savings from Bottled Water [Rp/Pers/Month}	61500
Average Income [%}	3.3

5.3 Calculation: Rainwater Storage

Month	**Precipitation [mm]**	**collected [m3]**	**efficiency factor**	**consumed [m3]**	**end of month inventory [m3]**
November	272	300.2	0.85	168.7	86.5
December	291	321.2	0.85	168.7	190.8
January	243	268.2	0.85	168.7	250.1

February	217	239.5	0.85	168.7	285.0
March	257	283.7	0.85	168.7	357.4
April	246	271.5	0.85	168.7	419.5
May	166	183.2	0.85	168.7	406.5
June	77	85.0	0.85	168.7	310.1
July	70	77.3	0.85	168.7	207.0
August	68	75.1	0.85	168.7	102.1
September	83	91.6	0.85	168.7	11.3
October	174	192.1	0.85	168.7	5.9
Total	**2164**	**2196.4**		**1855.7**	
Max. Storage Inventory [m3] **= Storage Size**	**419.5**				

5.4. Calculation: Need of Wudlu Water in Mosques

Based on "Rainwater harvesting as alternative source for wudlu water in Indonesia"[54]

	n	**%**	**Liter**
Attendance Friday Prayers			
Male, female, excl. children	260	52	
Mosque Occupation Rate			
Isya	39	15	
Subuh	13	5	
Zuhur	26	10	
Ashar	13	5	
Maghrib	52	20	
Friday Prayers	260	100	
Mosque Occupation Rate Ramadan			
Isya	156	60	

Subuh	52	20	
Zuhur	52	20	
Ashar	52	20	
Maghrib	156	60	
Friday Prayers	260	100	
Average visits/day	168.4		
Average visits/year	55172		
Average Water Use / Wudlu			3.24
Total Water Use: [Liter/Person/day]			**1.1**

5.5. Calculation: Volume Septic Tank

Based on "Low Cost Urban Sanitation"[55]

Term	Description	Formula	Result
	Black Water [l/person/day]		38.7
	Black Water total [m3/day]		19.35
V_{SC}	Zone 1: scum storage	$0.4*V_{sl}$	12
V_n	Zone 2: sedimentation	$10^{-3}P*q*t_n$	2.944148
V_d	Zone 3: sludge digestion	$0.5*10^{-3}P*t_d$	3.798542
V_{sl}	Zone 4: digested sludge storage	r*P*n	30
t_h	Hydraulic retention time [years]	1.5-0.3log(Pq)	0.304305
P	Population [n]		250
q	Wastewater flow [l/day]		38.7
t_d	Anaerobic Digestion time	$1853*T^{-1.25}$	30.38834
T	Bandung av. Temperature		26.8
r	Rate of Sludge digestion [m^3/person/year]		0.04

n	desludging interval [years]		3
V	**Septic Tank Volume [m3]**		**48.74269**

5.6. Calculation: Constructed Wetlands Area

Based on "Constructed Wetlands Manual"[56]

Term	Description	Formula	Result
Bodc	Bod Concentration before treatment [mg/l]		250
Bod_c	Bod Contribution [mg/pers/day]		40
Q_d	Daily flow rate [m3/day]	p*q	34.2956
C_i	Influent BOD_5 concentration[mg/l]		408.2
C_e	Efluent BOD_5 concentration[mg/l]		30
K_{BOD}	Rate constant [m/d]	K_t*d*n	0.2
K_t		$K_{20}\,(1.06)^{(T-20)}$	
K_{20}	rate constant at 20˚C	20˚C(d^{-1})	
d	depth of water column [m]		
n	porosity of substrate [percentage expressed as fraction]		0.3
	Substrate depth [cm]		70
P	population		500
q	Flow Rate [l/person/day]		68.6
A_h	**Surface area of Bed [m2]**	**(Qd(Ci-Ce))/KBOD**	**490**
A_p	**Surface area [m2]/person**	**A_h/p**	**0.98**

5.7. Calculation: Water Storage

Description	**m^3**
CW output total [m^3]	34.3
max daily need [m^3]	28.75
Safety factor	1.5
Water Storage:	**51.4434**

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