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A REVIEW OF SUSTAINABILITY OF URBAN DRAINAGE SYSTEM: TRAITS AND CONSEQUENCES

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Abstract

The negative effect of domestic effluents on the quantity and quality of water and urban amenities makes increasingly imperative to establish sustainable drainage systems in cities. Therefore, for a better plan and sustainable development of a town, it is highly imperative for environmentalists, hydrologists, land use planners and for storm and wastewater management to analyze the existing drainage system and predict the environmental responses to the discharges of urban drainage system. This study has analyzed the existing drainage system of Jimma city (Ethiopia) and identified the major factors contributing to the poor drainage performance. Jimma population growth has been increasing the problems caused by the uncontrolled release of domestic effluents and urban solid waste, with increasingly damaging consequences for the environmental quality, social wellness and economy of the city. With the intensification of Jimma development, surface water discharges from developed areas and uncontrolled wastes are being increasingly released, affecting social, environmental and economic state of the city. Lack of proper functioning drainage infrastructure, uncontrolled waste disposal, lack of periodic inspection and maintenance, poor connection of drainage networks and roads and carelessness led to the failure of the existing drainage system. These conditions caused drainage blockages, resulting in overflows and floods, leading to less and less attractive conditions in the city and making some places unfit to be inhabited.

Keywords: Environmental quality. Jimma city. Sustainable drainage. Water quantity and quality.

1 Introduction

Developing urban areas require suitable drainage infrastructure to work efficiently in extreme events of rainfall and for the maintenance of the city environmental quality (Zhou, 2014). Infrastructure is one of the indispensable elements in the process of urbanization, wellness and continuity of urban growth. However, in developing countries like Ethiopia, numerous problems have made the supply of physical infrastructure and services to continually lag behind the urban population growth rate (GTZ-IS, 2006). The high urban population growth rate, on the other hand, generate problems related to the urban expansion. For example, the increase in population generates greater infrastructure demand, including electricity, water supply and urban drainage facilities.

Traditional approaches of storm water management aiming to maintain public hygiene and protect urban dwellings from local flooding have focused on the rapid removal of storm waters away from urban areas using rather standardized methods and designs with little consideration for downstream secondary effects (Chocat et al., 2007).

Researchers have increased their concern about the long-term functionality of traditional drainage systems due to its inefficiency which results in negative effects on urban environments and receiving streams (Roy et al., 2008; Stewart and Hytiris, 2008). Besides, there also has been increasing criticism on the limited capacity and flexibility of conventional sewer systems to adapt to future climatic variability and urbanization growth (Krebs et al., 1997). This means that, even with a functioning drainage system, the design capacity is still limited to cope with the expected extreme rainfalls and floods when the system gets overloaded (Zhou, 2012).

Recently, much attention has been given to the sustainability of drainage systems, trying to find solutions that will ensure the establishment of sustainable drainage services that will continue to function under increasing urbanization and the effect of climate change.

However, sustainability criteria for urban drainage need to employ multidisciplinary engineering and sciences to consider all parts of the all urban water cycle in management to ensure economic, social, ecological and environmental sustainability (Miguez et al., 2012). Thus, integrated trans-disciplinary approaches attempting to embrace and accommodate different key criteria for future drainage systems are currently promoted by many researchers (Rauch et al., 2005). Unless the factors contributing to poor functioning of drainage system are fully explored, substantial achievements will not be achieved. This is mainly due to the fact that drainage is a regional feature that affects all governmental jurisdictions and all parcels of property.

In many urban areas of Ethiopia, drainage was based on a completely artificial system of sewers: pipes and structures that collect and dispose wastewater. In contrast, isolated or low-income communities normally have no access to the main drainage system. Wastewater is treated locally (or not at all) and storm water is drained naturally onto the ground. Lack of proper rainwater collection is a long-standing issue that has had low priority, resulting in increased urban flood risks, contamination of drinking water, soil and creating public health problems. With a rapid expansion of the infrastructures, the hard surfaces that replace the permeable soil have been increased and do not allow the water infiltration and its rapid channeling to the pipes. The combined effect of these problems results in increased rainwater accumulation and, consequently, in surface runoff (Belete, 2011).

According to "Road network, utilities and transport study of Jimma city" (Oromia Urban Planning Institute, 2008), there is a large gap in the sustainability of drainage services provided at different time at different places. The gap in drainage sustainability among different sub city (kebeles) of Jimma is a bottleneck for achieving the Town clean and appealing. It will therefore be important to explore the main reasons for gaps in the sustainability of drainage structures so that measures can be taken to ensure the longevity of drainage services.

It is therefore necessary to evaluate different approaches and select appropriate measures to achieve the sustainability of the drainage services. This is in turn important in order to forward these approaches to organizations that implement these services which are essential to make the Town clean.

Adequate drainage for urban area is necessary to preserve and promote general health, welfare, and economic wellbeing of the region. This study also has a special relevance for infrastructure inventory as a consequence of the new added and upgraded infrastructure information will easily be upgraded to a recent data report through appropriate software. Based on the finding of this study, the new suggestions and recommendations will be used as an alternative means of solution in ensuring sustainable development in Jimma city by strengthening the environmental and socioeconomic activities.

Thus, the focus of this study is to review the sustainability of Jimma drainage systems with the aid of both primary and secondary data collection. ArcGIS 10.1 was used to delineate the area of the town and prepare different spatial maps for the study. The specific foci of the study have included: assessing the existing Jimma drainage system, identifying the major factors contributing to the sustainability problems, investigating impacts of drainage system and, finally, formulating strategies through which the identified problems shall be addressed.

2. Study Area

The study area, Jimma city, is located in Ethiopia, at 352 km away from Addis Ababa in Southwestern direction. It is located at latitude 7.40º North and longitude 36.50º East. It is situated in the Ethiopia center and is accessible to all parts of the southwestern part in all directions.

Hydrologically, Jimma city is situated within the Gilgel Gibe river catchment on the upstream of Gilgel Gibe 1 hydropower reservoir. Locally, Jimma city is drained by two perennial rivers, namely Awetu and Kito, which will be combined together near Dedo bridge located towards the southwest tip of the city and pass through Boye Swamp before they join the Gilgel Gibe River. Emerging from the upper mountainous catchment, Awetu River flows down bisecting the center of Jimma city, and Kito flows along the western end of the city.

The northern part of the city is situated on a series of hills or escarpments and exhibits generally a rolling topography which constantly increases in slope to the northern direction finally forming highlands that again start to fall further north in the hinterland areas. On the other hand, the core areas of the southern part of the city are generally located on a low elevation area of alluvial plain with slope further decreasing to the south and southeast.

The city has dense and defined settlement at the core, individual housing at the intermediate and periphery areas. Series of settlements are intermingled with informal green areas. Coffee is abundant within the northern part of the city, while the southern part of the city is dominated by eucalyptus and other types of tree plantations.

Jimma city receives moderately heavy rainfall throughout the year, with annual precipitation ranging from 1450 to 1800mm. Relative humidity was 56.8% and the highest average humidity was observed during the main rainy season according to the data analyzed from meteorological data.

The map of Fig. 1 shows the current Jimma city limit and for the past one, before 2008. As evidenced in Fig. 1, Jimma City is highly expanded but the drainage infrastructures did not fully follow this development.

3. Materials and methods

Topographic data (digital elevation model, DEM), different spatial and temporal data on the Jimma city and previous master plan of the city were collected from both primary and secondary sources. Key informant interviews and direct field observation were employed as a method of primary data collection. Descriptive type of research was used to describe the existing condition and coverage of urban storm water drainage facilities. Exploratory type was used to explore the existing condition and coverage of urban storm water drainage facilities which were not found in the base-map of the city.

A digital elevation model (DEM) of 30 m by 30 m was downloaded from the United States Geological Survey (USGS) using Shuttle Radar Topography Mission (STRM) with 1 acre at https://earthexplorer.usgs.gov/. The 1997-2008 master plan of Jimma City was collected from Jimma city Municipality office with different reports.

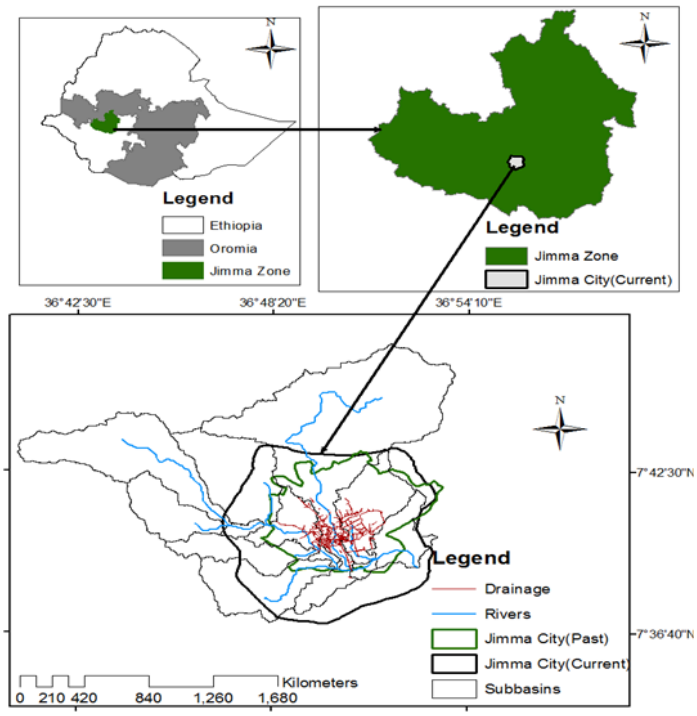

Fig. 1. Map of Jimma city showing the current Jimma city limit and the past one.

Key Informant Interviews: Interview with key informants such as environmental and climate change protection experts, local authorities, development agents at kebele to woreda level and community leaders was held to generate the information needed about the drainage of Jimma City. The key informants were selected depending on the criteria of having a wide spectrum of general, personal and professional views. Semi-structured interview guide and checklist were designed and contextualized to specific groups of informants. A face to face interview was conducted because it allows the researchers to observe any non-verbal communication and both the interviewer and the interviewee may seek a clarification. All notes and recordings of interviews were reviewed, summarized and analyzed on thematic basis. The final number of key informants was determined depending on the saturation of relevant information.

Field Observation: The researcher has carefully carried out field observation on the basis of checklists designed in advance to observe the drainage infrastructures and its challenges. The subjects of field observations were drainage lines and networks, land use of the city, streams in the City and waste management. Field observation was made first along the river starting from the entry of the stream into the city up to its outlet. Then, the drainage networks in the city were observed with aid of the map of drainage shape file.

The selection of informants, who participate in the individual interview sessions of the general residents of the city, was made based on the selection of residents who occupied the study area over a long period of time. Accordingly, Municipality of Jimma City, Kebele chairman and residents of the study area were involved.

4. Results and Discussions

4.1 General

Eco-system of Jimma was disturbed in the past due to over exploration of the nature through deforestation, poor land management and unplanned urban expansion for meeting the demands generated due to industrial growth (small-scale enterprises), which accelerated the rate of erosion and flooding. Based on the study survey of Jimma city, one of the most difficult issues of the community is street flooding, the floods coming from nearby river and its causes and drainage infrastructure performance. This topic was found creating extensive debate among local government officials, city administration and residents. The major challenges of Jimma city are found to be flooding, storm water drainage and waste management. In particular, Road and drainage infrastructure expansion is not satisfactory in Jimma city due to its unfair expansion and distribution activities of the infrastructure.

4.2 Existing status of the drainage system

The storm water drainage and flooding problems of the city are long-existed obstacles of the city and are under discussion, according to information obtained from officials of the city administration and local residents. Existing drainage service coverage in Jimma can generally be considered inadequate, both in quality and in coverage (Table 1). The types of drainage facilities in the city are trapezoidal, rectangular channel, circular, earthed channel, and natural waterway.

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The central part of Jimma is drained by a closed pipe drainage system built by the Italians. There is a more extensive network of piped drainage in core areas of Jimma as compared to urban centers of similar size. The other parts of the city where there is drainage system are being drained by open ditches of different shapes built of stones and some earthen. Most of the gravel and earth surfaced roads do not have proper drains except the side slopes that collect and drain storm water. Currently, most of the city has drainage facility and, however, most of the drainage lines in Jimma are in bad condition.

There are large water shade areas that drain into and across the city, which releases huge volume of storm water into the city core. Whereas, the capacity of the existing drainage lines at the core and intermediate areas is highly reduced by accumulation of solid waste and silt. In addition, there is also lack of organized drainage system incorporating those along the roads with the natural drainage system of rivers and streams in the city. As a result, there is flooding in commercial areas at the core and residential areas in intermediate and periphery areas.

The major factors contributing to the drainage problems of Jimma city were identified and, then, prioritized by using a structured questionnaire (Table 2). Accordingly, 35.29% of the respondents indicated that drainage blockage is the worst problem and 20.59% of them indicated inadequate capacity of the drainage system. The other 8.82% of the respondents specified that poor design of drainage system is one of the other challenges of Jimma drainage system. The remaining 11.76% have specified absence of drainage, lack of proper integration of road and drainage system and poorly constructed drainage system are the problems of drainage system. Field observation also revealed similar condition. Accordingly, sedimentation, inadequacy of drainage structures during the rainy season to pass the flood, poor quality construction and absence of maintenance service were found to be the problems of the current drainage system.

The problem of sedimentation is due to disposing solid waste into the drains, deposition of gravitational flux sediments and vegetation growth in the drains. It is also found that waste management programs are poorly organized and interventions are haphazard and available resources and infrastructures do not match to existing conditions. One can easily understand from the following photo manholes are filled with heavy wastes (Fig. 2). Unless it is periodically inspected and these materials are removed, small intensity of rainfall will block the drainage line and make heavy damage.

The main discharge of the existing drainage system was found to be towards the rivers in the city as shown in Fig 3. As a result, the rivers are suffering anthropogenic impacts ranging from excessive and indiscriminate use to waste discharge. The Awetu and Kito rivers are among the major rivers falling in this category. These rivers suffer from major activities by the city residents and these rivers are almost open sewers.

Field observation was also supported by verification with semi structured interview. The results are summarized in Table 3.

Fig. 2. Photos of the waste deposition in drainage infrastructure.

Tab. 1. Respondent responses on the status of the existing conditions of Jimma Drainage System.

Evaluation		Excellent	Very good	Good	Poor	Total
Jimma Drainage System	N°	--	--	20	90	110
	%	--	--	18.2	81.8	100

4.3 Factors affecting drainage system performance

Naturally, Jimma city is provided with rich ecological diversity that may be a tourist destination and promote eco-tourism if properly protected and managed. The presence of Awetu and Kito Rivers stretching along the city from opposite directions is a natural gift and adds beauty to this city. Unfortunately, however, the condition of the city deteriorated in unprecedented manner and its current situation is extremely worrying. Aging, unplanned urban settlements, population growth, increasing impervious and poor waste management infrastructure can be considered the major factors affecting the performance of drainage systems which resulted in water and environmental pollution.

The on-going construction activities and inappropriate waste disposal in the city have increased surface water runoff. On the other hand, lack of appropriate storm water drainage resulted in uncontrolled surface flow of water creating serious flooding problems in different parts of the city. As a result, flooding is among the highest priority concerns of the residents in Jimma.

In summary, these study results indicated that the following aspects are the most common factors affecting

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drainage performance: inadequate capacity of the infrastructures, clogging, storage capacity, waste disposal, poor integration with road, unexpected rate of urbanization, land use change, population pressure, lack of periodical inspection and maintenance, carelessness of the community. Poor workmanship, cleaning solid wastes and sediments are also the causes of resulting in malfunction of the existing drainage structure.

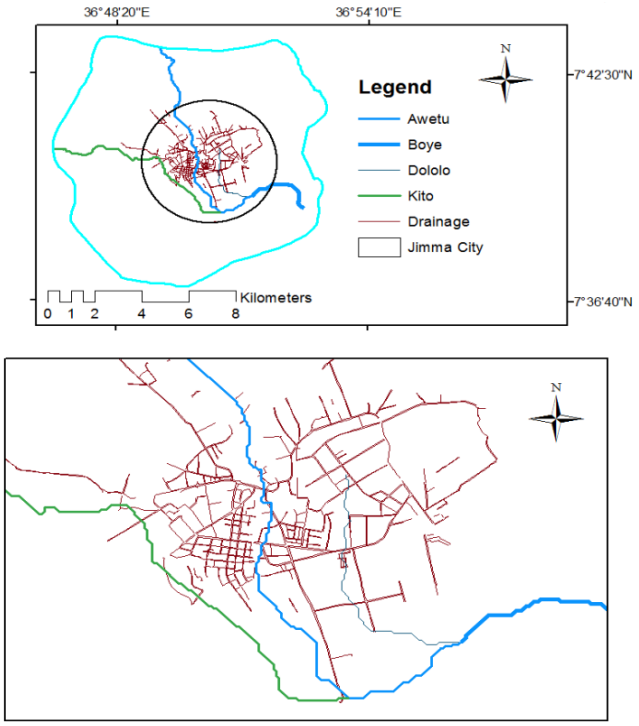

Fig. 3. Map of the drainage systems of major rivers of the city.

Tab. 2. Respondent responses on the major drainage problems.

Major drainage problems	Percentage of respondents (%)
In adequate capacity of the drainage system	20.59
It is not constructed/absence of drainage	11.76
Poorly designed	8.82
It is poorly constructed	14.71
Drainage blockage	35.29
Lack of proper integration with road	8.82

Blockages are mainly due to solid waste disposal. Respondents have also revealed the reasons to dispose solid wastes into the storm water drainage systems.

Experts from Jimma city municipality were also involved to get information regarding the handling of drainage systems. The result indicates that there is no guideline for drainage system; drainage inspection and maintenance are sometimes done only when necessary. However, it may be suggested that at least one annual periodic inspection be performed in order to identify damaged places.

Tab. 3. Respondent responses on waste disposal challenges.

Reason for improper disposal of waste	Percentage of respondents (%)
Lack of awareness	34.61
Shortage of disposing area	23.07
Carelessness	42.30

4.4 Basic problems and impacts of urban drainage system

As Awetu and Kito River starts crossing the city, they serve as natural sewerage lines for domestic (solid and liquid) waste and urban storm water making them unfit for any types of uses. Consequently, it is worth mentioning that almost the whole part of the city catchments drains into Awetu and Kito rivers, and the streams are highly polluted by domestic and urban wastes including uncontrolled discharge of sewage from residential as well as commercial areas. The natural eco-hydrological integrity of these rivers is deteriorating and the pond they form is dying, which otherwise was a heaven for hippos, fish and birds.

Even though the river water assumed to undergo some self-purification process while it passes through the Boye Swamp created by a small weir, the wastes transported with the rivers have blocked the area completely. As a result, the swamp constructed formerly for fishery development is entirely covered by wetland plant communities and it was found to be the main cause of flooding for the community residing along the river. In particular, the area called Bishishe on the upstream of the two rivers joint was found to be among the regions continuously affected by this flooding yearly.

The interviews and field observation of this study show that the commercial market areas and residents of Bishishe are among the mostly affected ones. There is also no protection against flooding and runoff and all types of pollutants, including chemicals and human excreta, which are washed to and enter the rivers through the drainage system. Another threat to the drainage system and for these rivers is the transport and accumulation of debris and sediment, namely for the Gilgel Gibe River, and lastly for the dam. Continued pollution has also resulted in the extinction of fauna and flora and eutrophication of Boye pond at the tip of the two rivers.

On the other hand, swamps and water pounding areas are also common features of the surface hydrology of Jimma city that are related to the runoff condition. This has caused drainage to be the main problem in the area.

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Based on the information gathered during interviews from municipal officials and elders of the town aided with field observation, the status of Boye swamp is highly polluted and there is bad smell that results in difficulty for health of human beings and aquatic ecosystem. This is caused by solid and liquid wastes dumped on drainage lines from different district of the city finally deposited in this sub catchment.

From the data collection of the Awetu River, it is observed that some people living along the river connected their toilets to the river, which, in turn, has an extremely negative effect on the health of the downstream community (flat topographic area of the city). Depending on the distance, the discharged wastewater is either diffused within the community creating health problems or washed out to the rivers by gravity or as surface runoff when it rains.

The accumulation of wastes from the drainage lines and damping of different solid waste into the river were reducing the river depth, making the river braided that in turn is the cause of river overflow. This enhances the flooding problem by increasing the discharges above the natural watercourse channel. With the high rate of urban expansion, the rapid increase in the number of small-scale industries such as an increase of large hotels, higher clinics and/or medium-sized hospitals, colleges, wood-processing enterprises and coffee processing plants in Jimma city, was found to be the sources from where wastes are released without any treatment to the nearby drainage lines and rivers.

4.5 Road and drainage integration

The study survey shows inadequate integration between road and urban storm water drainage and poor management have caused significant proportion of the area exposed to flooding risks. Due to lack of proper drainage facility and channels, roads are damaged and water ponds are created on the roadsides, in the urban centers and crossing structures (Fig.4). This situation causes the roads damage in the city. In addition, the delay in road construction, the inadequate slope of some drainage structures with respect to road alignment, and lack of integration among service institutions were among the main causes of the urban drainage system of Jimma city.

5. Conclusion

The existing drainage system in Jimma City (Ethiopia) has extensive defects and requires immediate reconstruction and maintenance to ensure proper operation of the drainage system. The drainage issue, associated with urban wastes, is among the most critical agenda of the city causing both physical and sanitation problems. The physical problem is associated with inundation and eventual destruction of personal and public properties; whereas, the sanitation problem resulted from the lack of proper management of municipal waste, which poses serious problems to the Jimma City. Therefore, an integrated solid and liquid waste management practice should be implemented in the city and the surrounding environment. This should include development plan to improve sustainable sanitation and disposal of the sewage system and to adopt the best practices of waste management for the city river basin ecosystem. In addition, city administration should have solid and liquid waste management master plan before making interventions for lasting solutions.

Fig. 4. Photos of poor road and drainages integration.

Provision of proper connections or integrations between the road network and drainage network system is required with regular maintenance. Furthermore, a system of self-management by the residents has to be devised. It is critical that the community should develop a sense of ownership in order to ensure sustainability. Regulations to control disposing of waste and construction material in drainage channel, manhole, water body and other structures should also be developed. Besides, silt and solid waste trap

mechanism must be provided before runoff enters into concrete pipe. This will reduce the complexity of cleaning the pipe drains.

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